Folded SIR with CSRRs for Ultra Wide Band Applications

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Abstract—**The paper presents a maximally flat compact planar filter employing folded Stepped Impedance Resonators (SIR) and Complementary Split Ring Resonators (CSRR), for Ultra Wide Band (UWB) applications. An interdigital quarter wavelength coupled line is used for achieving the band pass characteristics. The filter has low insertion loss in its pass band and steep roll off rate and good attenuation in its lower and upper stop bands. The measured microwave characteristics of the fabricated filter show good agreement with the simulated response.**

Keywords- ***CSRR, Folded SIR, Interdigital Coupled Line, UWB***

I. Introduction

Ultra Wide Band (UWB) communication is heading forward at an accelerating pace on account of its high data rate, low power and good multi path rejection [1]. Several works have been reported to meet the design challenges of UWB filters operating in the 3.1-10.6 GHz band. While using the conventional method of coupled lines for band pass filters, most of the designs pose fabrication problems, as they require exceptionally small coupling gap, of the order of 0.1mm or so, in order to achieve this wide bandwidth [2].

In the recent past different planar filter configurations have been reported for UWB applications. But the issues such as reducing size and simultaneously enhancing the performance have not necessarily been addressed in much of the UWB filter designs. This work concentrates on simple coupled line structure with adjustable transmission zeros to realize the desired bandwidth. The structure exhibits sharp roll off at both lower and upper cut off frequencies and low insertion loss in the pass band.

Conventional SIR configurations for UWB applications are not compact, while coupled line microstrip filter designs in ultra wide band require very small gaps between the coupled segments, demanding high manufacturing accuracy [4]. A modification with fewer resonators and easily realizable gap between coupled lines is reported in [5] and further improvement is achieved in size as well as performance using chip inductors, in [6]. The use of chip inductors cannot be advocated in all applications, as they are available only in discrete values and in some cases mounting angle of the inductors is to be properly maintained to ensure optimum performance. Also, their performance may degrade beyond the specified frequency range.

II. Filter Structure

The proposed filter uses conventional coupled lines of quarter wavelength at 6.85 GHz, the mid frequency of required bandwidth. The required transmission zeros are introduced using LC resonant circuits which can be realized using half wavelength open stubs [7]. Inductive stub of the stepped impedance resonator is folded so that the occupied chip area can be reduced. The combined LC resonator is responsible for the transmission zero at the lower band edge. The band pass response is achieved by a simple coupled line quarter wavelength long. To ensure wide pass band interdigital structure is employed. Additional cascade sections will result in sharp roll off. But the structure will become complex with increased chip area.

The introduction of CSRRs greatly helps to achieve steeper roll off rate at the upper band edge. The CSRRs affect the inductance and capacitance of the transmission line. The effective negative permittivity of the CSRRs contributes to the upper stop band characteristics [8-9].

The top and bottom view of the designed structure coupled to a 50 Ω transmission line section fabricated on a substrate of dielectric constant 4.4, thickness 1.6mm and loss tangent 0.02 are shown in figure 1(a-b). The folded inductive stub is tapered at the corners to reduce the current crowding at the sharp edges. The CSRRs etched on the bottom ground plane are aligned exactly below the transmission line portion for better performance. The radii of the CSRR rings are selected to get the required roll off rate and also for suppressing the higher frequencies in the upper stop band. The outer radii of the outer rings of the four CSRRs are 1.253, 1.2564, 1.2557and 1.253mm respectively. All the rings are of width 0.3 mm and are separated by a gap of 0.3 mm. The structure is compact with an optimized dimension of 12 x 17mm^2. The structure is simulated using FEM based simulator HFSS.

The simulated transmission and reflection parameters in figure 1c reveal the sharp rejection at lower and upper cut off frequencies. The out of band rejection obtained is approximately -11 to -18dB. The roll off rate is sharp, around -175dB/GHz at the lower band edge. The upper roll off is comparatively less with a value around -30dB/GHz. The insertion loss is approximately 1.2dB, but can be reduced further by reducing the gap between the coupled lines and by

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using a low loss dielectric material. Simulation results show that a substrate of dielectric constant 4.4, thickness 1.6mm and loss tangent 0.0018 causes an insertion loss less than 0.5dB. However, due to non-availability of low loss substrate, the filter is fabricated using a substrate of dielectric constant 4.4, thickness 1.6mm and loss tangent 0.02.

