A Compact UWB Ring Filter Using A Dual-Mode Resonator With Spurious Suppression

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Contents

Nomenclature

f_0 = Center frequency

f_n = Normalized frequency

Z_{in}^{e} = Even-mode input impedance

Z_{in}^{o} = Odd-mode input impedance

θ = Electrical length of the transmission line

λ = Wavelength

l_t = position of tapped-line point

Z_l = impedance of the tapped line

Q_s = loaded quality factor

Z_0 = characteristic impedance of the transmission line

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Abstract

A suggestion is proposed to use a circuit of microstrip ring resonators such as Ultra Wideband Bandpass filter in wireless communication.

The Ring Filter's dimension is small, with low insertion loss, satisfactory skirt characteristic and a constant group delay into the UWB bandwidth.

This filter makes it possible to control the cutoff frequencies which are dependent upon the ring and the parallel stub impedance. The rejected conditions of two cutoff frequencies on both side of the passband are dependable on parallel stub.

This Bandpass filter has cutoff frequencies between 3.1 and 10.7GHz with the resonable position of stub at the end of symmetry plane. The circuit conditions of two attenuation poles at either side of the passband are given together with controlling them. To reject spurious suppression which is placed at impedance zero, we employ stepped impedance line near input port and output port. This filter is appropriate for UWB systems in all applications.

Chapter 1. Introduction

Since the U.S. Federal Communications Commission(FCC) released the unlicensed use of the ultra-wideband(UWB) (3.1-10.6GHz) for indoor and hand-held systems in 2002[1], significant research activities and interests have been recently aroused in academic and industrial circles toward exploring various UWB component and devices[2]. As one of the essential component blocks, attempts to developing a UWB bandpass filter (BPF) were made in [3]-[7]. In [3], an initial UWB filter is presented by mounting a microstrip line in a lossy composite substrate and the reported insertion loss is higher than 6.0dB. In [4], a microstrip ring UWB filter is constructed by simultaneously exciting and allocating transmission zeros belows 3.1GHz and above 10.6GHz. Due to its nature of dual-stopband, this filter with multiple ring resonators usually has narrow lower and upper stopbands as well as large size ones. In [5], a composite UWB filter is proposed by combining lowpass and highpass filter structures or embedding one into the other. In [6], a broadside-coupled microstrip-coplanar waveguide (CPW) structure with tightened coupling degree is utilized to design an alternative UWB filter one, two, and three sections. In [7], a novel compact UWB BPF on microstrip line is constituted using a single multiple-mode resonator (MMR) that is driven at two sides by two identical parallel-coupled lines.

There are various kinds of resonators including the coaxial, dielectric, waveguide, and stripline resonators which are available in the frequency range from RF to microwave[8]. Coaxial resonators have many attractive features including an electromagnetic shielding structure, low-loss characteristics and a small size, but their minute physical dimensions for applications above 10GHz make it difficult to achieve manufacturing accuracy. Dielectric resonators also possess a number of advantages such as low-loss characteristic, acceptable temperature stability and a small size. However, high cost and present-day processing technology restrictions limit dielectric resonator utilization to applications below 50GHz. Waveguide resonators have long been used in this frequency range, possessing two main advantages: low-loss characteristic and practical application feasibility up to 100GHz. However, the greatest drawback of the waveguide resonator's size is that it is significantly larger than other resonators available in the microwave region. Presently, the most common choice for RF and microwave circuits remains the stripline resonator[14].

Due to practical features including a small size, easy processing, and good affinity with active circuit elements, many circuits utilize the stripline resonator. However a major drawback to the use of the resonators is a drastic increase in insertion loss compared to other types of resonators, making it difficult to apply such stripline resonators to narrow band filters. Microstrip line filter designing is reported frequently to use distributed elements like as coupled line filters and shunt stub filters which have met an established theory.

However currently suggested diverse microstrip resonators have high insertion loss due to primary factors such as conduct loss, dielectric loss, radiation loss and coupling loss. They obstruct development planner type of filter.

A few papers have been published for attenuation pole frequency control over a wide range using various combinations of stub perturbation and excitation angles. There have been many studies on dual mode ring resonator BPFs because such resonators have very simple structures[14].

This article extends the transmission line model to our ring resonator and stub. We will present the conditions for achieving attenuation poles for such a Ring Filter.

A required bandwidth of UWB is significant which should be wider than an octave bandwidth about 110%

In addition, we employ a parallel open stub.

The ring and the parallel stub lines creates a stopband frequency which can be varied by changing the tuned stub.

The contents of the thesis are illustrated as follows

Chapter 1 briefly introduces the thesis, the background and the purpose of this work.

Chapter 2 presents dual mode of conventional ring filter.

Chapter 3 proposed UWB ring filter design of single stage. Experimental results of the fabricated filter are also demonstrated and discussed.

Chapter 4 is the conclusion of this thesis. It summarizes the research work and proposed application of this new type of filters.

2. Conventional Ring Filter Theory

2.1 Introduction

The basic geometry of ring resonator is shown Fig. 2.1. Both I/O port are positioned 2θ length in ring filter. Z_3 is stub and θ length which is placed at the end of symmetry plane, which also contributes to the appearance of attenuation poles at both sides of passband[15].

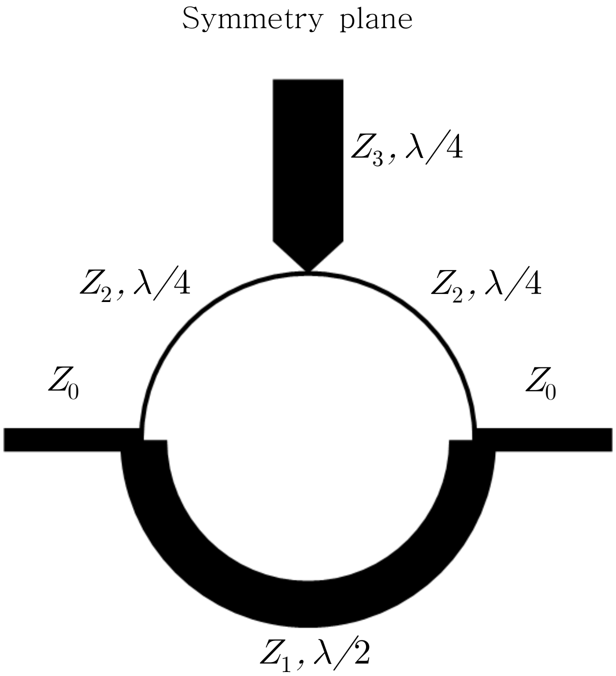


Fig. 2.1 Conventional ring filter.

2.2 Even-Odd mode Ring resonator

For even-mode calculation, the symmetry plane in Fig. 2.1 will act as an open end, i.e., as a perfect magnetic wall, and the equivalent transmission-line circuit of Fig. 2.1 will become as shown in Fig. 2.2.

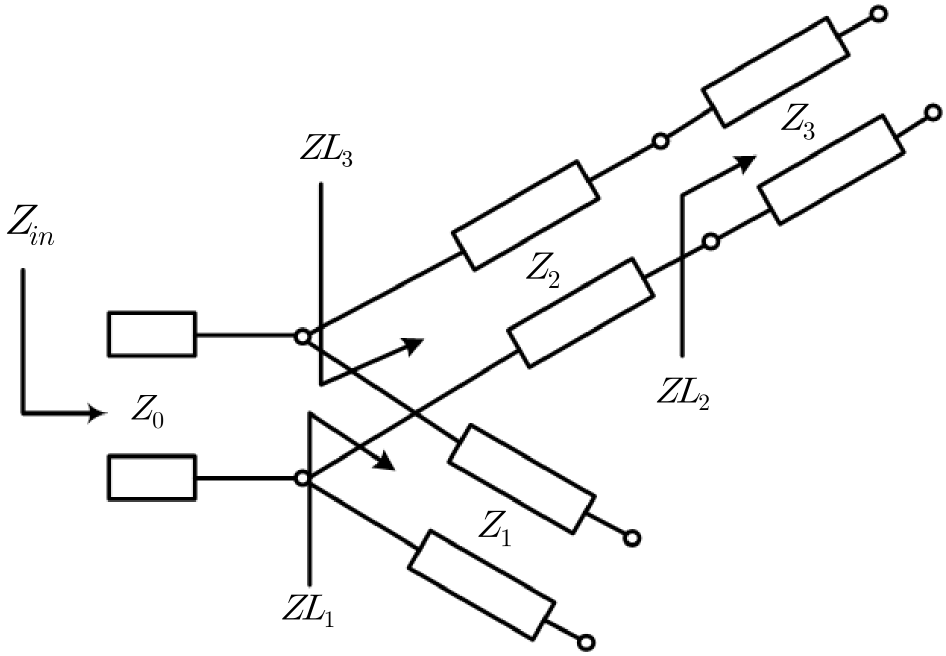


Fig. 2.2 Equivalent transmission-line circuit model for even-mode calculation.

