

**REALIZATION OF A HIGHLY MINIATURIZED  
ELLIPTIC-FUNCTION BAND-PASS FILTER USING MI-  
CROSTRIP QUASI MULTI-MODE RESONATOR FOR  
WIDE-BAND APPLICATION**

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**Abstract**—A compact elliptic-function band-pass filter (BPF) is introduced using microstrip folded quasi multi-mode resonator. The prototype filter is synthesized from the two-port network and equivalent circuit models using available element value tables. To optimize the performance of the filter, electromagnetic simulation (EM) is used to tune the dimensions of the filter. The filter using dual cascaded quasi multi-mode resonators provides a very sharp cut-off frequency response with low insertion loss. It also realized a broad band pass-band, a compact size and two transmission zeros at both the lower and upper stop-bands. The filter is also evaluated by experiment and simulation with good agreement.

## 1. INTRODUCTION

Wide-Band components are now highly demanded as wide-band systems in new communication satellite systems. In general, a wide-band circuit requires a large design area or complicated structure such as multilayer structure or wire-bonding connections. New wireless systems also need various types of band-pass filters to enable digital data transmit via microwave bands. Recent investigations show that wide-band band-pass filters using CPW structures are one of the most common candidates to enhance the band-width and reduce the size of these components [1–7]. They, however; yet occupy a large area of substrate in printed circuit. For example, the CPW band-pass filter designed in [7], has occupied an area about  $40 \times 40 \text{ mm}^2$  on a typical substrate.

Moreover, many authors have recently focused on the design of wide-band band-pass filter with microstrip technology in two major kinds, classical multiple-mode and optimum distributed high-pass filters, alongside CPW structures [8–11]. Altogether, the use of microstrip structures is much easier than CPW and other ones in design and implementation. They, however, have a relatively large area and need to be more reduced in size and volume. For example, the proposed band-pass filter in [10], has occupied an area about  $35 \times 14 \text{ mm}^2$  on its substrate.

To reduce the size of such crucial components, in another study, the use of triple coupled microstrip transmission lines has been introduced [11], and in other ones the edge and cross coupled transmission lines have been suggested. The main disadvantage of this group is that they provide a narrow band-pass. Furthermore, the study on transmission zeros of two coupled lines has been carried out in [12] and a compact band-pass filter has been designed and proposed using effective even-and-odd-mode characteristic impedances, but with very narrow pass-band.

The use of connected lines as a cascaded two unit elements instead of internal series stubs is a useful method to increase the bandwidth in interdigital elliptic filters [13, 14] which is also considered in this paper to design a compact BPF with a wide-band pass-band. In this paper, a novel arrangement of triple coupled transmission lines is proposed to design a highly compact band-pass filter with a wide pass-band. Initially, the equivalent circuit of the proposed model is synthesized from network model, and afterwards, a wide-band pass-band filter is analyzed, designed, fabricated and proposed using this technique. The novel BPF is designed at the central frequency of the pass-band 5 GHz, and fabricated on a 30-mil-thick RF-35 PTEE/Woven

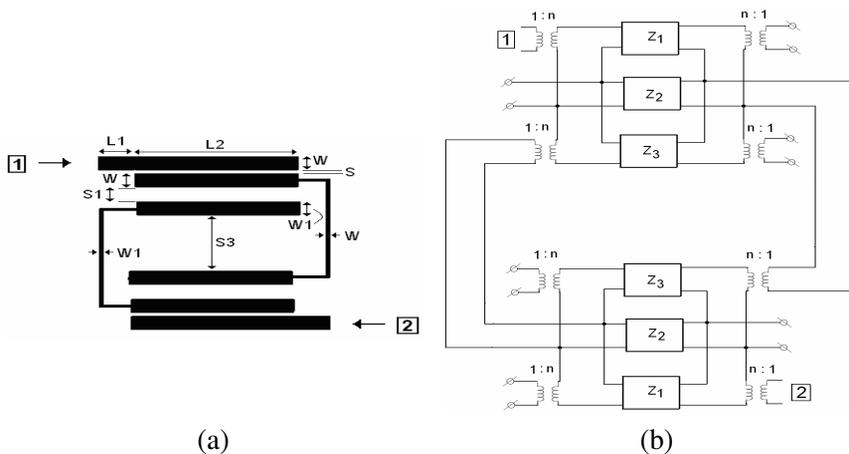
substrate with a relative dielectric constant  $\epsilon_r = 3.5$ . Furthermore, the EM simulated and measured results of the proposed BPF are simultaneously presented.

