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A Review on Novel Design Method for Compact UWB Bandpass Filters

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Abstract: *This paper presents a brief review of Ultra wide band (UWB) Bandpass filter (BPF) using multiple mode resonator (MMR).The Bandpass filters are designed for the frequency range of 3.1-10.6 GHz. The brief history of the multiple mode resonators and the evolution of the filter by adding different techniques to enhance the filter performance and also the techniques which are used for miniaturization of the filter size are studied. With the help of these techniques the performance and size have increased and decreased resp. The outputs of various filters are compared with each other for proper analysis of the filter design to study the limitations of the previously proposed techniques.*

Keywords: Bandpass filter (BPF), multiple-mode resonator (MMR, stepped impedance stub load resonator (SISLR, ultra wideband (UWB)

INTRODUCTION

SINCE the Federal Communications Committee (FCC) authorized the unlicensed use of the ultra-wideband (UWB) frequency spectrum for short-range and high-speed wireless communication in 2002, tremendous interests in both academic and industrial fields have been attracted to explore various UWB devices, antennas, and systems. To meet the required UWB frequency mask (3.1 to 10.6 GHz), it has been commonly recognized that UWB Bandpass filters (BPFs) with good in-band transmission and out-of-band rejection performances are highly demanded. So far, several prototype UWB filters have been reportedly developed based on varied principles, such as dual-stopband features , composite lowpass-Highpass filter topology , cascaded broad- side-coupled structure and resonance characteristics of Stepped-impedance multiple-mode resonator (MMR).

In a filter with tightened coupling extent via a three-line coupling section originally showed its capacity in realizing a wide passband of 40% to 70%. A wideband passband of 49.3% was achieved in terms of two Stopbands of a filter block with the two tuning stubs on a ring resonator. However, this filter configuration was found theoretically difficult to be directly employed for the design of such a UWB filter with a bandwidth of about 110.0%.UWB passband. A Microstrip ring filter with the dual Stopbands below 3.1 GHz and above 10.6 GHz was constructed to make up the most initial UWB filter. However, this filter in fact has many problematic issues, such as unexpected Passband below 3.1 GHz, narrow lower/upper Stopbands, and large size.

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It was initially exhibited in that the first two resonant modes of the constituted MMR could be utilized together with the input/output parallel-coupled lines to achieve a 70% wide passband with four transmission poles. The first three resonant modes of an improved MMR were newly constructed to realize five transmission poles with lowered return loss in the whole passband. Then, an improved Microstrip line UWB BPF was presented by forming an alternative MMR with proper loading of three open-ended stubs. The open-ended stubs are introduced at the center of a stepped-impedance resonator to allocate the first two resonant modes more closely with each other. By feeding this resonator with two parallel-coupled lines at two sides, a class of wideband filters with a fractional bandwidth of 60% to 80% were constructed. Open ended stub, placed at center, to a great extent. However, with the use of only a single loaded stub or paired stubs at the central position, these filters have been found to hardly achieve the FCC defined UWB passband with a fractional bandwidth of 110% at 6.85 GHz. Following this work, two identical stubs were in addition introduced at the two symmetrical positions with respect to the central plane. It provided us with an additional degree of freedom to relocate the first four resonant modes within the UWB band while pushing up fifth mode, aiming at achieving sharpened out-of-band rejection skirts and widened upper stopband. All the above mentioned SIR-type UWB BPFs showed good passband performance except the Stopbands suffer the slow increase in attenuation and there were no longer enough degrees of freedom for effective control of resonant frequencies and also suffered from large size. Then the MMR increasing the degree of freedom and miniaturizing the size of the filter were developed in [4], [5].

DIFFERENT DESIGN TECHNIQUES FOR DESIGNING UWB BANDPASS FILTER USING MMR.

