Highly Selective, Compact Ultra-Wide Band Bandpass Filter Using a Novel Multiple Resonances Resonator (MRR)

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Abstract— **In this paper a high selective compact ultrawide band (UWB) bandpass filter has been designed using a novel multiple resonances resonator (MRR). Equivalent circuit has been extracted for the proposed single order MRR where the filtering function was derived, showing the feasibility of a maximum of six transmission poles in the passband. Finite frequency transmission zero was introduced by having a mixed coupling in the MRR structure, resulting in a compact UWB filter with high selectivity filtering response. A prototype is fabricated to validate the proposed design. Experimental and simulated results shows good agreement.**

Index Terms— **Multiple resonance resonator, Ultra-wideband filter, Bandpass filter.**

I. INTRODUCTION

With the advent of commercial use of UWB in 2002, the demand of compact, high selective UWB bandpass filter has been increased. Bandpass filters using parallel coupled microstrip lines are widely used in microwave systems due to their compact size, low cost and simple design. Since 2002 many UWB bandpass filter design techniques are presented with different advantages and disadvantages [1]-[7]. In [1] multiple-mode-resonator (MMR) technique was proposed. The given topology is used to deploy multiple mode using SIR structure. Two input output (I/O) high impedance coupled lines are attached to low impedance transmission line section in the middle, produce five transmission poles in the pass band (3.1 to 10.6)GHz. Filter topology used was single layer printed circuit board (PCB) with circuit size $(1.2 \times 0.15)\lambda_g$ at center frequency 6.85 GHz. Although the design is simple but with increased size and tight coupling required for parallel coupled lines. In [2] hybrid microstrip and coplanar waveguide technique is used to design compact UWB filter having five transmission poles. High-pass filter is realized by quasi-lumped circuit elements such as microstrip to CPW transition and CPW shorted stubs. Filter topology used here is double layer PCB with circuit dimensions $(0.25 \times 0.08)\lambda_g$ at 6.85 GHz. Measured and simulated results are not well correlated. Short circuited highpass structure was reported in [3] to develop UWB filter with nine transmission poles in passband. I/O cross coupling will introduce extra transmission zeros to increase selectivity. Filter topology used here is single layer PCB with increased circuit dimensions $(0.93 \times 0.49)\lambda_g$ at 6.85 GHz. One intuitive way is to cascade bandstop and bandpass filters to realize UWB bandpass filter. In [4] $\lambda/2$ transmission line shunted with two $\lambda/4$ short circuited stubs at I/O ports to achieve wide band bandpass filter. Two open stubs and two shunted transmission lines are used to deploy wideband bandstop filter. Cascading these two filters gives UWB frequency response with wide stopband. Similarly, highpass and lowpass filters can be cascaded to achieve UWB response [5]. These two mentioned techniques have disadvantages in term of large circuit size and high insertion loss. In [6] multilayer liquid crystal polymer (LCP) is used to design compact UWB filter. A lumped element circuit model is used, in which series capacitance is achieved by broadside-coupled radial patches. Low impedance lines are used to design inductances. Circuit size is $(0.55 \times 0.27)\lambda_g$ at 6.9 GHz. In [7] UWB bandpass filter is fabricated using low-temperature cofired ceramics technologies (LTCC). Total of ten layers has been used. Two identical T resonators are placed on fourth and sixth layer. The I/O port and $\lambda/4$ short-circuit line were on fifth layer. Via holes are added to the structure for reduce interference. Five transmission poles are obtained by this structure with circuit dimensions $(0.57 \times 0.57)\lambda_g$ at 6.85 GHz. Last two mentioned techniques are best suitable for UWB band pass filters as compared to previous discussed techniques, but the manufacturing cost is higher due to the use of LCP and LTCC technologies.

In this work, a compact UWB filter with highly selective response is designed using coupled lines, chip capacitor and MRR. The two main constraints for designing UWB filters using coupled lines are presence of second and third harmonic response and most importantly need of very narrow spacing between coupled lines in order to achieve wideband. In order to address these challenges, chip capacitor is used to decrease the odd mode impedance and hence widen the spacing for fractional bandwidth up to 83.2%. Simulated and measured frequency response shows good agreement.

