A DESIGN APPROACH FOR COMPACT ULTRA-WIDEBAND BANDPASS FILTER BASED ON HYBRID MICROSTRIP COPLANAR WAVEGUIDE RESONATORS

Le Trong Hieu*, Tran Trong Thang, Hoang Van Dong

Abstract: *In this paper, we present a simple hybrid coplanar waveguide (CPW) and microstrip ultra-wideband (UWB) bandpass filter using five quater-wavelength resonators, three microstrip ones on the top and two CPW ones on the bottom side. The proposed filter exhibits a quasi-elliptic function response, with one finite-frequency transmission zero closer in the low side and two finite-frequency transmission zeros in the high side of the passband. The experimental filter shows the measured 3-dB fractional bandwidth of 80% at a center frequency of 6.02 GHz, with the mesured insertion loss is 0.6 dB. This design not only improves the harmonic-suppression characteristic in high-frequency stop-band but also reduces the size of filter with 15 × 18 (mm). The filter will have great potential applications in UWB microwave circuits and systems, especially, in C-band radar systems.*

Keywords: Ultra-wideband; Coplanar waveguide; Microstrip resonator; Bandpass filter; Microwave circuits.

1. INTRODUCTION

The rapid development of 5G [1] and the Internet of Things (IoT) [2] has an urgent demand for high response speed and high positioning accuracy, and the ultra-wideband (UWB) can perfectly meet this requirement. The emergence of key reports and research process, whether from an academic or engineering perspective, has greatly advanced the development of UWB over the past few decades. The UWB bandpass filters served as key building block in UWB wireless communication systems have aroused much research interest in this century. And various attempts to design UWB have been reported continuously. Various techniques have been presented to develop the UWB bandpass filters. One of the straightforward methods is cascading a low-pass filter and a high-pass filter to accomplish UWB bandpass filter [3-5]. In [6], a highly selective UWB bandpass filter is achieved by short-circuit stub-loaded structure, which can excite 11 resonant modes to fulfill the requirement of UWB with miniature circuit size. In [8], a quintuple-mode UWB bandpass filter is designed by difficult and expensive high-temperature superconducting technique.

In this paper, a simple microstrip UWB bandpass filter (BPF) using three symmetrical multiple-mode resonators along with two quater-wavelength resonators is investigated. The basic idea and the filter topology are introduced. This design not only improves the harmonic-suppression characteristic in high-frequency stop-band but also reduces the size of filter structure. The proposed UWB-BPF presents good performance in terms of insertion loss, return loss, fractional bandwidth and compact size than those reported in the literature. The filter will have great potential applications in UWB microwave circuits and systems.

2. FILTER DESIGN

Figure 1 shows an interdigital filter with open-circuited lines at the input and output [6-8]. It differs from the other type interdigital filter in that the first and last lines, which connect directly to the terminals (Y_0) at one end, and are open-circuited instead of shorted-circuited at the other end. These open-circuited lines at the input and output also count as resonators, so that there are *n* line elements for an *n*-pole filter [7].

The filter configuration, as shown, consists of an array of n TEM-mode or quasi-TEM-mode transmission-line resonators, each of which has an electrical length of 90◦ at the midband

frequency and is short-circuited at one end and open-circuited at the other end with alternative orientation. In general, the physical dimensions of the line elements or the resonators can be different, as indicated by the lengths l_1, l_2, ..., l_n and the widths W_1, W_2, ..., W_n. Coupling is achieved by the fields fringing between adjacent resonators separated by spacing $s_{i,i+1}$ for $s = 1 \cdots n - 1$. The filter input and output use tapped lines with a characteristic admittance Y_t, which may be set to equal the source/load characteristic admittance Y_0. An electrical length θ_t, measured away from the short-circuited end of the input/output resonator, indicates the tapping position, where $Y_1 = Y_n$ denotes the single microstrip characteristic impedance of the input/output resonator.