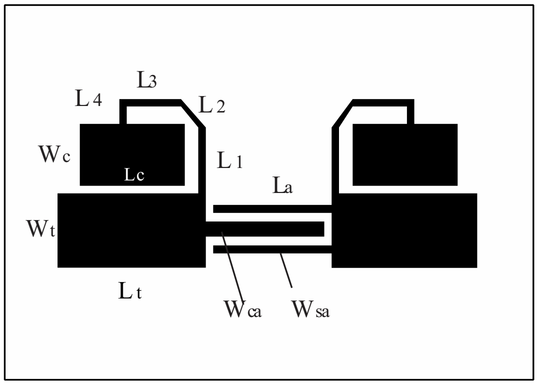

Figure1a. Top View of the Proposed Structure
L_t=6.5,W_t=3.1,W_c=2.73,W_{ca}=0.63,W_{sa}=0.35,L_a=4.7,
L_c=4.4,L_1=2.65,L_2=1.92,L_3=1.7,L_4=0.7
All Dimensions in mm

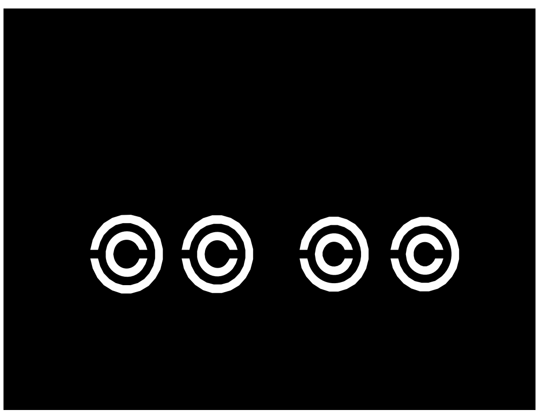

Figure1b. Bottom View of the Proposed Structure

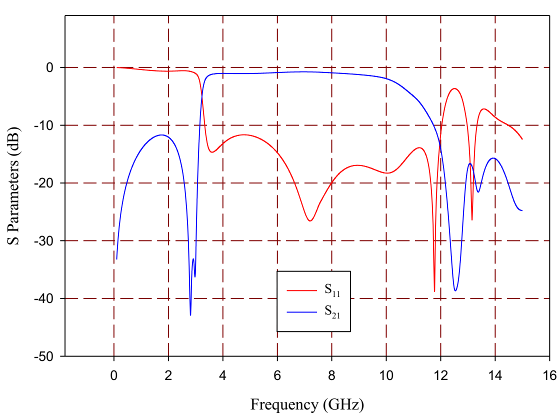

Figure 1c Simulated S Parameters

The flat group delay characteristics in figure.2 reveal the linear phase nature of the filter, making it suitable for most of the communication applications. Simulated group delay is less than 0.25 ns over the entire pass band. The group delay at the cut off frequencies shows abrupt changes.

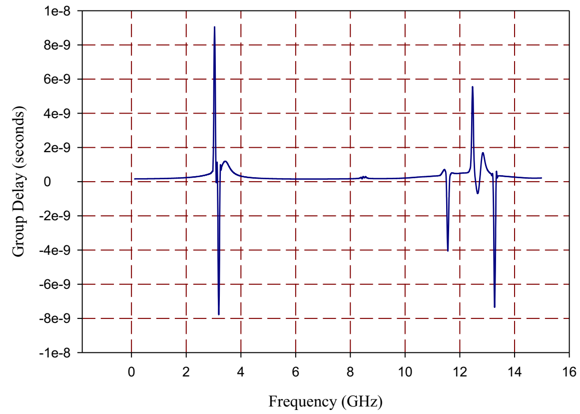

Figure 2 Simulated Group Delay

Parametric study as shown in figure 3 reveals the dependence of the lower cut off with the dimensions of SIR. The variation of the length of the inductive stub L_stub ($L_1+L_2+L_3+L_4$) from 5.85mm to 6.85mm results in a lower cut off frequency variation from 3.8 to 3.5 GHz. The upper cut off frequency is also affected, though not significantly.