## 2. CIRCUIT ANALYSIS

Figure 1(a) shows the basic layout of the proposed model to design wideband band-pass filter. At the central frequency of a pass-band, this structure consists of two triple microstrip coupled transmission lines. The electrical length is considered  $\lambda/4$  for all lines, therefore, there are two microstrip lines with electrical length  $\lambda/2$  as well as two microstrip lines with electrical length  $\lambda/4$ . According to the classification presented in [10], this structure can be considered as a classical multi-mode resonator. The network transformer model of this structure can be easily obtained using instructions presented in [14]. Figure 1(b) shows the network transformer model of this proposed structure.

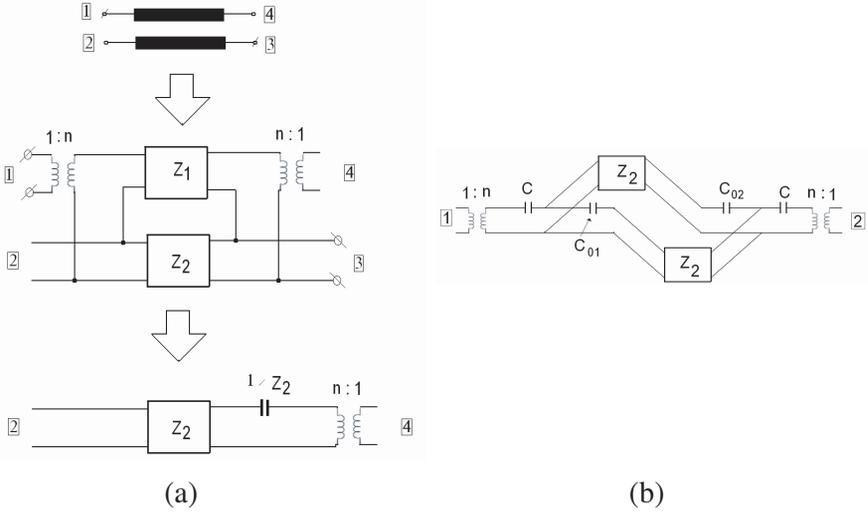
Subsequently, the obtained equivalent circuit of the proposed structure given in Figure 1(b) can be simplified to that shown in Figure 2(b) by direct application of the network model and application of the relevant port conditions as conceptually indicated for two coupled lines in Figure 2(a).

Inspecting the simplified equivalent circuit, it is observed that this circuit consists of two parallel sections which can be more simplified to ease the difficulties of the design off.



**Figure 1.** (a) The proposed structure to design wideband band-pass filter. (b) Its network model.

To do this, first consider the calculation of ABCD matrix for the series unit element and capacitor in each paralleled section is initially considered. Assuming  $Z_{c1}$ , and  $Z_{c2}$  as impedances of the series capacitances  $C_{01}$ , and  $C_{02}$ , respectively, and  $Z_0$ , and  $\theta = \pi/2$  as characteristic impedance and electrical length of the both unit elements, respectively, the ABCD matrix for the circuit including the two parallel sections can best be done by multiplying the ABCD matrices of each cascade component in that circuit.



**Figure 2.** (a) The equivalent circuit of a coupled lines. (b) Simplified equivalent circuit of the proposed structure.

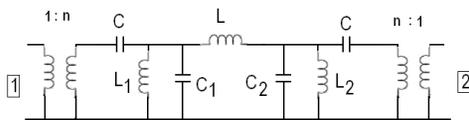
In the next stage, by converting ABCD matrices to admittance matrices and using this fact that the admittance matrix of the two parallel connected two-port- $\pi$  network can be found by adding the admittance of the individual two-port, the parameters of the two-port- $\pi$  network in terms of admittance parameters can be obtained as follows:

$$Y_1 = \frac{Z_{c1}}{Z_0^2} - \frac{2}{jZ_0} \quad (1)$$

$$Y_2 = \frac{Z_{c2}}{Z_0^2} - \frac{2}{jZ_0} \quad (2)$$

$$Y_3 = \frac{2}{jZ_0} \quad (3)$$

From (1)–(3), the equivalent lumped element circuit of the network



**Figure 3.** The equivalent lumped-element circuit of the proposed microstrip coupled lines in Figure 1(a).

model shown in Figure 2 can be derived in the form of two-port- $\pi$ . It can be known that  $Y_1$  parameter can be realized by two parallel capacitance  $C_1 = C_{01}Z_0^2$  and inductor  $L_1 = C_{01}Z_0^2$ . Similarly,  $Y_2$  and  $Y_3$  can be realized by lumped elements. By substituting of this two-port- $\pi$  for the two parallel cascaded sections in Figure 2, the final equivalent circuit shown in Figure 3 can be synthesized for proposed structure in Figure 1(a).

Considering  $f_0$  as the central frequency of the pass-band, the values of the lumped elements indicated in the equivalent circuit can be determined as follows:

$$C = \frac{1}{\omega_0 Z_1}, L_1 = C_{01}Z_0^2, C_1 = C_2 = \frac{2}{\omega_0 Z_0}, L = \frac{Z_0}{2\omega_0}, L_2 = C_{02}Z_0^2 \quad (4)$$

where the given variables have been indicated in Figures 2 and 3.

### 3. THE COMPACT ELLIPTIC-FUNCTION BAND-PASS FILTER

#### 3.1. Band-pass Filter Using Lumped Elements

As indicated in previous section, a band-pass filter can be realized using lumped elements. To design this filter, initially, the combline filter presented in [14], can be referred. This kind of filter consists of an array of coupled lines, all shorted at one end and terminated at the other in lumped capacitances, while the ports are connected by means of short circuited lines.

As discussed and indicated in [14], the equivalent circuit of a combline filter is exactly similar to that of the proposed structure in this paper, shown in Figure 3, but with much more complicated difficulties to realize in practice.

According to (4), there are several degrees of freedom to design a band-pass filter using lumped elements. Without regarding the existent coupling among coupled lines, to initiate the design of a band-pass filter, the values of characteristic impedances of  $Z_1$  and  $Z_0$  can be arbitrarily selected. According to available L-C value tables [15],

given in Table 1, these two parameters are selected as 120 and 172 ohm, respectively.

It should be noted that the capacitances of  $C_{01}$  and  $C_{02}$  can be determined by the same way. These two parameters depend on the characteristic impedances of the two unit elements  $Z_3$ , indicated in Figure 1(b), which can normally have different values. In this case, and in order to have a simple design, the value of  $Z_3$  would be selected similar to  $Z_1$ . Subsequently, the unknown parameters to design a band-pass filter can be determined using (4). Table 1 gives the available [15], approximated (obtained using (4)), and optimized values to design a dual cascaded band-pass filter using lumped elements.

Following this, a dual cascaded of the circuit shown in Figure 3 is simulated by the  $S$ -Parameter method of ADS software.

In order to have a comparable frequency performance with the conventional ones, the performance of this band-pass filter is optimized using this soft ware. Figure 4 shows its frequency response and Table 1 gives the optimized values for this filter.

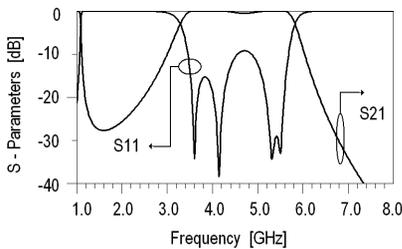
Initially, the design of a single element of the proposed band-pass filter using microstrip quasi multi-mode is followed. A compact band-pass filter is designed and simulated based on equations obtained in previous sections.

### 3.2. The Compact Elliptic-function Band-pass Filter Using Microstrip Quasi Multi-mode Resonator

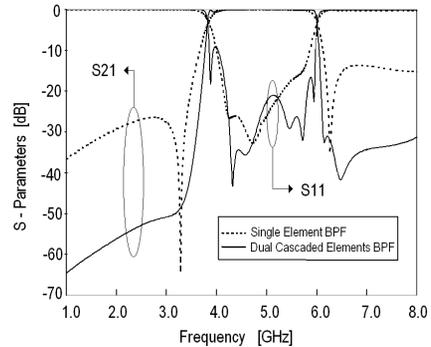
Figure 5 shows the frequency response of a single element of this filter in comparison with that of dual cascaded-element of this filter optimized by EM simulator tools. Observing their frequency responses shown in Figure 5, they approximately provide the same pass-band as well as the same return loss; however, the insertion loss ( $S_{21}$ ) of the dual cascaded-element filter is far better than that of the first one in the stop-bands.