$$f_n = \frac{f}{f_0} \tag{2-1}$$

f_n is normalized frequency and f_0 is center frequency. Before calculating even-mode input impedance, Z_{in}^e has to know ZL_1, ZL_2 and ZL_3.

$$ZL_1 = \frac{Z_1}{j\tan(\frac{\pi}{2} f_n)} \tag{2-2}$$

$$ZL_2 = \frac{Z_3}{j\tan(\frac{\pi}{2} f_n)} \tag{2-3}$$

$$ZL_3 = Z_2 \frac{ZL_2 + jZ_2\tan(\frac{\pi}{2} f_n)}{Z_2 + jZL_2\tan(\frac{\pi}{2} f_n)} \tag{2-4}$$

$$Z_{in}^e = \frac{ZL_1 ZL_3}{ZL_1 + ZL_3} \tag{2-5}$$

$$\Gamma_e = \frac{Z_{in}^e - Z_0}{Z_{in}^e + Z_0} \tag{2-6}$$

For odd-mode calculation, the symmetry plane in Fig. 2.1 will act as an short end, i.e., as a perfect electric wall, and the equivalent transmission-line circuit of Fig. 2.1 will become as shown in Fig. 2.3

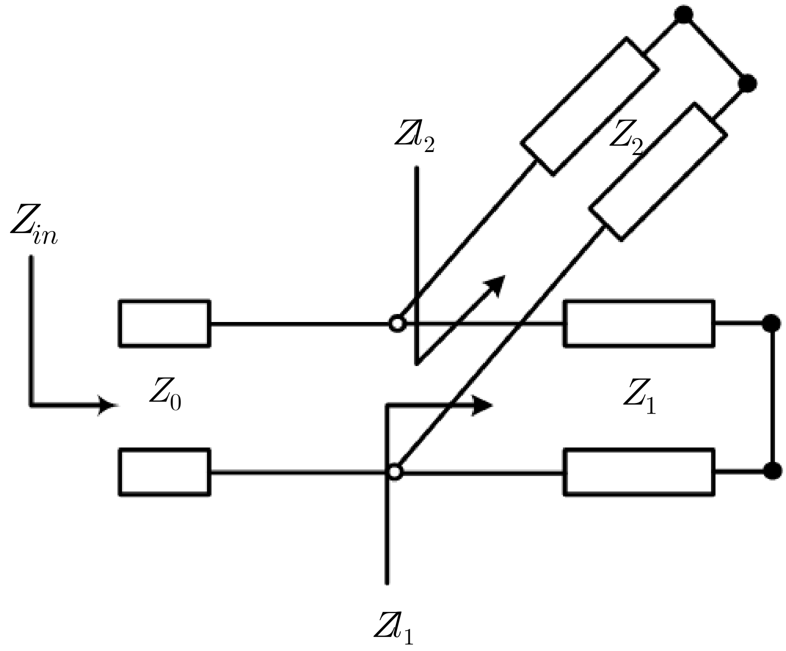


Fig. 2.3 Equivalent transmission-line circuit model for odd-mode calculation.

Before calculating odd-mode input impedance Z_{in}^{o} has to know Zl_1 and Zl_2

$$Zl_1 = j\,Z_1 tan\left(\frac{\pi}{2} f_n\right) \tag{2-7}$$

$$Zl_2 = j\,Z_2 tan\left(\frac{\pi}{2} f_n\right) \tag{2-8}$$

$$Z_{in}^{o} = \frac{Zl_1 Zl_2}{Zl_1 + Zl_2} \tag{2-9}$$

$$\Gamma_o = \frac{Z_{in}^o - Z_0}{Z_{in}^o + Z_0} \tag{2-10}$$

S-parameter is calculated by (2-6) and (2-10)

$$S_{11} = \frac{\Gamma_e + \Gamma_o}{2} \tag{2-11}$$

$$S_{21} = \frac{\Gamma_e - \Gamma_o}{2} \tag{2-12}$$

2.3 Conventional Dual-mode ring filter

Use of Dual mode resonators allows the realization of a compact high-quality microwave BPF(Band Pass Filter) whose attenuation poles play a role in improving the skirt characteristics. There have been many studies on dual mode ring resonator BPFs because such resonators have simple structure [16]. This paper extends the transmission line model to our ring resonator and stub. We will present the conditions for achieving attenuation poles for such a ring filter. The feeding lines are directly coupled to a ring. The circumference of the ring is one wavelength λg long at the center frequency. Attenuation poles in the ring filter are easy to find. The condition for producing attenuation poles is given by setting the S_{21} to zero [17].

$$S_{21} = - Z_0 Z_1 Z_2^3 (tan^2\theta + 1)(tan^2\theta - \frac{2Z_3(Z_1+Z_2)}{Z_2^2})/A$$

(2-13)

where

$$A = (Z_1 Z_2 jtan\theta + Z_0(Z_1+Z_2))(-Z_0 Z_2^2 jtan^3\theta - Z_1 Z_2^2 tan^2\theta + Z_0(Z_1 Z_2 + 2Z_3(Z_1+Z_2))jtan\theta + 2Z_1 Z_2 Z_3)$$

(2-15)

Setting S_{21} to zero gives the following characteristics equation for attenuation frequencies, $f_p = \theta_p v/(2\pi\theta)$

$$tan^2\theta_p = 2(1+\frac{Z_1}{Z_2})\frac{Z_3}{Z_2} \quad (2\text{-}16)$$

2.4 Calculation and measurement of attenuation poles of ring bandpass filter

Fig. 2.4 shows the response of the fabricated ring filter with $Z_0 = Z_1$=50Ω, Z_2=92.7Ω and Z_3=17Ω. The thickness and relative dielectric constant of the substrate are 0.38mm and 2.2, respectively. Lower stub impedance is to get wider gap of rejected frequency.

