Microstrip Low Pass Filter Based on Complementary Split-Ring Resonators

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Abstract— There is an increasing demand for microwave systems to meet emerging telecommunication challenges with regard to cost, size and performance. In this paper a new multilayered fifth order microstrip low pass filter is designed retaining all above factors. The new microstrip low pass filter with cut off frequency 3.4GHz based on metamaterial structure is proposed and simulated. The filter is fabricated in the middle layer and a periodic pattern of complimentary split ring resonators (CSRR) are etched on the top layer of metamaterial structure. Computer simulated technique (CST) is used to simulate the filter design. Main objective of this Paper is to offer a unique RF/microwave microstrip filter based on the complementary square ring resonator structures. A comparison between a traditional microstrip low pass filter with a new modified design of multilayered microstrip low pass filter based on complimentary split ring resonator structure has been done. The return loss and insertion loss has improved significantly both in pass band and stop band.

Key words: Maximally flat microstrip low pass filter prototype, Metamaterials, Richard's Transformation, Kuroda's identities, complimentary split ring resonator (CSRR)

I. INTRODUCTION

An ideal filter is a linear two port network that provides perfect transmission of signal for frequencies in a certain pass band region and infinite attenuation in the stop band region and a linear phase response in the pass band (to reduce signal distortion). The aim of filter design is to estimate the ideal requirements within acceptable tolerance with circuits or systems consisting of real components. A size reduction and better performing low pass filters are of great demand in the application of microwave circuits. For improvement of performance of microwave filter we can use Metamaterials (artificial material).

These Metamaterials were first introduced by Russian physicist Victor Veselago in late 1960s, Metamaterials are artificial Structures which Exhibit negative permittivity, permeability and negative refractive index which is not found in the readily available material [1]. A metal below plasma frequency-the point at which it becomes transparent to light- show the effect and it comes from free electrons in the metal that act to screen out external electromagnetic radiation. The plasma frequency depends on the density of carriers and their effective mass. In a wire lattice structure, the geometry controls both parameters- by making wires thinner; it is possible to increase the effective mass of charge carrier which, in turn, reduces the effective plasma frequency. In principle, it is possible to achieve negative permittivity using wire meshes or gratings all the way from the low radio frequency to the optical region of the spectrum [2]. Prof. Pendry's team proposed a structure for negative permeability. The Split Ring Resonator (SRR) with a negative permeability. As the name accomplishes that it is complete circle of metal., which acts like an inductive-capacitance resonator of an electrical circuit of filter. When this resonator is placed in magnetic field that changes with time, the charge produced across the gap in the ring. At high frequencies, the current that oscillate within the resonator stay out of phase with the driving field. On the other hand, at low frequencies the current start to lead, generating an in phase response. So at higher frequencies, this produces the effect of negative permeability [3],[4]. Following this interesting discovery, hence the metamaterial is defined as "the manmade or artificial materials, which gain its properties such as negative permeability from its structure rather than directly from its composition". Doctor Albert Smithrom Duke University combined the two structures and became the first to fabricate the metamaterial [5]. In 1968 Veselago proposed left handed material (LHM) and right handed material (RHM), which exhibits negative permeability and permittivity ($\varepsilon < 0$ and $\mu < 0$).The resonators can be considered as quasi- lumped elements and are, therefore, also very interesting for the miniaturization of planar microwave devices such as filters and diplexers. A low pass filter is a filter that passes low frequency signals and attenuates higher frequency signals above a cut off frequency. Microwave filter is a device which offers different impedances for different frequency range of signal. A microwave low pass filter offers high impedance for high frequencies and low impedance for low frequencies. Hence microwave low pass filter passes low frequency band up to certain frequency called cut off frequency and it block all high frequency signals [6].

II. DESIGN OF THE PROPOSED LOW PASS FILTER

There are two methods of Microwave filter designing, Image parameter method and insertion loss method. Image parameter method consists of a cascade of simpler two port filter sections, which provide the desired cut off frequencies and attenuation characteristics but it is specified for particular frequency response, it is not specified for complete operating frequency range. In the second method of microwave filter designing, it uses network synthesis technique [7]. In this paper, we use insertion loss method for designing low pass filter. In the designing of maximally flat low pass filter, firstly we have to choose or select an appropriate low pass filter prototypes which are then normalized in terms of frequency and impedance and after selection of appropriate prototype, scaling of their frequency and impedance is done. Basic design steps of microwave low pass filter operating at random frequency are designed with the prototype low pass filter by using following steps:

1) Filter specification in term of desired frequency, impedance and order of the filter.