In [1], the initially proposed UWB Bandpass filter using a Microstrip line multiple-mode resonator (MMR) was presented. Here the MMR has been properly modified in configuration so as to reallocate its first three resonant modes close to lower-end, center, and upper-end of the targeted UWB passband. Also, the coupling degree of the input/output parallel-coupled line sections is largely raised. At the central frequency of the UWB passband, i.e., 6.85 GHz, the MMR consists of one half-wavelength low-impedance line section in the center and two identical $\lambda/4$ high-impedance line sections at the two sides.

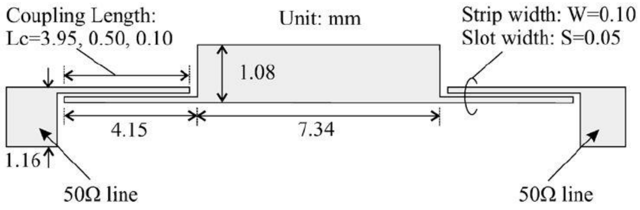

Fig. 1. Schematic of the compact Microstrip-line UWB Bandpass filter

With respect to the configuration, the proposed MMR was categorized as a so-called stepped-impedance resonator (SIR). As a non-uniform transmission line resonator, the SIR was proposed in to enlarge the frequency spacing between the first and second-order resonant modes so as to effectively widen the upper stopband above the dominant passband of a Bandpass filter. Here, all the first three resonant modes are taken into account together and they are applied to make up a wide dominant passband. In this case, the first and third-order resonant frequencies basically determine the lower and upper cutoff frequencies of a wide passband. Further the two additional transmission poles in the $\lambda/4$ parallel-coupled lines, a UWB filter can be built up with good insertion and return loss in the entire passband of concern.

Then in [2], the Microstrip line stepped impedance stub loaded MMR was proposed. As discussed in [1], the first three resonant modes in the stepped-impedance MMR can be quasi-equally allocated within the concerned UWB passband by adjusting width/length ratios of central-to-side sections. However, this MMR-based filter usually suffers from a high insertion loss of about 2.0 dB in the upper UWB passband and a narrow upper stopband of 11.0 to 14.0 GHz. The former is mainly caused by parasitic radiation from the central part with wide strip conductor at high frequencies, while the latter is due to the 4th resonant mode in this stepped-impedance MMR.

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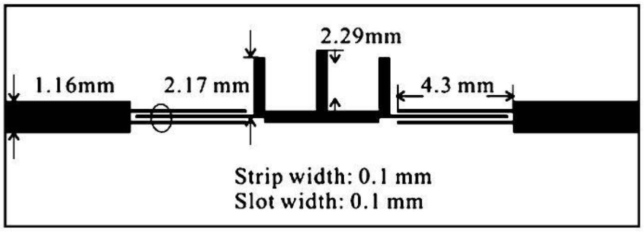

Fig no 2 Configuration of the proposed UWB BPF based on stub-loaded MMR in ref [2].

As shown in Fig.2, the proposed stub-loaded MMR is formed by properly attaching one single open-ended stub in the middle and two identical ones in the two symmetrical positions. The lengths of the central stub and side stubs are indicated by Lc and Ls, respectively. In this way, the first four resonant modes expect to be relocated within the UWB passband while pushing up the fifth mode to make up a wide upper stopband.

Now the novel stepped impedance stub loaded resonator (SISLR) was proposed in [3] to design UWB BPF. The previously mentioned SIR type UWB BPF showed good performance in passband except the Stopbands suffer the slow increase in attenuation and there were no longer enough degree of freedom for effective control of resonant frequencies.