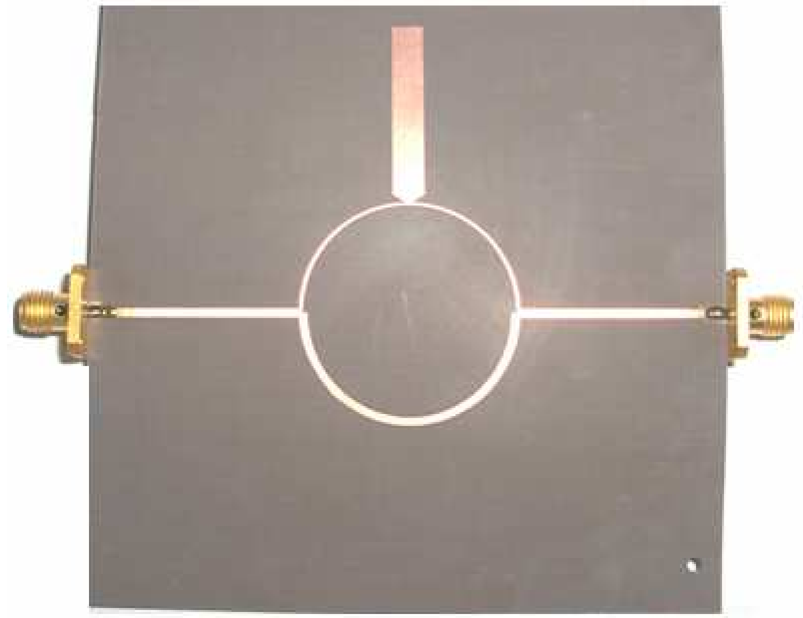
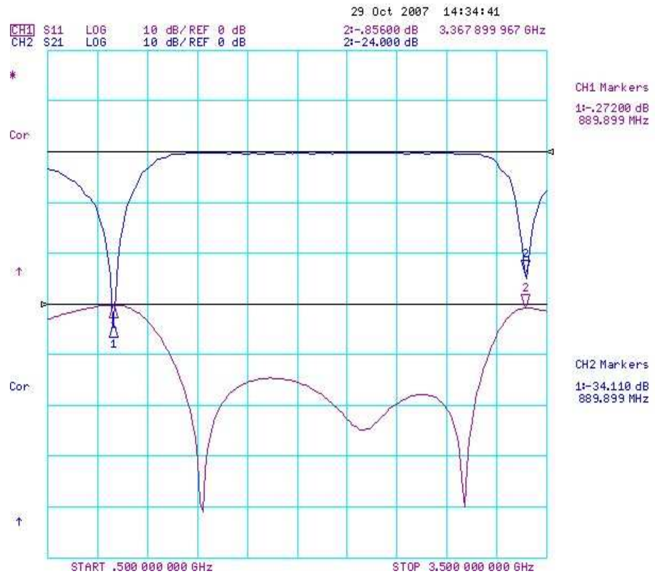
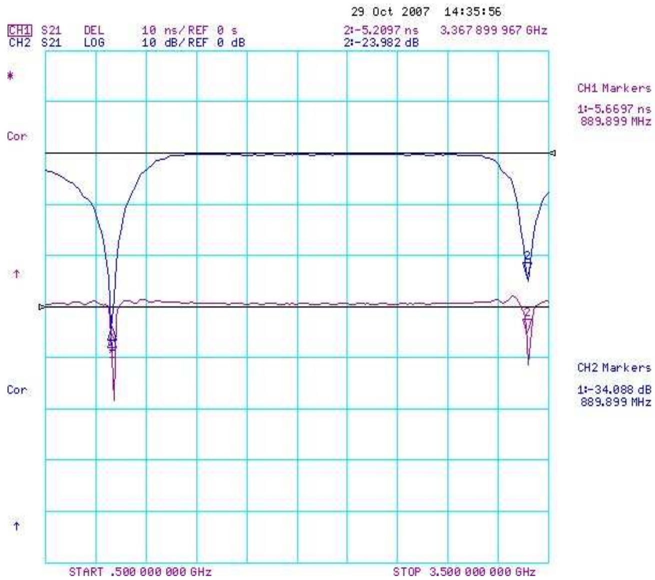


Fig. 2.4 Photograph of the fabricated bandpass filter.



(a)



(b)

Fig. 2.5 Measured results of the ring filter. (a) Transmission and reflection characteristics. (b) Group delay characteristic.

Fig. 2.5 shows the attenuation poles were observed at 0.81 GHz and 3.19GHz. The total insertion loss including feeding line loss is about 0.18dB and the group delay is about 0.7nsec at the center frequency of 2GHz.

By using equation (2-16), we can also obtain the following relationship for the ring bandpass filter.

$$tan^2\theta_p = 2\left(1+\frac{Z_1}{Z_2}\right)\frac{Z_3}{Z_2} = 0.567$$

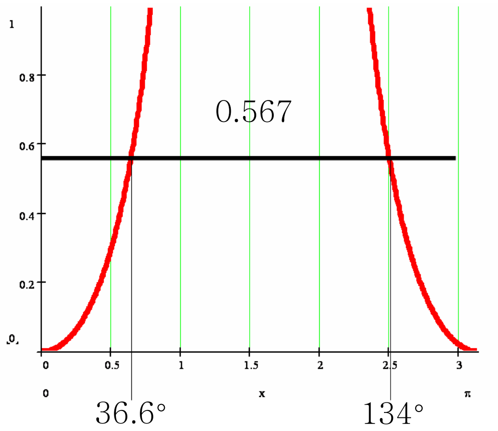


Fig. 2.6 The attenuation pole θ_p as a function of degree.

Hence, the attenuation pole frequencies can be calculated using $tan^2\theta_p$=0.567, which leads to the results in case of 2GHz center frequency below

37° x 2GHz/90°= 0.82GHz

143° x 2GHz/90°= 3.17GHz

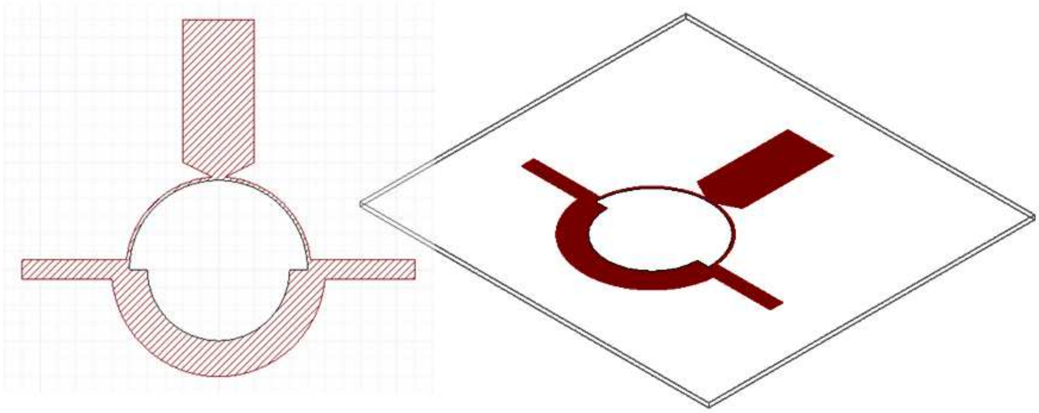
Table. 2.1 Experimental and theoretical of ring bandpass filter attenuation pole frequencies

	1st Frequency	2nd Frequency
Theoretical	0.82	3.17
Simulation	0.92	3.35
Experimental	0.88	3.36

The experimental and theoretical attenuation pole positions are shown in Table 3.1, and are 93 percentage in agreement with each other and simulated result and experimental result have almost the same result. We think experimental performances have little error during manufacturing process.

2.5 Conventional 5-stage UWB BPF

To obtain high rejection, we have tried various values of the tuning stub of characteristic impedance and we try to cascade ring filters. The theoretical values calculated through the (2-16) equations have been confirmed. And the width and length of each transmission line can be obtained by Line Calculation Tool.



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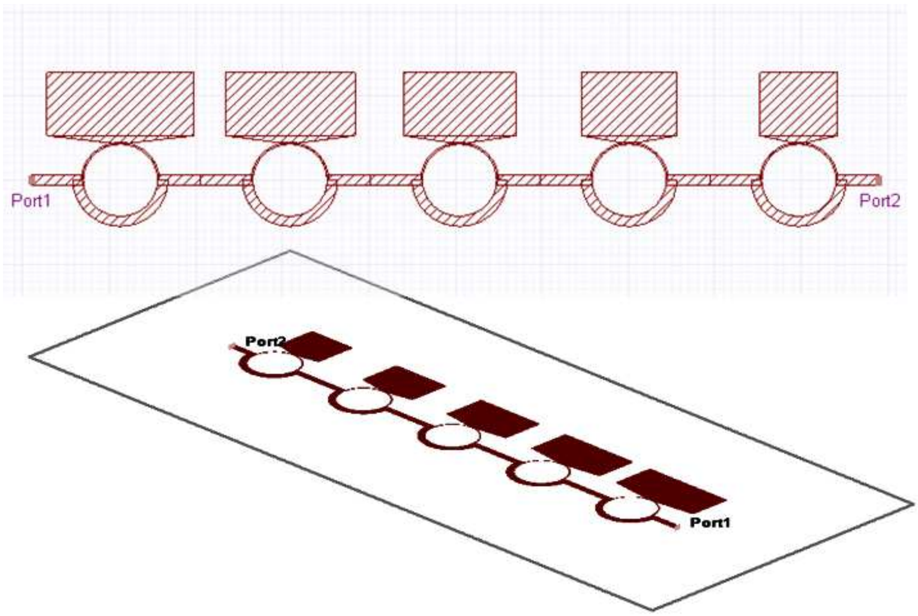


(b)

Fig. 2.7 Models of the designed filters in Designer. (a) single stage of bandpass filter. (b) 10-pole BPF Filter.