2) Designing prototype low pass filter with specified frequency.
3) Scaling of normalized frequency and impedance to desired values.
4) Transformation of the lumped elements circuit to distributed circuit to operate at higher frequencies.

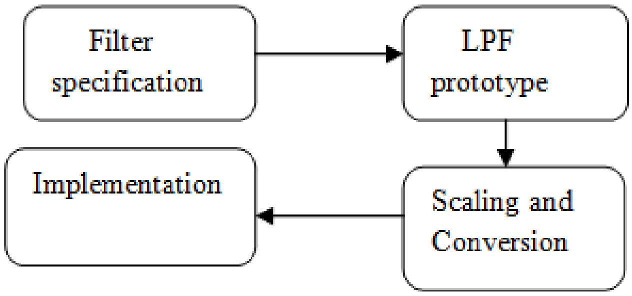

Fig. 1: Process of microstrip filter design.

Frequency scaling is used to change the cut-off frequency of a low pass filter prototype from unity to ω_c. After that scaled electronic lumped element components are replaced with distributed circuit elements for implementation at microwave frequencies. Lumped elements are replaced with distributed circuit by using Microstrip line theory, Richard's transformation and Kuroda's identities [7] [8]. Richard's transformation is used to convert lumped elements to transmission line sections, the series inductors to the equivalent series stubs, and the shunt capacitors to the equivalent shunt stubs. Kuroda's identities are then used to physically separate filter elements by using transmission line sections. Kuroda's identities are useful to transform the series stub into shunt stubs. Finally proposed low pass filter is designed and simulated at resonant frequency 3.4GHz.

Design specifications for the filter under consideration are:
Relative Dielectric Constant, $\varepsilon r = 4.3$
Cut-off frequency, fc = 3.4GHz
Height of substrate, h = 1.6 mm
General Ladder circuit for 5th low-pass filter is illustrated in fig.2.

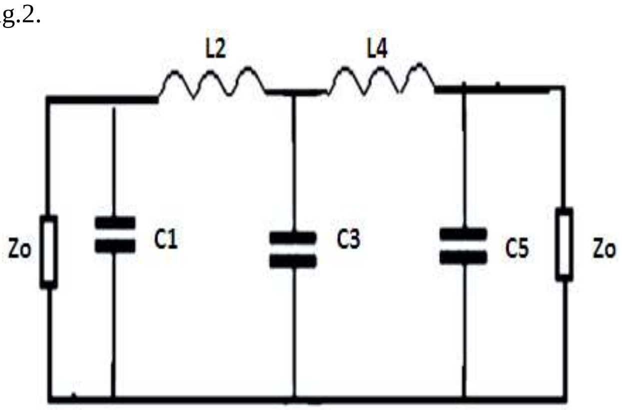

Fig. 2: Low pass prototype networks with five components.

The parameters of the micro strip filter are determined by the formulas that are given below:

For w/h<=1

$$Zo = 60\frac{60}{\sqrt{\varepsilon e}}\ln\left(\frac{8h}{w}+\frac{w}{4h}\right)$$

For w/h>=1

$$Zo = \frac{120\pi}{\sqrt{\varepsilon e}\{\frac{w}{h}+1.393+0.667\ln(\frac{w}{h}+1.414\}}$$

With

$$\varepsilon e = \frac{\varepsilon r+1}{2}+\frac{\varepsilon r-1}{2}\frac{1}{\sqrt{1+12h/w}}$$

The w/h ratio to determine microstrip line impedance

For w/h<2 $\quad \frac{w}{h} = \frac{8e^{A}}{e^{2A}-2}$

With

$$A = \frac{Zo}{60}\sqrt{\frac{\varepsilon r+1}{2}}+\frac{\varepsilon r-1}{\varepsilon r+1}\left(0.23+\frac{0.11}{\varepsilon r}\right)$$