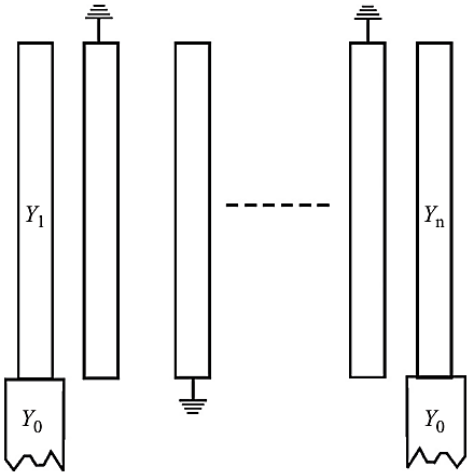


Figure 1. *Interdigital filters with open-circuited lines at the input and output.*

Although this type of filter is most practical for designs having moderate or wide bandwidths, an implementation on microstrip with conventional parallel-coupled lines for an UWB filter can be difficult since very tight coupling gaps are required. To overcome this difficulty, broadside coupling structures can be used. Original theory and design procedure for interdigital bandpass filters with coupledline input/output (I/O) can be found [6]. Explicit design equations based on Caspi and Adelman [8] for the type of bandpass filter with tapped-line I/O are given by:

$$\theta = \frac{\pi}{2}\left(1 - \frac{FBW}{2}\right) \tag{1}$$

$$Y = \frac{Y_1}{tan\theta} \tag{2}$$

$$Y_{i,i+1} = Y_0\left(\frac{J_{i,i+1}}{Y_0}\right) \; for \; i = 1 \; to \; n-1 \tag{3}$$

Wherein:

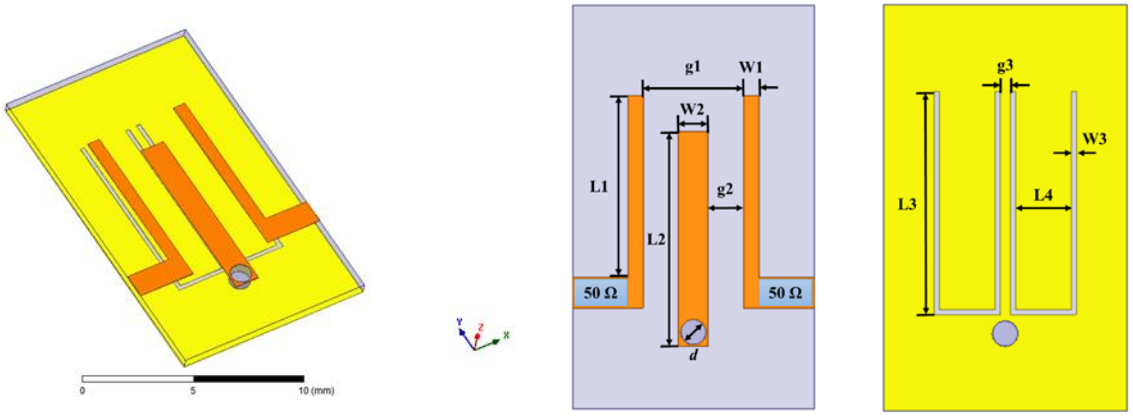
$$\frac{J_{i,i+1}}{Y_0} = \frac{h g_0 g_1}{\sqrt{g_i g_{i+1}}} \; for \; i = 2 \; to \; n-2 \tag{4}$$

Where *FBW* is the fractional bandwidth, *h* is a dimensionless admittance scale factor whose value should be chosen to give a convenient admittance level in the filter, and g_i is the element value of a ladder-type lowpass prototype filter.

In order to support the C-band operation frequency, we wish to design a five-pole (n = 5) generalized Chebyshev UWB filter, with a *FBW* of 80% at midband frequency f_0 = 6 GHz, a 0.1 dB passband ripple and the asymmetrical responses with the controllable TZs located at both side of passband. The prototype parameters were $g_0 = g_6 = 1.0$, $g_1 = g_5 = 1.1468$, $g_2 = g_4 = 1.3712$, $g_3 = 1.9750$. A 50- Ω terminal line impedance is chosen, which gives Y_0 = 1/50 (mhos). Using equations (3)-(4), the computed design parameters are summarized in table 1.