However, equations and calculation tool are carried our in ideal cases, which have not taken into consideration many potential factors that may affect the performances of filter.

For the above reasons, we utilized an electromagnetic simulator Ansoft Designer to simulate the designed filter before fabrication. Fig. 2.8 shows response of attenuation poles versus the stub width. Even though the width of stub has changed to wider range, bandwidth of ring filter is not changed significantly. Fig. 2.9 shows total attenuation poles of sum. On one hand we can get to know the different parts that affect the performances of mutual effect between microstrip line and ring filter, and on the other hand we can save both the fabrication cost and time.

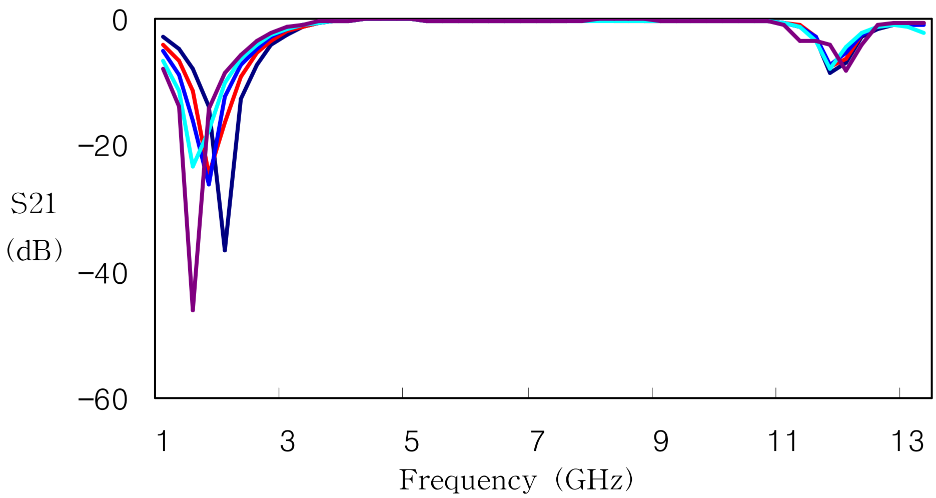


Fig. 2.8 Simulated two attenuation poles versus the stub width of ring filter.

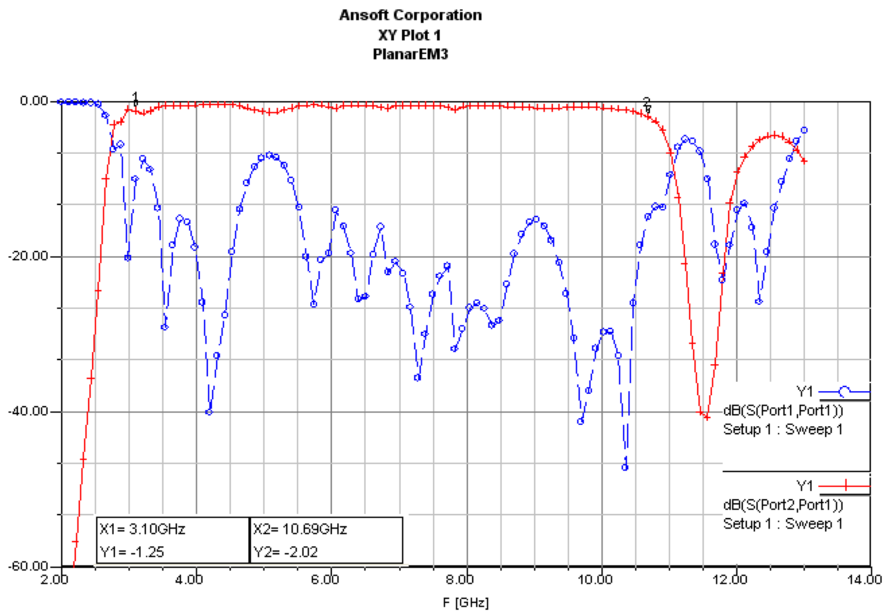


Fig. 2.9 Simulated results of 5-stage bandpass filter.

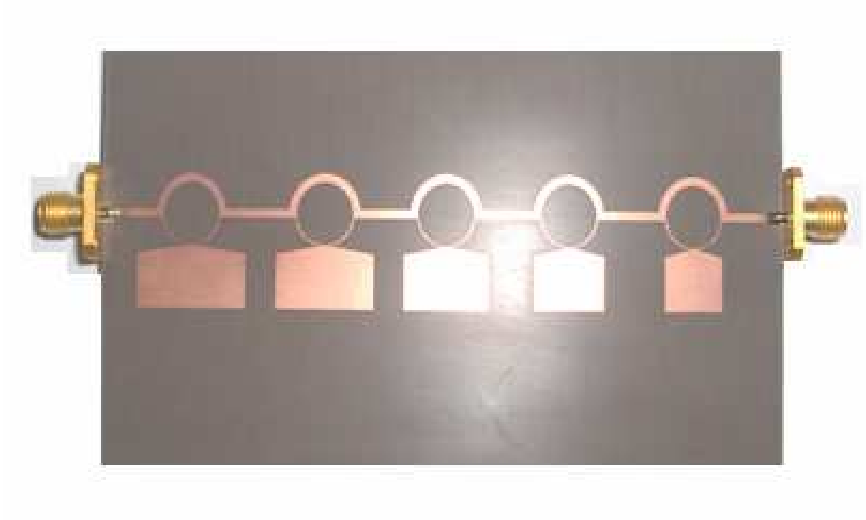


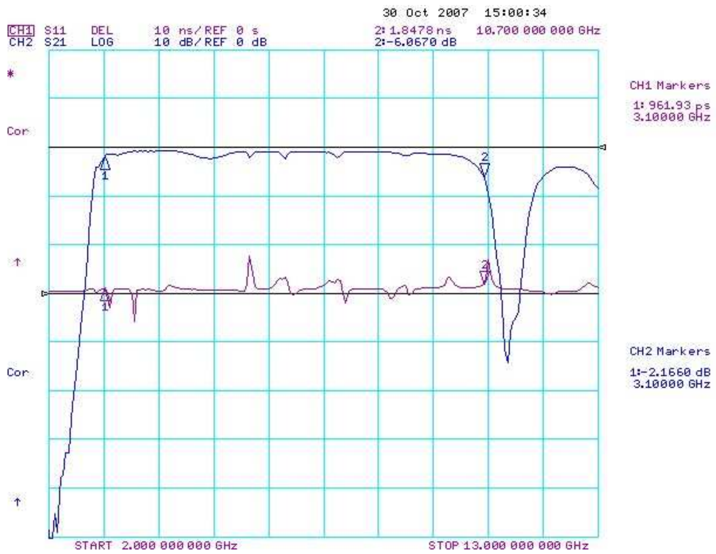
Fig. 2.10 Photograph of the 5-stage UWB bandpass filter.

Fig. 2.10 shows the fabricated UWB BPF. The thickness and relative dielectric of the substrate are 0.38mm and 2.2, respectively. To produce the necessary 10-poles we have tried various of stub characteristic impedance, Z_3 = 5.3Ω, 5.9Ω, 6.8Ω, 7.9Ω and 9.5Ω in case of 6.8GHz center frequency. Fig 2.7 shows the response of the fabricated 10-poles UWB BPF

Table 2.2 Simulated two attenuation poles (1st frequency, 2nd frequency) versus the width of single stub for the ring resonator

Z_3	length	Simulated results	
		1st frequency	2nd frequency
9.5Ω	9 mm	1.97 GHz	11.67 GHz
7.9Ω	11mm	1.85 GHz	11.67 GHz
6.8Ω	13mm	1.71 GHz	11.78 GHz
5.9Ω	15mm	1.61 GHz	11.81 GHz
5.3Ω	17mm	1.48 GHz	11.87 GHz

(a)



(b)

Fig. 2.11 Measured the results of the 5-stage UWB bandpass filter. (a) Transmission and reflection characteristics. (b) Group delay variation characteristics.

Fig. 2.11 shows the UWB bandpass filter has insertion loss better than -2.3 dB and return loss greater than 10dB in the passband from 3.8GHz to 9.2GHz. The group delay of the filter is below 7.4 nsec within the UWB passband.