For w/h>2

$$\frac{w}{h} = \frac{2}{\pi}[B-1\ln(2B-1)+\frac{\varepsilon r-1}{2\varepsilon r}\{\ln(B-1)+0.39-\frac{0.61}{\varepsilon r}\}]$$

With

$$B = \frac{377\pi}{2Zo\sqrt{\varepsilon r}}$$

The value of the components of low pass filter is calculated by the following equations:

Li = (Zo /go) (ωo/2pfc) gi
Ci = (go/Zo) (ωc/2pfc) gi
Where normalized cut off frequency $\omega_c = 1.0$
$\ell = (L/C)\,(3.\,10^8/\sqrt{eff})$
$\ell = (C/Zc)\,(3.\,10^8/\sqrt{eff})$
L= Value of inductance
C= Value of capacitance

components	Length (mm)	Width (mm)
C1=0.98662pF	6.70	4.0
L2=2.9491nH	5.87	1.0
C3=1.6991pF	5.89	10
L4=2.9491nH	5.87	1.0
C5=0.98662pF	6.70	4.0

Table 1: Dimensions for a stepped-impedance low pass filters (for n=5)

III. DESIGN AND SIMULATION RESULTS OF MICROSTRIP LOW PASS FILTER WITHOUT CSRR

In this paper, Conventional microstrip low pass filter is designed as shown in figure 3. Fig. 4 shows its simulated results of S11 and S21 parameters with cut off frequency 3.4 GHz.

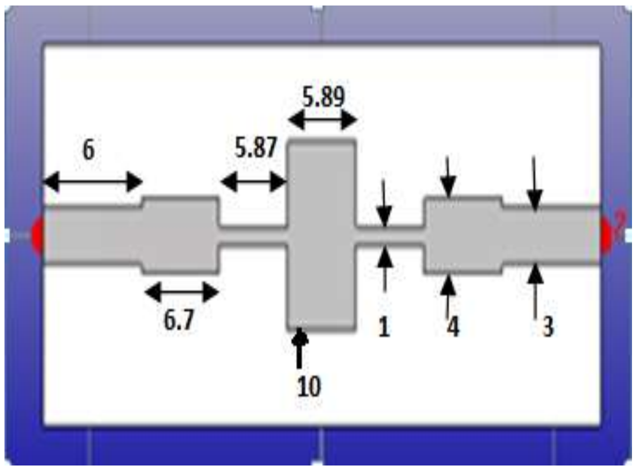

Fig. 3: Layout diagram of conventional microstrip low pass filter on substrate with εr =4.3 and height from substrate h= 1.676 mm at 3GHz frequency

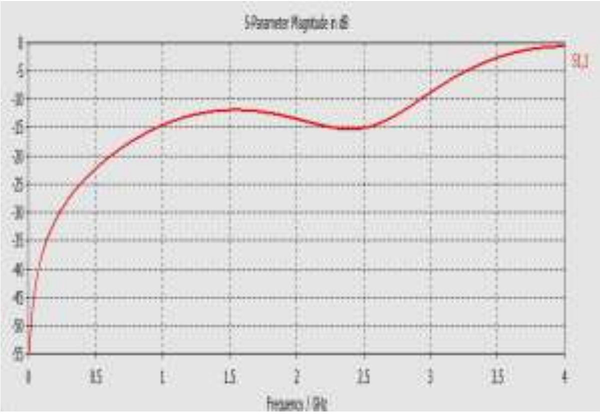

Fig. 4(a): Simulated S11 (return loss) response of conventional microstrip low pass filter.