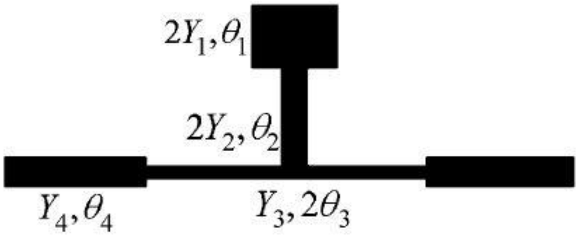

Fig no 3 Basic structure of SISLR in ref [3]

This resonator has more degrees of adjusting freedom to control its resonant frequencies, which results in conveniently relocating the required resonant modes within the UWB band. The basic structure of the proposed SISLR is shown in Fig no 3.It consists of a traditional SIR with the characteristic admittance, and electrical lengths and, which is tapped-connected to a stepped-impedance stub (SIS) in the center. The SIS is also made of transmission-line sections of characteristic admittance, and electrical length. Since the SISLR is symmetrical in structure, odd- and even-mode analysis can be adopted to characterize it.

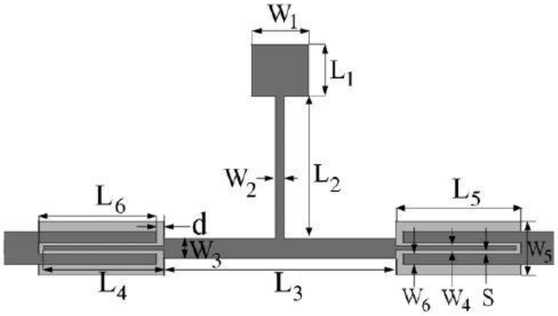

Fig no 3: Configuration of the UWB SISLR in ref [3]

Compared with the conventional multi-mode resonator in [1], this filter design had an extra stepped-impedance stub loaded in the center. The performance of the filter was good but was large in size.

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Now the filter size miniaturization was the major challenge faced by the design engineers so the Novel UWB Bandpass filter using stub load multiple mode resonator was proposed in [4] .this paper has the filter size less as compared to the filter proposed in ref [3]. This filter used a uniform impedance resonator and consisted of the SIS at the center and two extra added open stubs at the side of the center stub placed symmetrically around the center. The MMR consists of three open stubs in a uniform impedance resonator, and five modes, including two odd modes and three even modes within the desired band are combined to realize UWB passband.

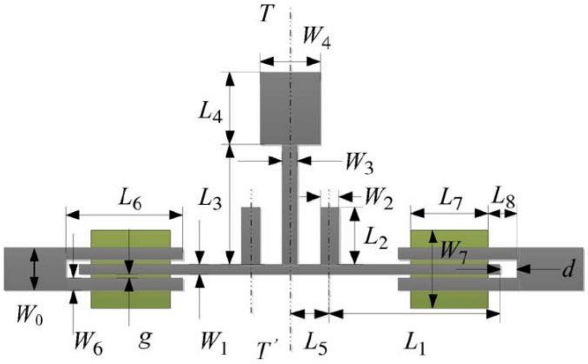

Fig no 4 - Structure of the SISLR in ref [4].

There are five modes, including two odd modes and three even modes within the desired band, and two transmission zeros generated by the stepped-impedance stub are at the lower and upper cutoff frequencies. The two odd modes could be located within the UWB band by properly designing the horizontal uniform-impedance resonator and the two side stubs. Otherwise, the even modes could be flexibly tuned by the stepped-impedance stub while the odd modes are fixed.

In this design method mentioned in ref [5], the size of the filter is further reduced improving the performance of the filter in the passband as well as in stopband.

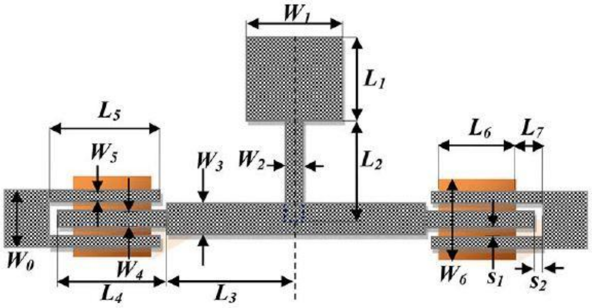

Fig no 5 UWB Bandpass filter in ref [5]

The size of the filter is further reduced as compared to the filter designed in ref [4]. Also the technique uses only a single SIS connected at the center of the uniform impedance transmission line and an aperture-backed beneath three inter-digital parallel coupled lines at connected at each side of the filter for coupling enhancement. The adopted method leads to a simplified objective function with a minimum number of variables to avoid convergence and implementation problems.