3. Proposed compact size UWB Filter

3.1 Introduction

When we make 5-stage cascade UWB filter, there is problem to conjoin one another which have too wide width of stub to connect because of low characteristic of stub.

Open stub ring filter is made to control the attenuation pole frequency by adjusting both the ring and the stub impedance. However, to produce the 1.61GHz and 11.08GHz attenuation pole positions, we have to produce the minimum stub characteristic impedance Z_3= 7.36Ω(16mm).

Fig. 3.1 shows schematic diagram of a microstrip ring filter with parallel stub. The feeding lines are directly coupled to a ring resonator. The circumference of the ring is about one wavelength λg long at the center frequency.

The ring has λg/4 length Z_1 and Z_2. We employed a parallel stub which is Z_3 = 25Ω and length is shorter than λ/8 which is the same effect to the ring resonator's stub such as Z_3= 7.36Ω and λ/4 open stub.

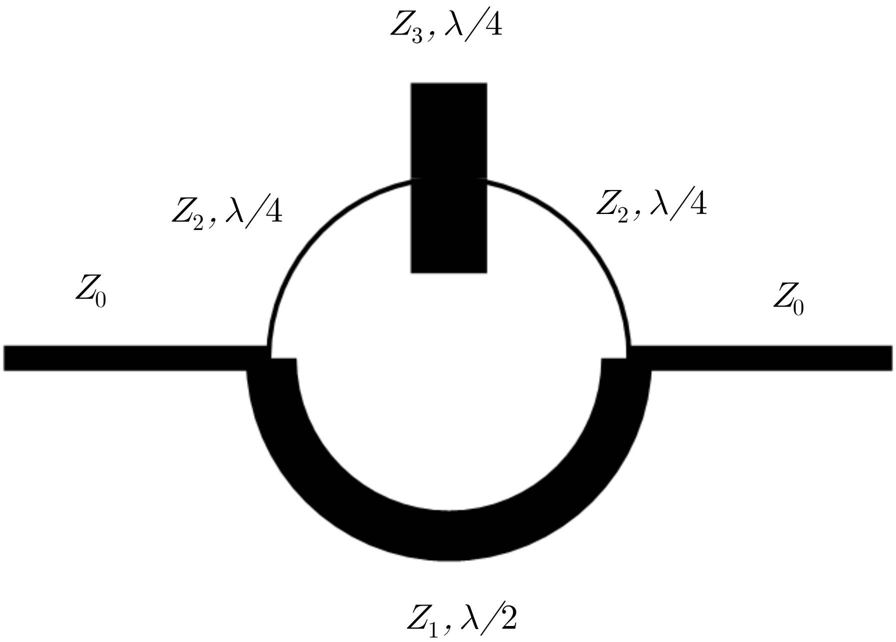


Fig. 3.1 Schematic diagram of a microstrip UWB banspass ring filter.

Proposed filter shows schematic of ring filter with parallel stub, which is better than one side open stub. We considered about width and length of parallel stub and try several kinds of width and length for getting an interesting result.

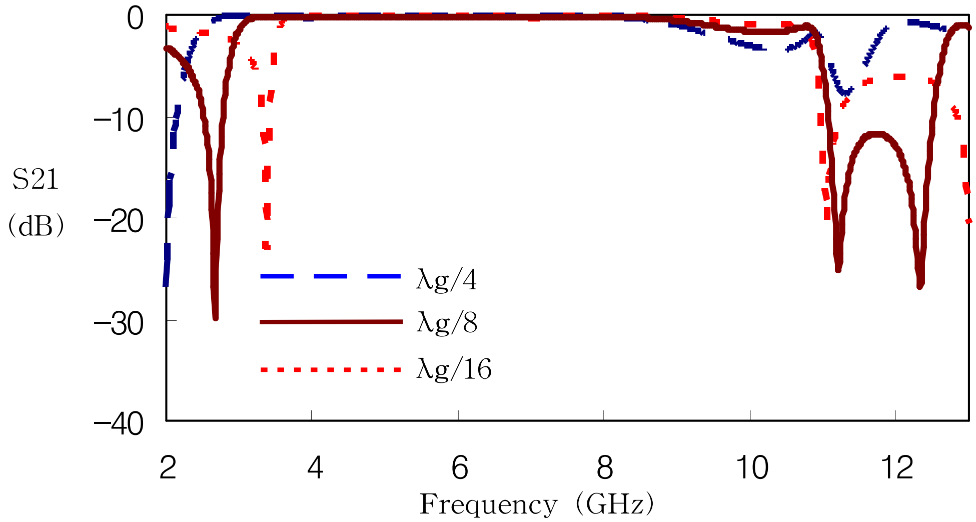


Fig. 3.2 Simulated results of transmission response versus the length of parallel stub.

Fig. 3.2 shows a appropriate length of parallel stub. The bandwidth of ring filter is getting wider when it takes longer than λg/8 stub length. However ring filter has drawback of increasing insertion loss. If the length is shorter than λg/8, ring filter get better insertion loss but bandwidth of the ring filter is smaller than a longer stub.

Table 3.1 Simulated two attenuation poles versus the width of parallel stub for the ring resonator

Parallel stub width	1st frequency	2nd frequency
1mm	3.32GHz	10.58GHz
3mm	2.55GHz	11.35GHz
5mm	2.22GHz	12.34GHz

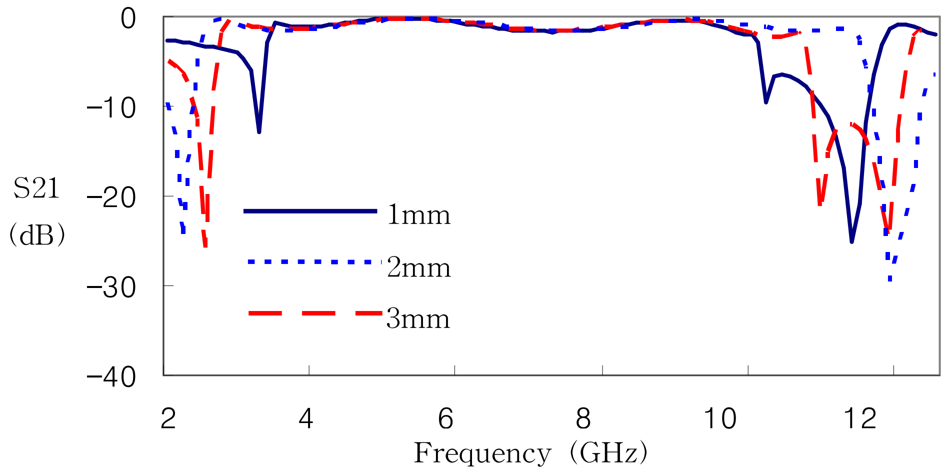
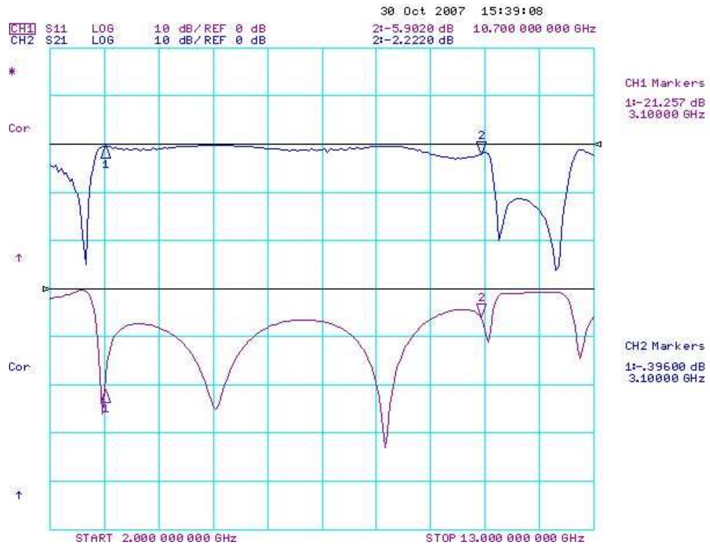


Fig. 3.2 Simulated results of bandwidth versus the width of parallel stub.