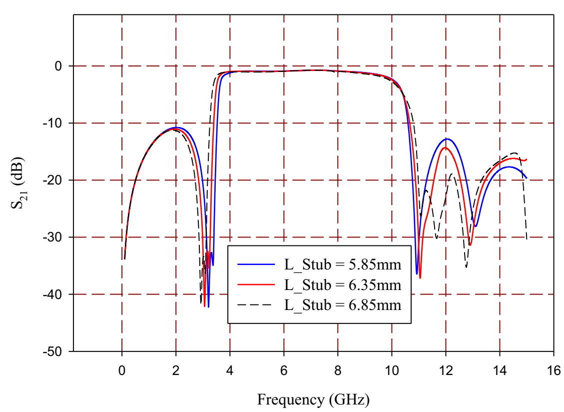

Figure 3. Variation of lower cut off for L-Stub =6.85mm, 6.35mm, and 5.85mm

The variation of upper cut off frequency with the coupled line length (L_a) is shown in figure.4. As the coupled line length decreases, the upper band edge advances, while the lower band edge remains almost unaffected. The results are shown for coupled line length of 5.3mm and 4.5mm varying the upper cut off from 10.11 to 10.7GHz. Due to the inter dependent nature of resonators and the change in the effective permittivity of the entire structure with the change in individual dimensions, the lower and upper band edges cannot be controlled independently beyond a limit. But this can be used as a guideline for designing the filter for different bandwidths.

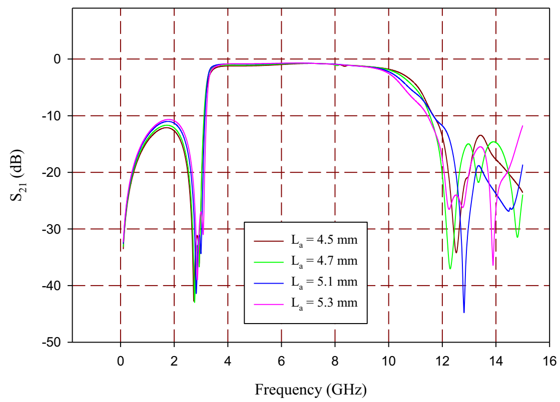

Figure 4 Variation of Upper Cut off with Coupled Line Length L_a

III. Fabrication And Results

Figures 5(a-b) show the photograph of the fabricated filter structure along with the SMA connectors. The structure is compact as can be seen in figure.

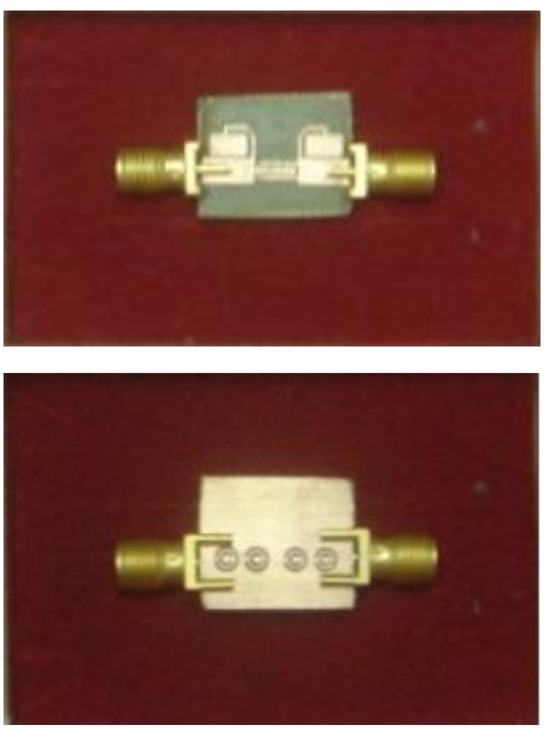

Figure 5(a-b). Photograph of the Fabricated Filter

Standard photolithography is used for the fabrication process and the S parameter measurements are taken using Agilent 8753ES Vector Network Analyzer. The experimental results in figure 6 agree reasonably well with the simulated results (figure 1c).