Table 1. *Circuit design parameters of a five-pole UWB filter with λ/4 short-circuited stub.*

i	Y_0 (mhos)	$Y_{i,i+1}$ (mhos)
1	0.03525	0.02587
2	0.06937	0.02587
3	0.06824	0.02587
4	06937	0.02587
5	0.03525	

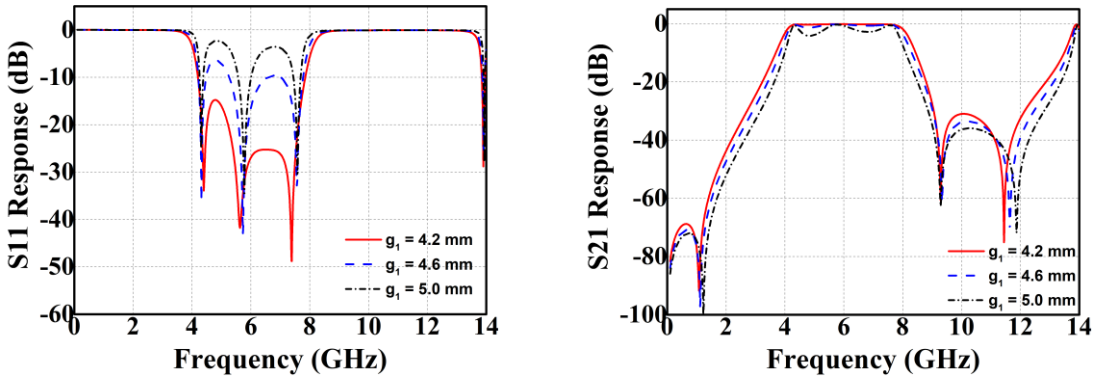


(a) *(b)* *(c)*

Figure 2. *(a) Structure of UWB bandpass filter on HFSS simulation software. (b) Top view for the microstrip resonators. (c) Bottom view for the CPW resonators.*

According to the theory analyis method above, the schematic configuration of the proposed UWB-BPF is shown in figure 2. The filter consists of five quater-wavelength resonators, three microstrip ones on the top and two CPW ones on the bottom side. It can be seen as a five-pole interdigital filter having a form of figure 1 It is designed on a substrate with a relative dielectric constant of 3.0 and a thickness of 0.508 mm. A top view of the microstrip is shown in figure 2 (b). On the top side of the substrate, two parallel microstrip open-circuited stub lines of W_1 wide and L_1 long and a short-circuited stub of W_2 wide and L_2 long, in the center, are coupled to the two CPW resonators through the dielectric substrate. The two open-circuited lines, separated by a gap of g_1, are connected to 50-Ω input/output (I/O) feed lines. The use of parallel coupled feed lines is able to enhance the coupling degree between the feed lines. Accordingly, the symmetrical parallel coupled feed lines can work together to keep the UWB-BPF in the desired range. A bottom view for the CPW is given in figure 2 (c). Two parallel quarterwavelength CPW resonators with a width of W_2 and a length of L_3 which are separated by a gap of g_3, are formed on the bottom side of the substrate. The broadside-coupling and the existence of the dielectric substrate make the coupling between the microstrip lines and the CPW very tight. Tight coupling therefor provides a very wide bandpass operation. The input and output ports are designed to Z_0 of 50 Ω. The gap g_1 between the two parallel microstrip stub lines was allowed to vary in the simulations to optimize the performance of the filter, since it was found to be a critical design parameter.

To clearly verify the independent tuning operation frequencies, using software package simulations full wave EM given by Ansoft HFSS to prove and results illustrated as figure 3. As can be seen from the transmission (S_{21}) response in figure 3, the filter exhibits a quasi-elliptic function filtering characteristic with three transmission zeros closer to the passband, which enhance the selectivity effectively. This is because the connecting lines also contribute to the selectivity of the filter and, hence, add additional four poles to the filter order. When the gap g_1 between the two microstrip open-circuited stubs is varied between 4.2 to 5 mm, two effects can be observed and the return loss (S_{11}) of the filter is improved.