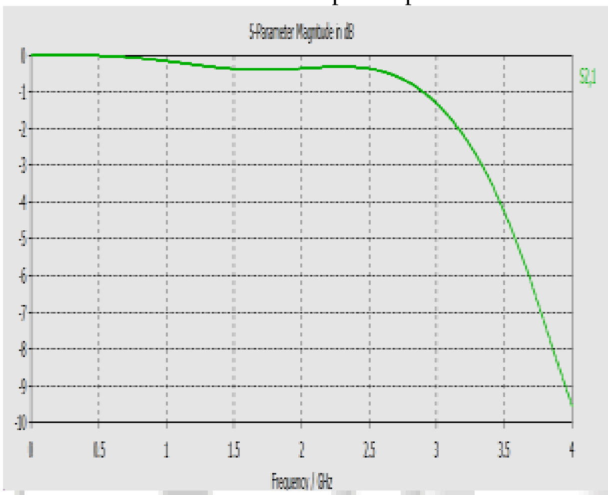

Fig. 4(b): Simulated S21 (insertion loss) response of conventional microstrip low pass filter

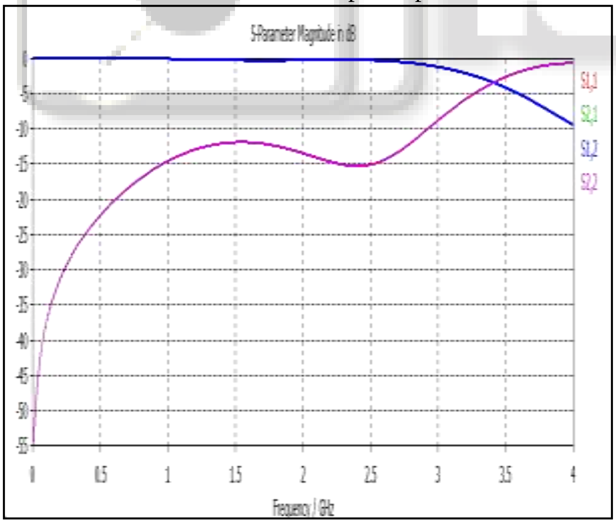

Fig. 4(c): Simulated S11 and S21 response of microstrip low pass filter.

III. DESIGN AND SIMULATION RESULTS OF NEW MICROSTRIP LOW PASS FILTER WITH COMPLIMENTARY SPLIT RING RESONATOR

Split ring resonator (SRR) is a set of two concentric metallic planner rings, with splits opposite sides in them [3]. In 2001, Smith, Schultz used array of wires that gives rise in negative permeability at microwave frequencies [1]. The electromagnetic properties of SRRs have been already analyzed, in this analysis shown that SRRs behave as a resonator that can be excited by an external magnetic flux, exhibiting a strong diamagnetism above their first resonance [10]. SRRs also exhibit cross-polarization effects (magneto electric Coupling) so that excitation by a properly polarized time-varying external electric field is also possible [6], [11]. Split ring resonator (SRR) is forming an LC network. In SRR, the inductance is due to the gap between the rings and capacitance is due to the rings and the gaps in the rings itself [3] [12]. The resonant frequency can be easily tuned to desired value. Fig 5 shows the dimensional view of the split ring resonator. The proposed low pass filter is designed by using computer simulated technique (CST) software. The SRR structure is fabricated or designed on the top layer.

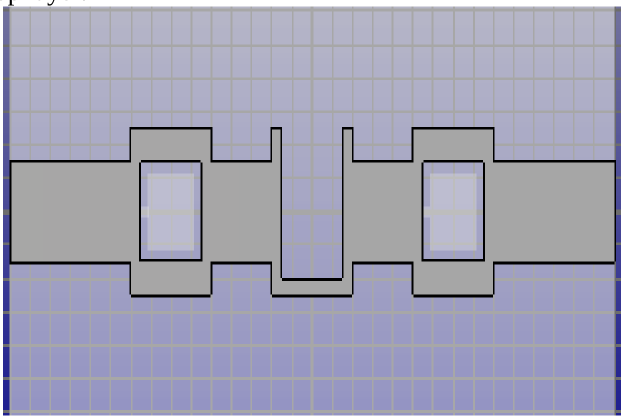

Fig. 5(a): Middle layer of microstrip low pass filter

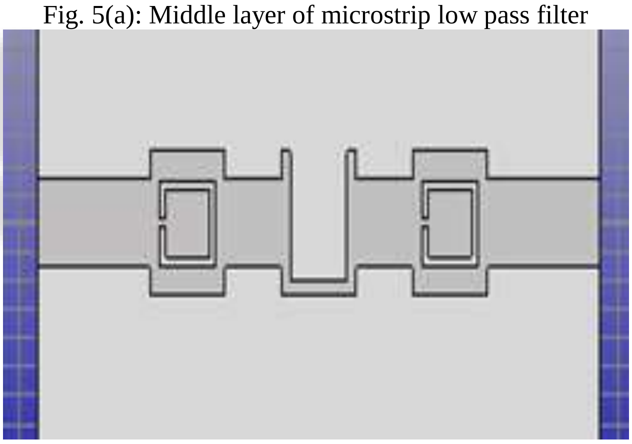

Fig. 5(b): Transparent view of microstrip low pass filter with middle layer and top layer.