Proposed filter design is satisfied with width 3mm in Ultra Wideband application The parallel open stub perturbation having a characteristic impedance of 25Ω and length of λg/8 respectively at both sides. Because we experiment a length of parallel stub.

If the length is longer than λg/8, filter's bandwidth is getting smaller and insertion loss is getting bigger and then parallel stub is placed in the symmetry plane.

Fig. 3.3 Photograph of ring filter with parallel stub.



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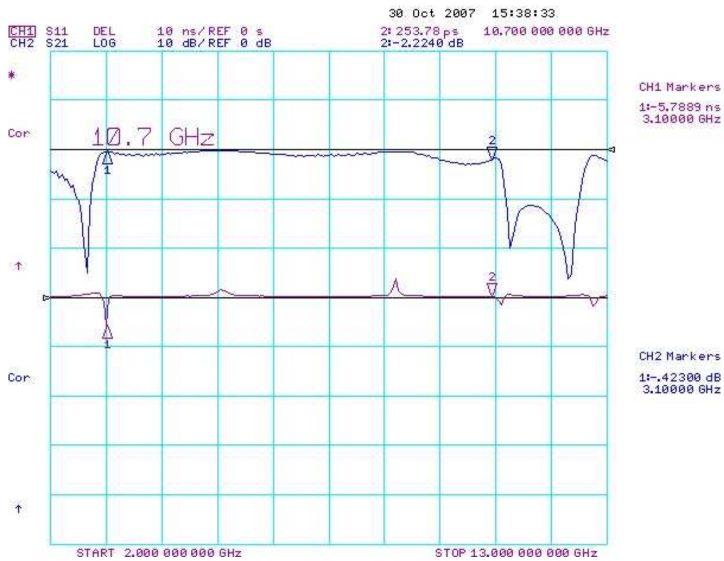
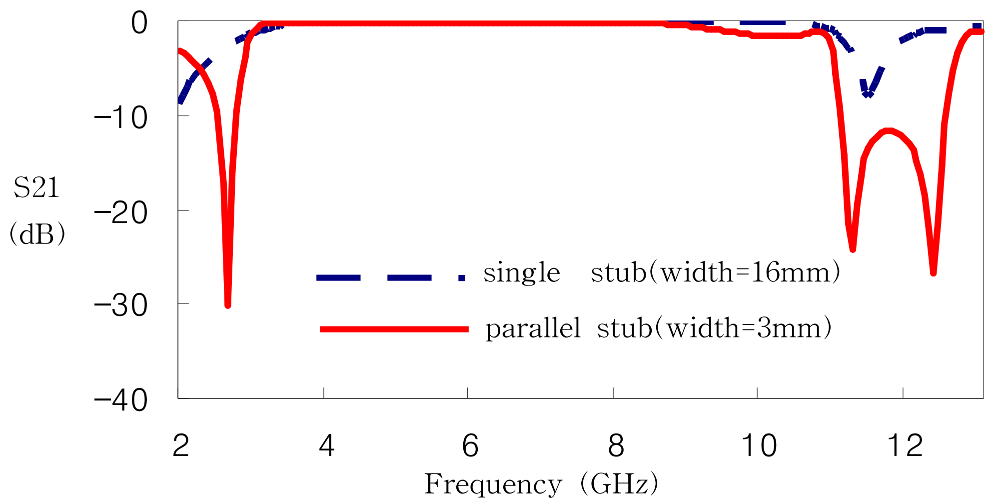
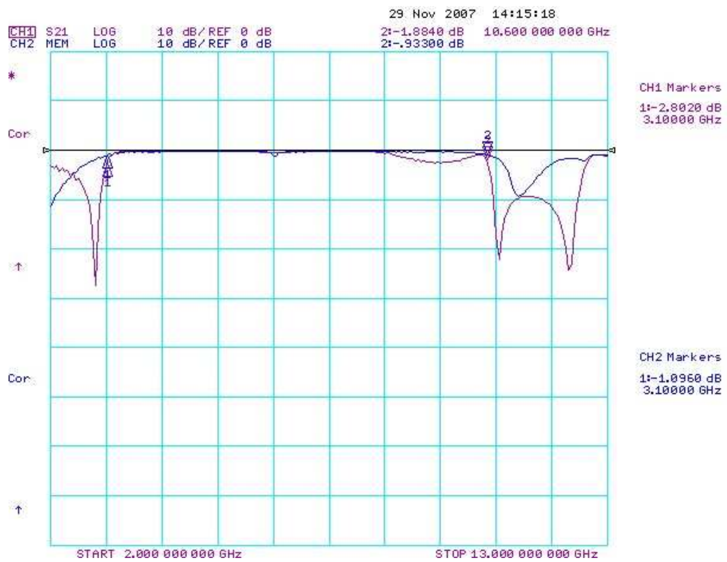


(b)

Fig. 3.4 Measured results with parallel stub. a) Transmission and reflection characteristics. b) Group delay variation characteristics.



(a)



(b)

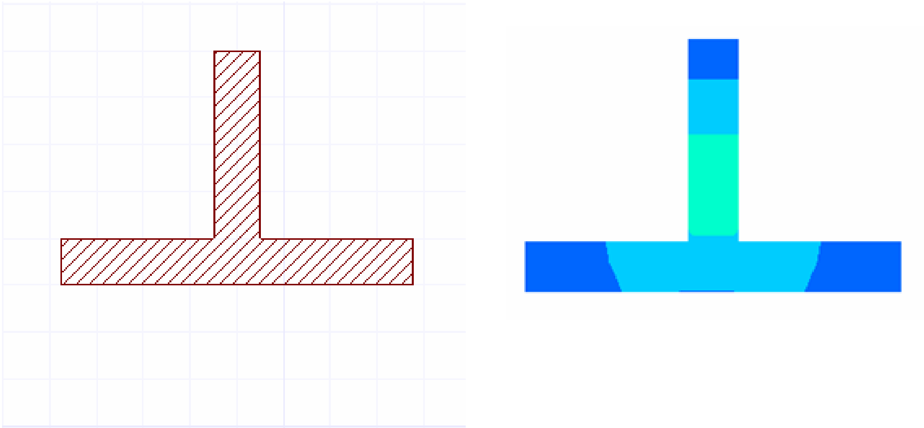
Fig. 3.5 Simulated and measured transmission results of single stage ring filter with parallel stub (width = 3mm) versus single stub (width = 16mm) ring filter. (a) Simulated. (b) Measured.

Fig. 3.5 shows the results between the ring filter with $\lambda/4$ stub and the ring filter with parallel stub. We employed a parallel stub to get compact size and wider upper stopband. The proper stub's width is important when applied to cascade structure to get spurious suppression. If a stub's width is wider than ring filter's width, ring filter need longer microstrip I/O line to contact another ring filter and it has drawback in insertion loss and group delays. Thus, the results indicated that the ring filter with parallel stub has advantages of size, skirt characteristics and wider upper stopband.

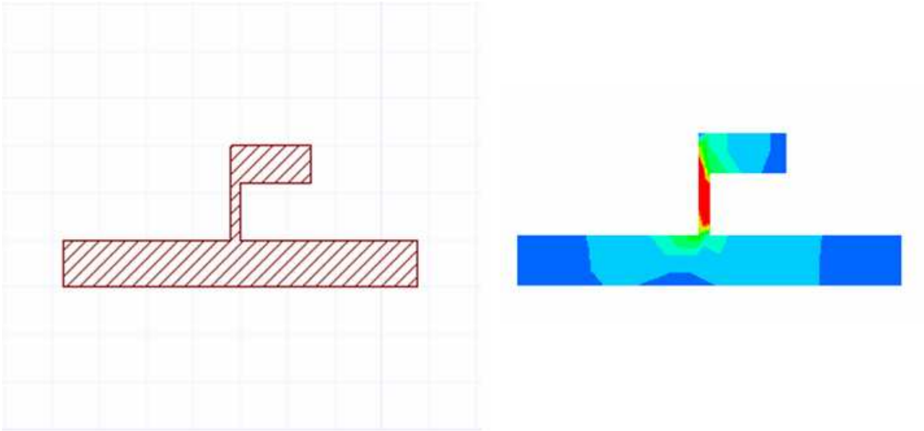
3.2 Stepped impedance line for spurious suppression

The idea presented in this method which is based on a ring resonator structure, with the addition of stepped impedance resonator lines, to construct a high performance bandpass filter.