(a) *(b)*

Figure 3. *Simulated results of bandpass characteristics with different gap g_1: (a) Return loss (S_{11}); (b) Insertion loss (S_{21}).*

The first effect is on the bandwidth of the filter. For a larger g_1, smaller bandwidth is observed. This is because the overlap between top microstrip stubs and the bottom CPW resonators is reduced, hence reducing the resulting inter-stage coupling. The second effect of varying the gap g_1 is able to shift the locations of transmission zeros (TZs). The smaller g_1 moves the transmission zeros or attenuation poles towards the passband, resulting in a higher selectivity. Compared with the conventional stub bandpass filter for achieving the same filtering characteristics, this type of UWB bandpass filter not only uses less short-circuited stubs, but also has much more reasonable impedance levels for all the short-circuited stubs. This makes the realization easy with a low-cost fabrication technology and suppress the unwanted spurious response.

After carefully tuning, the performance of the proposed filter has been optimized to approach the specifications. The final dimensions are listed in table 1 as following:

Table 2. *Optimized physical dimension of the designed UWB BPF (in mm).*

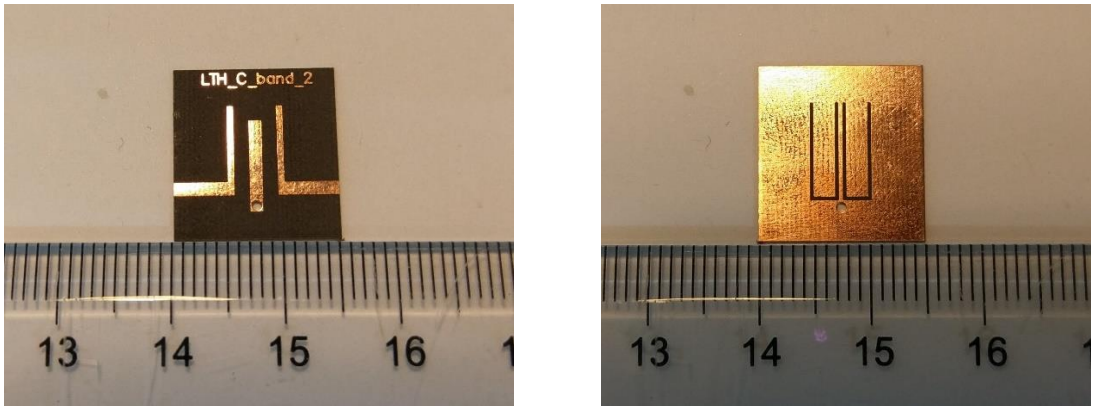
Symbols	Value	Symbols	Value
L_1	7.2	W_2	1.4
L_2	8.1	W_3	0.3
L_3	9.8	g_1	4.2
L_4	2.5	g_2	1.2
W_1	0.5	g_3	0.5
d	1.0		

3. FABRICATION AND FILTER PERFORMANCE

The proposed hybrid microstrip/CPW UWB bandpass filter with Chebyshev frequency response is built on single layer of Taconic RF-30 substrate with a thickness of 0.508 mm, a thickness of copper cladding t of 0.035 mm, relative permittivity of 3.0 and loss tangent of 0.0014. Figure 4 shows the photograph of the fabricated layout with the top view and bottom view. The whole size of the fabricated filter is only 15 × 18 (mm). Figure 5 indicates the S-parameters measured result proposed filter. The measurement is accomplished with Agilent E8363B PNA Series Network Analyzer.