COMPARATIVE PERFORMANCE ANALYSIS OF VARIOUS UWB BANDPASS FILTER

In the ref [1], the structure of the filter is shown in the figure no 1 the performance obtained good as compared to the previously designed filters without MMR. The MMR design had good performance in the passband but slow attenuation in the stop band. The figure no 6 shows the varying effect of the length of parallel coupled line on the gain and the insertion loss varied with frequency. The attenuation obtained is about -30 dB at 1 GHz and less than 30 till 13 GHz from the upper cutoff frequency.

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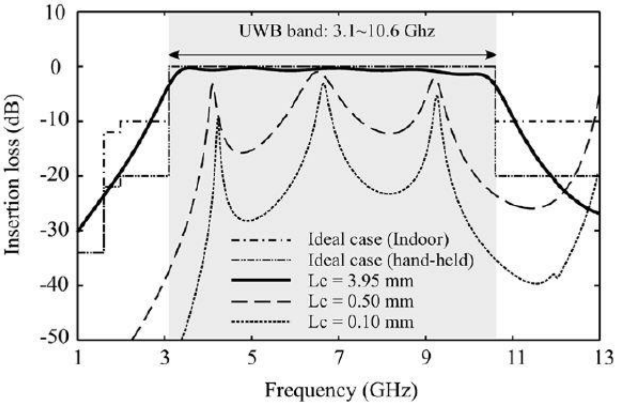

Fig. 6. Insertion loss of the Microstrip-line UWB Bandpass filter with different parallel Coupled line lengths (Lc).

The figure no 6 shows the varying effect of the length of parallel coupled line on the gain and the insertion loss varied with frequency. The attenuation obtained is about -30 dB at 1 GHz and less than 30 till 13 GHz from the upper cutoff frequency. The slope or the roll off of the filter is less so the transition band is more. The filter is fabricated and measured using the substrate dielectric of ε_r=10.8 and height =1.27mm. In the measurement, the lower and higher cutoff frequencies of the fabricated filter are equal to 2.96 GHz and 10.67 GHz. This shows that the relevant fractional bandwidth achieved is about 113%. At the central frequency of 6.85 GHz, the measured insertion loss is found as 0.55 dB. The fabricated and the simulated results are in the good agreement with each other.

The performance of the filter designed in ref [2] is comparatively better as compared to the ref [1]. The filter designed as shown in fig no 2 is fabricated using the substrate RogersRT/Duriod 6010 with the relative permittivity ε_r= 10.8 and the substrate thickness h=1.27. The tool used here for simulation is the Agilent Momentum software and the fabricated filter is measured with universal test fixture and Agilent network analyzer.

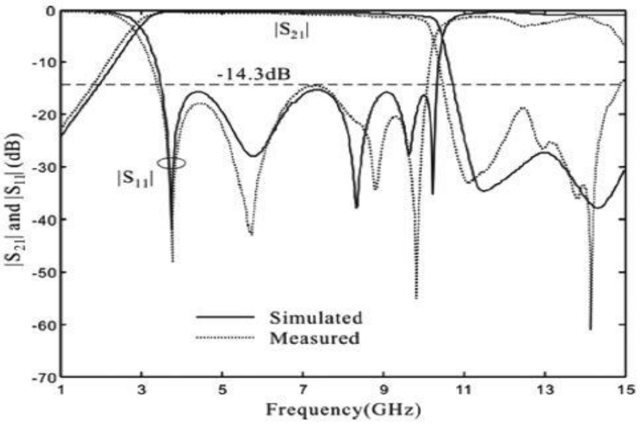

Fig. 7- Simulated and measured frequency responses of the optimized UWB BPF in ref [2]