The stepped impedance lines may have an independent extra transmission zero in the stop-band without requiring complex coupling between resonators[18][13]. Without alternating the passband response, stepped impedance line can be properly applied to near to both feeding ports in order to control the positions of the extra zero.



(a)



(b)

Fig. 3.6 Band-stop circuits. (a) an open stub. (b) a stepped-impedance stub.

This is a very useful feature in practical receivers for rejecting spurious responses and enhancing the rejection level in the stop-band of a bandpass filter. The proposed structure can save more area of the overall filter structure without degrading the performance of the bandpass filter. Fig. shown designed λ/4 and stepped impedance line in Ansoft designer.

The band-stop circuits, illustrated in Fig. 3.6, are designed to excite a band-stop response by adding two λ/4 open stubs on two sides (0′ and 180′) of the ring resonator. Based on transmission line theory, a transmission line section having a length (l<λ/4) can be replaced by combining a short length (l<λ/8) of line of high characteristic impedance with a short length (l<λ/8) of line of low characteristic impedance. The latter can be referred to as a stepped-impedance structure. The EM simulated electric current distributions in an open stub band-stop filter and in a stepped-impedance open stub band-stop filter at the same fundamental resonant frequency are shown in Fig3.6.

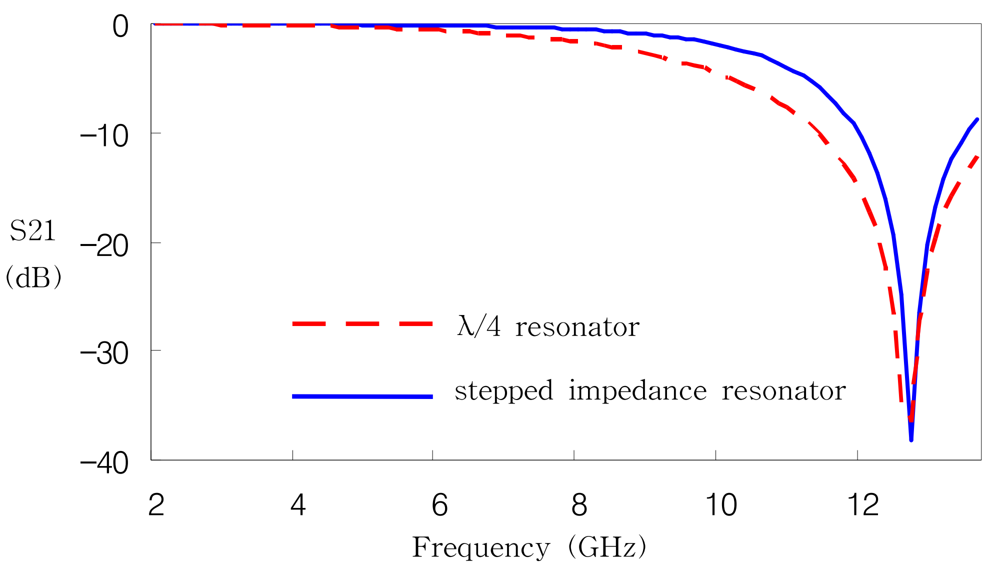


Fig. 3.7 Simulated results of a λ/4 resonator and a stepped impedance resonator

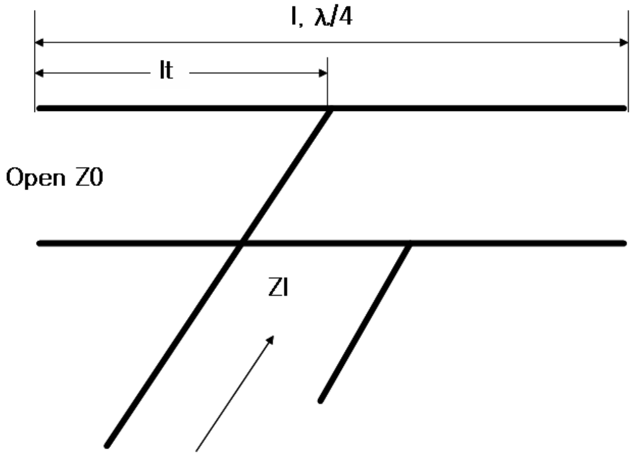


Fig. 3.8 Equivalent circuit of tapped-line resonator.

Fig. 3.6 shows stepped impedance resonator has higher Q factor than λ/4 stub resonator. Figure 3.6 and figure 3.8 show the tapped-line structure and its corresponding transmission line model. The position parameters of the tapped line can be obtained from [16].

$$l_t = \frac{2l}{\Pi} \cos^{-1}\left(\sqrt{\frac{\Pi}{2}\frac{Z_0}{Z_1}\frac{1}{Q_s}}\right) \qquad (1)$$

or

$$Z_1 = \frac{2}{\pi} Z_0 Q_s \cos^2\left(\frac{2}{\pi}\frac{l_t}{l}\right) \qquad (2)$$

where

l_t = position of tapped-line point

Zl = impedance of the tapped line

Q_s = quality factor

Z_0 = characteristic impedance of the transmission line

3.3. Fabrication and measurement

We have co-joined both parallel stub and stepped impedance line for ultra wideband application. Fig. 3.9 shows designed UWB filter with parallel stub and stepped impedance resonator.

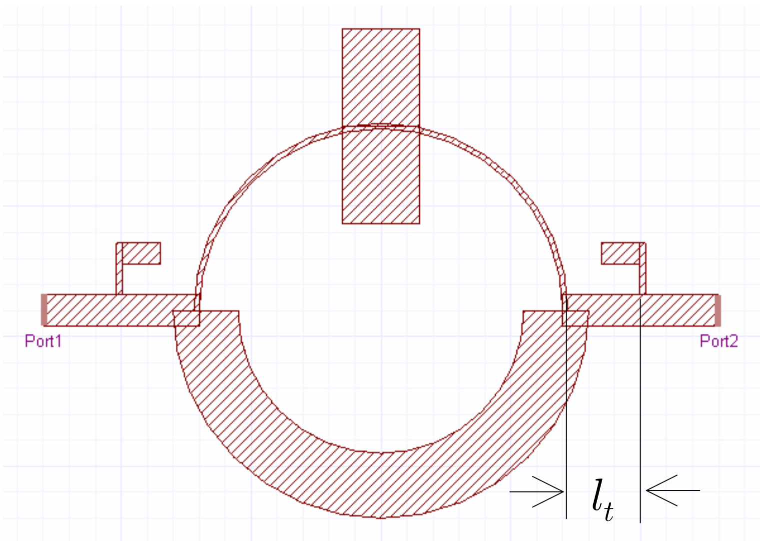


Fig. 3.9 The proposed UWB filter with stepped impedance resonator.

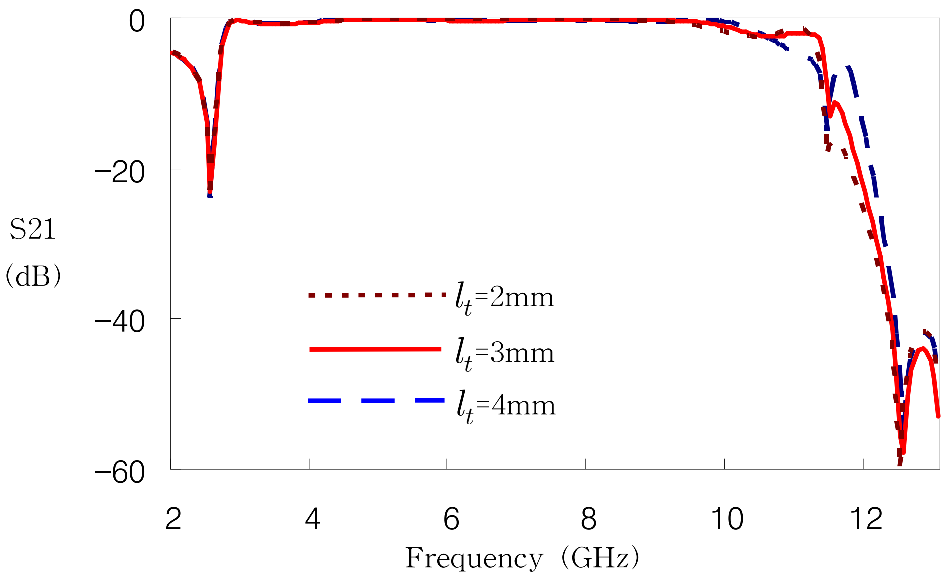


Fig. 3.10 Simulated results in variable distance between ring resonator and stepped impedance resonator.