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II. THEORY AND DESIGN OF MRR

The proposed UWB bandpass filter is shown in Fig.1. Filter consists of two high impedance parallel coupled lines attached to a low impedance coupled lines in the center. Chip capacitor is used to widen the gap and increase the coupling between low impedance parallel coupled lines. The centered coupled lines end up with via holes in the middle. The low impedance coupled line with chip capacitor and via holes constructs MRR. So in this configuration MRR structure produces four transmission poles while two more poles are introduced by side parallel coupled lines. Moreover one transmission zero can be shown in the lower side of passband. This is because of the extra cross coupling between low impedance coupled line. Now in order to analyze the design, equivalent circuit model has been extracted.

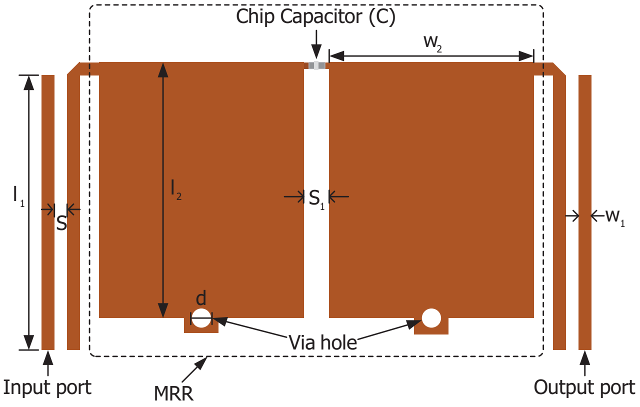

Fig. 1. Proposed UWB bandpass filter.

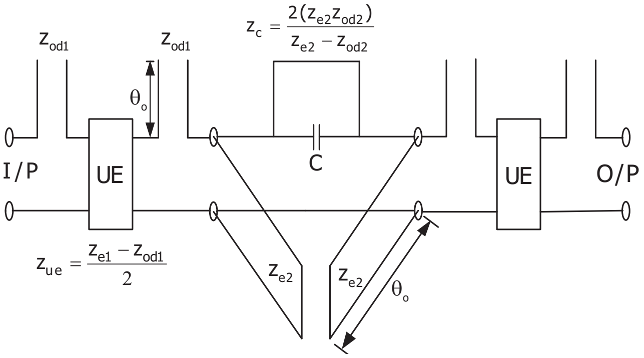

Fig. 2. Equivalent circuit of proposed UWB bandpass filter.

Figure 2 shows the equivalent circuit, where I/O parallel coupled line section can been shown by unit element with impedance z_{ue} and electrical length θ_o separated by open circuit stub with impedance z_{od1}. MRR can be shown as short circuit stub with impedance z_c parallel with a chip capacitor z_{cap} separated by two parallel short circuit stub with impedance z_{e2}. All stubs are quater wavelength long denoted by θ_o. For simplicity the location of chip capacitor is set to the bottom of low impedance couple line section. It is worth mentioning that chip capacitor and series short stub behaves as resonating circuit, thus producing a transmission zero at lower side of passband that tends to further increase the selectivity.

Due to symmetrical design, even-odd mode analysis has been adopted to extract the transfer function.

$$|S_{12}(\theta)|^2 = \frac{1}{1 + F^2(\theta)}\,, \tag{1}$$

Now by using relationship in (1), filtering function is extracted from transfer function as shown below:

$$F(\theta) = \Bigg\{ \Bigg[\sum_{n=0}^{n=6} x[2n] \cos^{2n}(\theta) + x[2n+1] \cos^{2n+1}(\theta) \sin(\theta) \Bigg]^{\frac{1}{2}} \Bigg\} \times \Bigg\{ 2 \sin^3(\theta) z_e^2 z_{ue}^2 \big[(\omega^2 C^2 z_c^2 - 1) \cos^2(\theta) + 2\,\omega\, C z_c \sin(\theta) \cos(\theta) - \omega^2 C^2 z_c^2 \big]^{\frac{1}{2}} \Bigg\}^{-1} \tag{2}$$

Here $x[n]$ is vector containing filtering coefficients. All these coefficients are function of characteristic impedances shown in Fig. 2. Summation limits shows maximum of six transmission poles in the passband. It is observed that the denominator of filtering function has frequency dependent terms. For narrow band SIR filter these terms can be neglected, but for UWB one can not neglect this term as it will change the frequency response for the given band of frequency. In generalize first type chebyshev polynomials, the selectivity is increased only by increasing the number of transmission poles, hence by increasing number of resonators. Whereas, in this design the frequency dependent terms in the filtering function $\frac{1}{\sin^3(\theta)}$ gives sharp cutoff near the passband edges, thus responsible for higher selectivity without introducing another resonator. To show the location of transmission zero, let transfer function $S_{12} = 0$. One solution for θ is:

$$\theta = \arctan\left(\frac{1}{\omega C z_c}\right) \tag{3}$$

Equation 3 shows the location of transmission zero. It depends on the resonating structure consist chip capacitor parallel with short circuit stub as shown in Fig. 2.