Here compared to the initially designed UWB filter in ref [1] the insertion loss is more that is that is -23 dB at 1 GHz where as in ref [1] it is -30 dB. The performance of the filter is increased by increasing the roll off in the upper cutoff frequency i.e. we can observe the attenuation of -35 degree at 11.5GHz in ref[1] the attenuation is -25 dB at 13 GHz. The size of the filter is also reduced in this design to 13.80mm from 15.64mm from design shown in ref [1]. This designed helped to increase the roll-off and also to reduce the size of the filter.

The filter designed in ref [3] as shown in the figure 3 the filter performance is the best compared to the earlier designs. Two transmission zeros at the edge of both the passband results in the sharper roll-off as compared to the ref [2]. The selectivity factor

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of this design is more as compared to the previous designs in ref [1] and [2].compared to the conventional multimode resonator MMR in ref [1] the substrate used in this design has a dielectric constant of ε_r= 2.55 and the substrate thickness as h= 0.8mm.

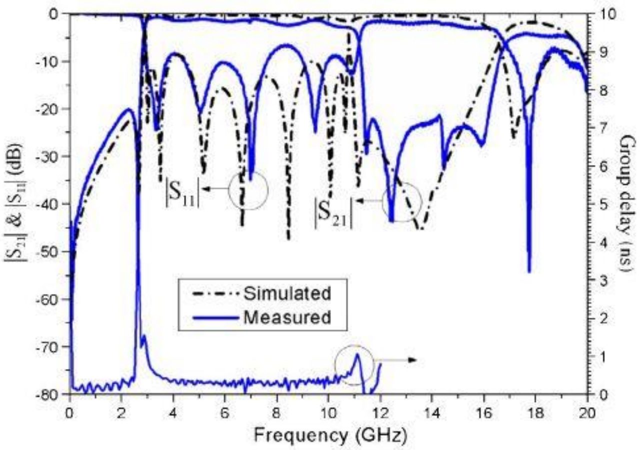

Fig. 8. Simulated and measured results of proposed UWB BPF in ref [3].

The measured passband of the measured filter is from 2.90 to 10.90 GHz against the simulated frequency range of passband as 2.92 to 10.72 GHz. The measured return loss is lower than -10 dB for most of the passband of the filter. The major drawback of the design was its large size. The filter designed by this techniques has the best performance compared to the ref [1],[2] but also had the largest size of 24.14 mm as compared with the size of 15.64 in ref [1] and 13.80 mm in ref [2].

The filter structure shown in fig 4 shows the filter design of ref [4] the filter has two extra open stubs in the designs as compared to the ref [3] design structure. The filter is fabricated and simulated using the substrate dielectric constant as er=2.55 and substrate thickness of h=0.8 mm. This filter design has the same filter performance as compared to ref [3] but has the reduction in size of about 33.6 %. The size of the filter structure in ref [3] was 24.14 mm and that of this filter is 16.1 mm. The simulated and the measured results are in the good agreement with each other. The passband covered is from the frequency range of 3.1 - 11.1 GHz which 117 % which is more than in the ref [3] which has fractional bandwidth of 114 %. The measured return loss is less than -10 dB for most part of the passband. The attenuation of the upper stopband is less than -20 dB up-to 17GHz which means the design has an extended stopband as compared to the design results of ref [3]. The selectivity factor of ref [3] is 0.926 and that of this design is 0.921 which means they have the same performance.