Fig. 3.10 shows appropriate distance between ring resonator and stepped impedance resonator. If the distance is less than 3mm the ring filter has getting more insertion loss at higher frequency. If leave a space more than 3mm, the ring filter's skirt characteristic is getting worse. So we chose the gap of distance between ring resonator and stepped impedance resonator.

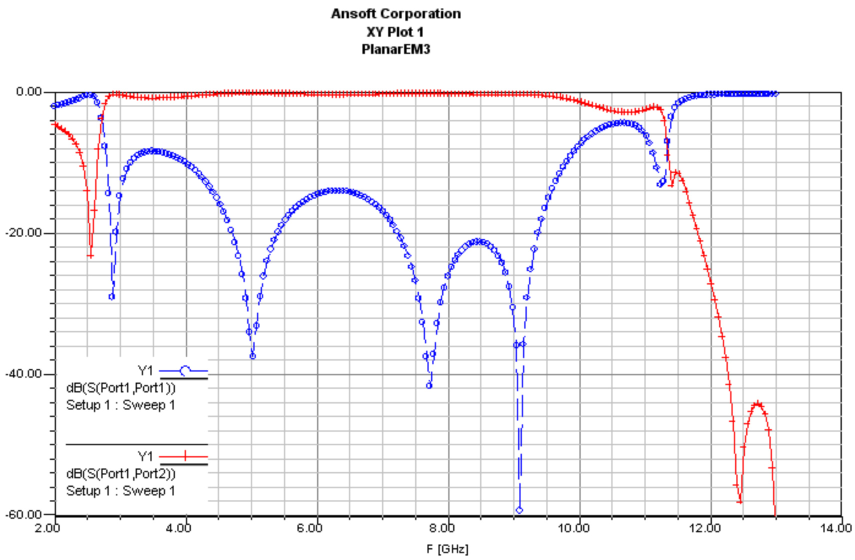


Fig. 3.11 Simulated transmission and reflection results of the proposed UWB filter.

We focus on the design method of compact size UWB filter. We try to make single stage bandpass filter and then we suggested using parallel stub for compact size and step impedance filter for spurious suppression.

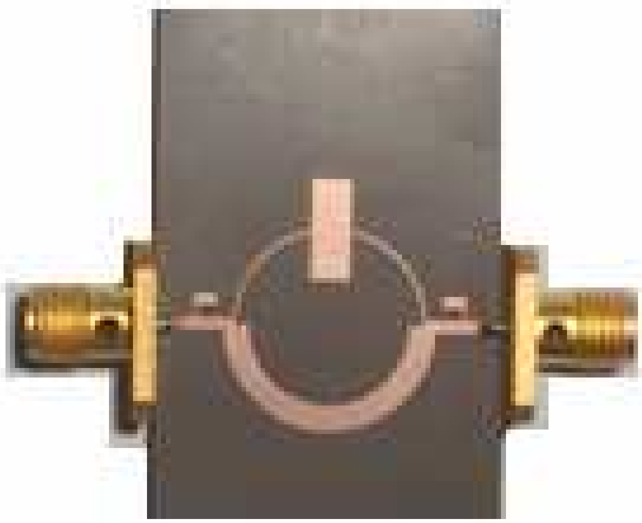
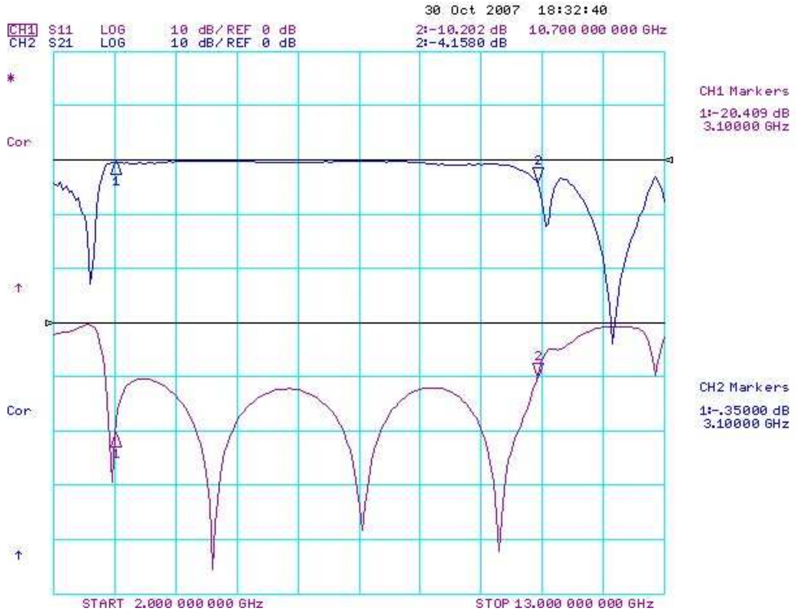
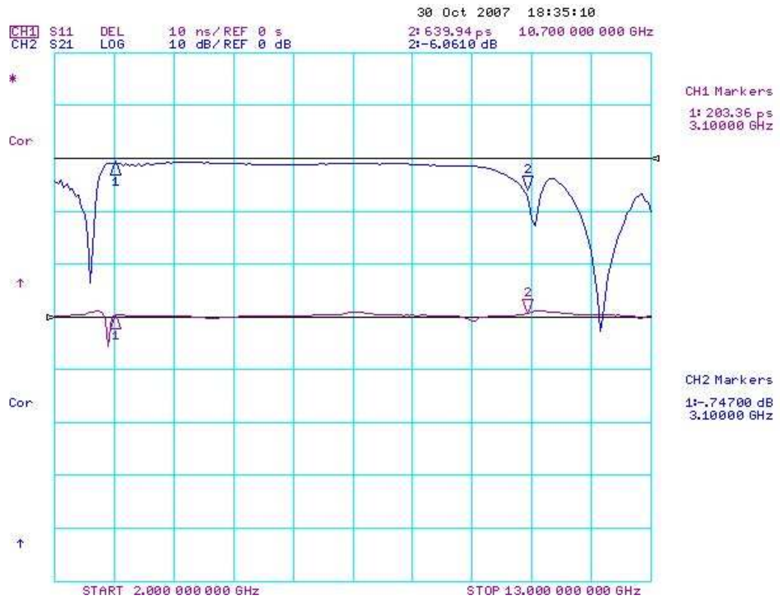


Fig. 3.12 The photograph of the proposed UWB filter.



(a)



(b)

Fig. 3.13 Measured results of the proposed UWB filter;. (a) transmission and reflection characteristics. (b) Group delay variation characteristics.

In many filter applications, in order to reduce interference by keeping out-of-band signals from reaching a sensitive receiver, a wider upper stopband is required. A cascade lowpass or bandstop filter may be used to suppress the spurious passband at the cost of extra insertion loss and size. Lumped element filters ideally do not have any spurious passband at all. Bandpass filters using stepped impedance resonators(SIR) [17] or end-coupled slow-wave resonators[18] are able to control spurious response. We employed stepped impedance resonator which is placed near both input port and output port. Thus, a wide upper stopband is obtained in ultra wideband.

Chapter 4. Conclusion

We can successfully control the attenuation pole frequency of the ring filter over a wide range using parallel stub which is placed in the symmetry plane. Using this method is expected to very useful in Ultra Wideband system. This article presents a wideband microstrip bandpass filter with parallel stub and stepped impedance resonator. Electromagnetic simulations, using Designer shows good agreement with experiments. The proposed microstrip bandpass filter has the advantage of high performance, providing wider and deeper stop-band characteristics. The measured data for the fabricated band-pass filter also shows a fairly good insertion loss of approximately -0.35dB at center frequency and group delay variation is 0.7nsec. This size-reducing concept can also be extended in another UWB radio system.

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