The quadratic equation in the denominator of $F(\theta)$, as separately written in equation (4), effects the number of transmission poles in the passband.

$$(\omega^2C^2{z_c}^2-1)\cos^2(\theta)+2\omega C z_c\sin(\theta)\cos(\theta)-\omega^2C^2z_c^2 \tag{4}$$

When equation (4) gives non-zero real roots, total of six transmission poles can be achieved. Now in order to get parameter values, design procedure given in [8] is adopted. Bandwidth of 5.5 GHz is achieved with passband (4.1 to 9.6) GHz centered at 6.85 GHz. Characteristic impedances shown in Fig.2 are calculated as: $z_{e1}=198.407$, $z_{od1}=77.749$, $z_{e2}=24.844$, $z_{od2}=22.5446$. Broadband chip capacitor $C=0.3$ pF from Murata Electronics is used for fabrication.

III. RESULTS

A prototype is fabricated to validate the simulated design using RT duriod 5880 with ($\varepsilon_r=2.2, \tan\delta=0.0009$ and height $h=787\mu$m). Full wave simulation is done using ADS momentum [9]. From characteristic impedance found in previous section, physical dimensions, shown in Fig. 1, are calculated as: $l_1=7548.56\mu m$, $w_1=253.0884\mu m$, $s=204.1004\mu m$, $s_1=1500\mu m$, $l_2=7951.39\mu m$, $w_2=6581.927\mu m$ and $d=3000\mu m$. Fig. 3 shows simulated and measured results of designed filter. Measured results are well correlated with full wave simulation results. Passband of 5.4 GHz has been achieved. However there are some discrepancies specially on higher frequencies. Moreover there is slight bandwidth shift in full wave simulation response whereas in measured response shift is quite significant specially from 9 GHz to 10 GHz. This indicates the lower obtained value of coupling. Inspecting the the performance of frequency response shows a need of improvement in 4 GHz to 6 GHz region, where the return loss is slightly high. This effect is due to nonlinear loss factor for wide bandwidths. The high return loss in this region can be minimized by using tuning and optimization tools. Slotted ground plane can be introduced at the backside of coupled lines for maximizing even-mode impedance thus increasing coupling gap. This will restrict the ripple level under 10 dB. The transmission zero on lower passband can be controlled by spacing s_1. The transmission zero moves on lower frequency as s_1 increases and vice versa. So the value of s_1 is selected carefully in order to have maximum selectivity while the response still exhibits maximum number of transmission poles.

IV. CONCLUSION

An UWB bandpass filter with compact size, high selectivity and six transmission poles has been designed using two parallel coupled lines and MRR. The MRR creates four transmission poles whereas extra two transmission poles were realized by input output parallel coupled lines. Filtering function is extracted to show maximum transmission poles and a transmission zero at lower stop band. This design can be further analyzed to obtain better performance by changing the position of chip capacitor and also by introducing the slot at ground. Prototype has been fabricated which shows good agreement with measured results.

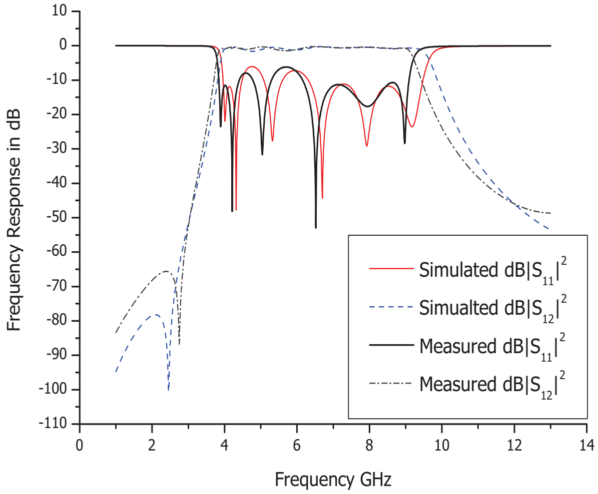

Fig. 3. Frequency response of $|S_{12}(\theta)|^2$ and $|S_{11}(\theta)|^2$ using simulation and measurement.

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