**Table 1.**  $L$ - $C$  values of the band-pass filter using dual cascaded quasi multi-mode resonators.

	$L$	$L_1$	$L_2$	$C$	$C_1$
Available $L$ - $C$ tables [15]	2.9 nH	2.9 nH	3.45 nH	0.2 pF	0.74 pF
Approximated $L$ - $C$ values	2 nH	2.664 nH	3.816 nH	0.265 pF	0.53 pF
Optimized $L$ - $C$ values	4.38 nH	4.541 nH	4.41 nH	7.56 pF	0.499 pF



**Figure 4.** The frequency response of the proposed filter designed using optimized  $L$ - $C$  elements given in Table 1, and with  $n = 1.9341$ .

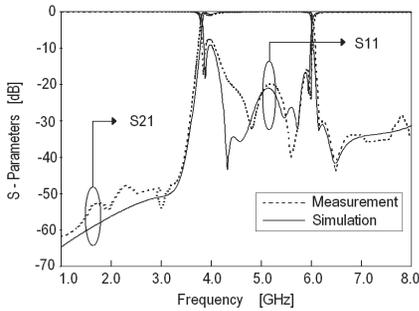


**Figure 5.** A comparison between two band-pass filters using single (dashed lines) and dual cascaded elements (solid lines) of quasi multi-mode resonators with  $L_1 = 0.55$  mm,  $L_2 = 9$  mm,  $W = 0.2$  mm,  $W_1 = 0.05$  mm,  $S = 0.1$  mm,  $S_1 = 0.3$  mm,  $S_3 = 0.9$  mm.

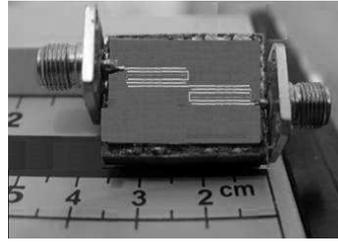
#### 4. SIMULATED AND MEASURED RESULTS

According to the given specifications in the previous sections, the initial band-pass filter dimensions are chosen based on the design of the equivalent circuit model of this filter shown in Figure 3, and then, they are tuned by EM simulation tools (ADS). The optimized dimensions of the wideband BPF are given in the beneath of Figure 5. After tuning the dimensions, a compact wideband BPF is realized on a 30-mil-thick RF-35 PTEE/Woven substrate with a relative dielectric constant  $\epsilon_r = 3.5$ . Figure 7 shows a photograph of the fabricated BPF, and a comparison between simulated and measured results is presented in Figure 6.

The scattering parameters measurement is performed using an Agilent 8722D network analyzer over the frequency range from 1.0 to 8.0 GHz. Figure 6 gives the simulated and measured frequency responses of the wideband BPF in which the 3-dB fractional bandwidth is found to be over 45% from 3.78 to 6.03 GHz.



**Figure 6.** The simulated (solid lines) and measured (dashed lines) frequency responses of the dual cascaded BPF using microstrip quasi multi-mode resonator.



**Figure 7.** Fabricated proposed compact wideband BPF.

## 5. CONCLUSION

A highly miniaturized elliptic-function band-pass filter has been designed, analyzed and proposed using microstrip quasi multi-mode resonators. The prototype filter has been synthesized from the two-port network and equivalent circuit models using available element value tables. To optimize the performance of the filter, electromagnetic simulation (EM) has been used to tune the dimensions of the filter. The filter using dual cascaded quasi multi-mode resonators provides a very sharp cut-off frequency response with low insertion loss. It also realized a broad band pass-band, a compact size and two transmission zeros at both the lower and upper stop-bands. This filter has occupied an area of about  $23 \times 7 \text{ mm}^2$  on a substrate in comparison with the proposed filter in [10], which has occupied an area of about  $35 \times 14 \text{ mm}^2$ . The filter is also evaluated by experiment and simulation with good agreement.

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