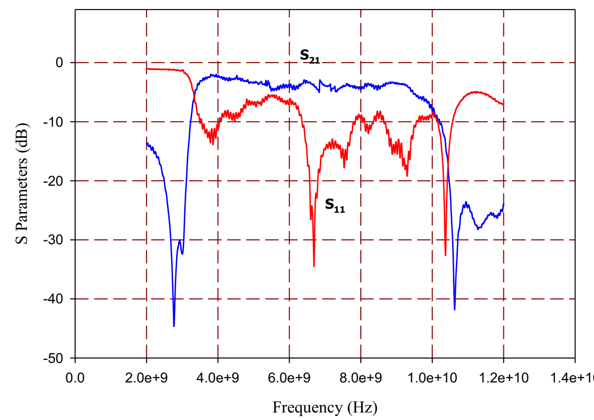

Figure 6 Measured S Parameters

Small discrepancies in the result can be attributed to the inaccuracies in the fabrication process and/or numerical errors in simulation. The insertion loss is around 4dB including those introduced by the SMA connectors which may contribute around 0.3 dB. The tolerance of the substrate material may also contribute. The attenuation in the lower stop band is less than -12dB and upper stop band is less than -20dB. The roll-off rate is sharp with 110dB/GHz at lower and 30dB/GHz at upper band edges and the fractional bandwidth attained is approximately 109% [1].

The measured group delay in figure 7 also agrees with simulated results. The group delay is almost flat in the entire pass band and has a value less than 0.13ns.

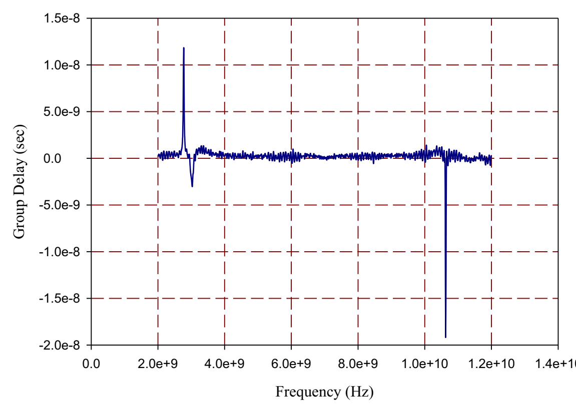

Figure 7 Measured Group Delay

IV. CONCLUSION

The filter designed is a stepping stone for future implementations. The design is simple and dimensions are easy to fabricate. Further, it can be re-designed for any bandwidth of interest, by varying the lengths of open stubs and coupled lines. The fundamental fabrication restriction, namely, the gap between the coupled lines is sufficiently large and practically feasible.

The insertion loss is slightly more, but can be reduced by using a low loss substrate material. The roll off achieved is steep and the attenuation in the stop bands is reasonable. It can be further brought down by cascading more sections as desired. However, there is a limitation that the structure may become complicated as more sections are to be incorporated. Table 1 gives a comparison of the filter performance with other reported works [2-4].

Table 1. Comparison of Parameters of Similar Works

Parameters/ Ref	[2]	[3]	[4]	Proposed Filter
Pass band(GHz)	3.5-14.5	3.1-10.6	3.1-10.6	**3.1-10.6**
Insertion Loss(dB)	0.75	≤2	0.5	**1.2**
Roll off Rate- Lower, Upper (dB/ GHz)	16	Not specified	50,30	**175, 30**
Group Delay(nS)	Not specified	1	0.21	**0.24**
Size (mm^2)	34 x 6	28 x 15	18.6 x 13.5	**17 x 12**
Substrate [ε_r/,h(mm)]	6.15/1.27	6.15/0.64	3.38/0.8	**4.4/1.6**

Proposed filter can be used in the RF front end in almost all UWB transceiver systems. It helps to limit the frequency characteristics of the UWB antenna and optimize its front end behavior.

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