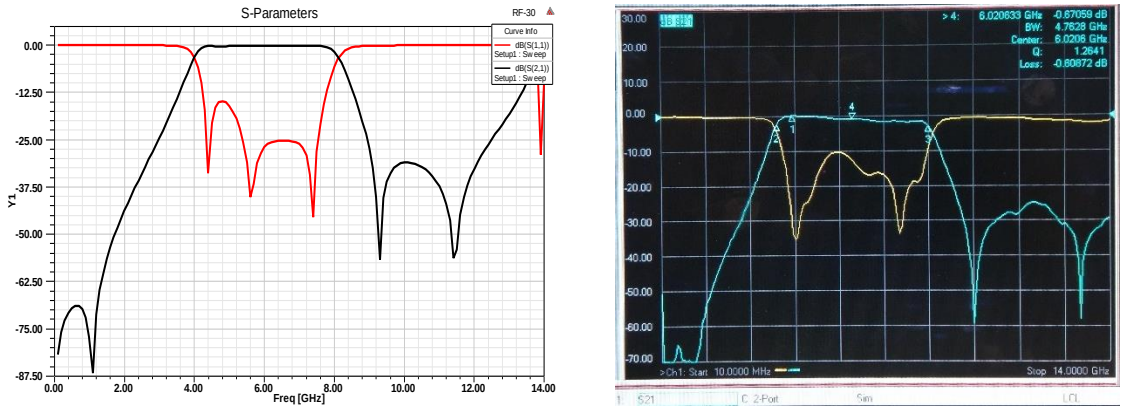
The experimental filter shows the measured 3-dB fractional bandwidth of 80% at a center frequency of 6.02 GHz, with three observable transmission zeros at 1.1, 9.8 and 13.0 GHz, respectively. The midband insertion loss was measured to be 0.6 dB including the loss from two SMA connectors. The measured return loss is better than 10 dB. The location of the TZs on both side slopes of the bandpass with high attennuation level more than -60 dB which enhances filter selectivity and improves the ability out-of-band rejection of the UWB BPF. Some slight

differences between the simulated and measured results may be caused by unavoidable tolerance in fabrication and measurement.



(a) Top view *(b) Bottom view*

Figure 4. *Photograph of the fabricated UWB filter.*



(a) Simulated result *(b) Measured result*

Figure 5. *S-parameters results of the UWB filter.*

4. CONCLUSIONS

In this study, a simple hybrid coplanar waveguide and microstrip UWB BPF using five quater-wavelength resonators, three microstrip ones on the top and two CPW ones on the bottom side is presented. The resonance mechanism and the frequency change of the resonator have been analyzed in detail. The proposed filter exhibit good selectivity and cost-effective due to the use of a single dieletric substrate. The proposed filter exhibits a quasi-elliptic function response, with one finite-frequency transmission zero closer in the low side and two finite-frequency transmission zeros in the high side of the passband. Thus, a high selectivity is achieved using a small number of resonators, which leads to low insertion loss and group delay across the passband. The development direction of the problem of filter design on the hybrid structure such as controlling the center frequency, bandwidth, stop band, will be further studied in next prototypes. This filter structure also will be attractive for UWB system applications such as satellite communications, traffic radar and automotive radar systems.

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TÓM TẮT

GIẢI PHÁP THIẾT KẾ BỘ LỌC THÔNG DẢI BĂNG SIÊU RỘNG, NHỎ GỌN SỬ DỤNG BỘ CỘNG HƯỞNG VI DẢI KẾT HỢP ỐNG DẪN SÓNG ĐỒNG PHẲNG

Bài báo này đề xuất giải pháp thiết kế bộ lọc thông dải băng siêu rộng ống dẫn sóng đồng phẳng (CPW) kết hợp đường truyền vi dải sử dụng năm bộ cộng hưởng một phần tư bước sóng. Trong đó, có ba bộ cộng hưởng vi dải ở phía trên và hai bộ cộng hưởng CPW ở phía dưới bản mạch in. Bộ lọc được đề xuất có hàm đáp ứng tần số quasi-elip, với 3 điểm truyền tần số hữu hạn 0 ở hai phía của dải thông. Kết quả đo đạc của bộ lọc được chế tạo thử nghiệm cho thấy băng thông hiệu dụng 3dB là 80% ở tần số trung tâm 6,02 GHz với suy hao chèn trong băng là 0,6 dB. Giải pháp thiết kế này không chỉ cải thiện đặc tính triệt tiêu sóng hài ở dải chặn tần số cao mà còn giảm kích thước bộ lọc xuống 15 × 18 (mm). Bộ lọc có khả năng ứng dụng trong các hệ thống siêu cao tần UWB, đặc biệt là trong các hệ thống ra đa băng tần C.

Từ khóa: Băng siêu rộng; Ống dẫn sóng đồng phẳng; Cộng hưởng vi dải; Bộ lọc thông dải; Mạch cao tần.

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