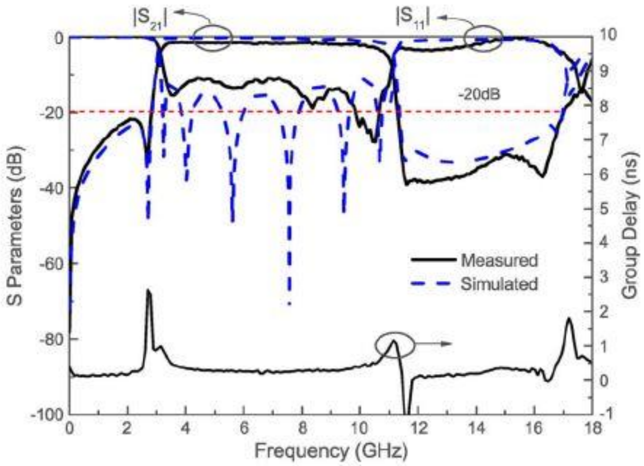

Fig. 9. Simulated and measured frequency responses of fabricated UWB BPF.

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In ref [5] design structure shown in fig 5 the filter is simulated using the momentum simulation software and the filter used RT Duriod 5870 substrate having the relative dielectric constant of ε_r=2.33 and substrate height of h= 0.5 mm. The substrates used in the ref [3] and [4] used the substrate having ε_r=2.55 and the substrate height of h= 0.8 mm.

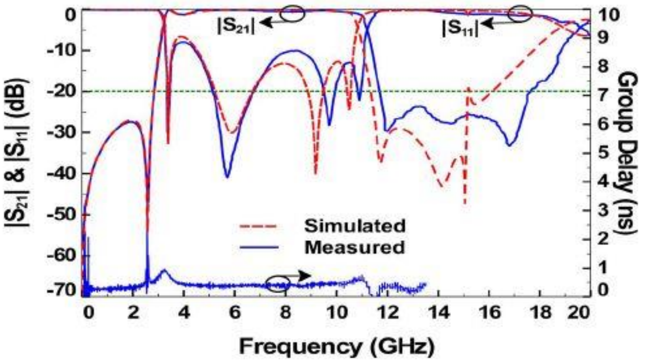

Fig. 10. Measured and simulated results of the UWB BPF in ref [5].

The measured passband extents from 3.2 to 11.1 GHz covering a fractional bandwidth of 115 % as compared to 117 % of that of the filter designed in the ref [4]. In addition to good performance of the filter the filter design has the least size amongst all the filter designed earlier. This design has the filter size of 11.72 mm as compared to the filters having size 15.64 mm, 13.80 mm, 24.14 mm and 16 mm in the ref [1], [2], [3] and [4] respectively. The filter has the size reduction of 54.12 % and 27 % compared to the ref [3] and [4]. This design focuses on the compactness and the good performance of the filter.

TABLE I

Reference	Dielectric	S.F	-3 dB FBW	Size in $\lambda_0 \times \lambda_0$	Size in (mm)
[1]	10.8/1.27	0.642	116 %	0.371× 0. 043	15.64
[2]	10.8/1.27	0.594	114 %	0.315×0.061	13.80
[3]	2.55/0.8	0.926	114 %	0.73×0.35	24.14
[4]	2.55/0.8	0.921	117%	0.514×0.312	16.1
[5]	2.33/0.5	0.861	115 %	0.382×0.307	11.72

λ_0 is the free space wavelength at 6.85 GHz. The selectivity factor or skirt factor ref [4] is defined by the ratio $\Delta f|_{-3dB}/\Delta f|_{-30dB}$ at -3 dB and -30 dB of bandwidth of filter.

CONCLUSION

The various design structures using the MMR for the design of UWB BPF are discussed in this paper. The comparative analysis of the various structures and their respective outputs are done. The filters from the conventional MMR to the latest MMR developed recently are seen and their comparison table is carried out to study the various advantages and limitations of the design. The paper properly explains about the evolution of the MMR in UWB BPF and its benefits in terms of performance and the size of the filter. The study has revealed that the design developed in the ref [5] is the best design in terms of the performance and size of the filter compared to the various other designs developed earlier. The design has good performance in the passband as well as an extended stopband till 18 GHz after the upper cutoff frequency also the filter is very compact i.e. 11.72 mm in size.

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