The simulated result of transmission coefficient s21 and reflection coefficient s11 is shown in fig. 6.

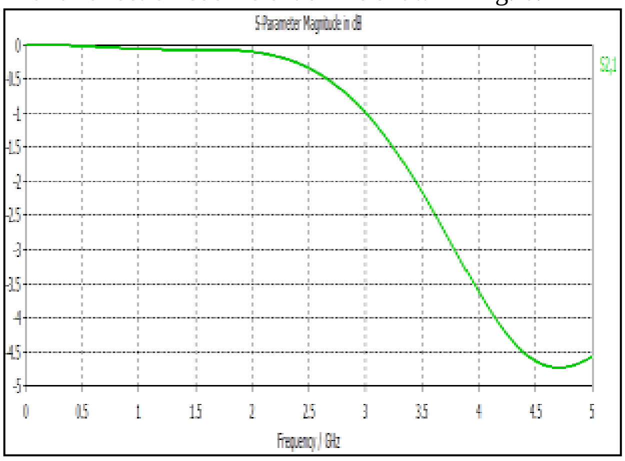

Fig. 6(a): Simulated result of transmission coefficient s21.

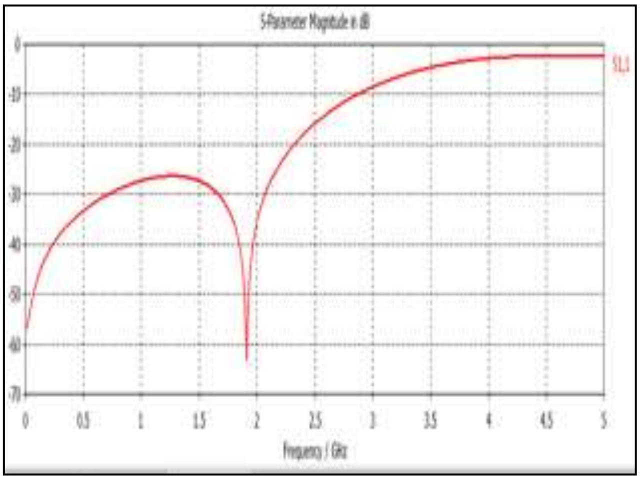

Fig. 6(b): simulated result of reflection coefficient s11.

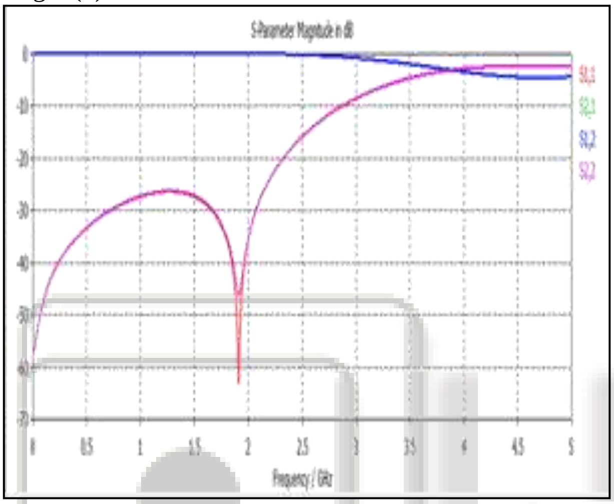

Fig. 6(c): Simulated results of s11 and s21 coefficients with cut off frequency 3.4 GHz, using CSRR on the top layer of microstrip low pass filter.

IV. CONCLUSION

This paper has presented a design and analysis of microstrip low pass filter by using split ring resonator structure. New filter by using split ring resonator, performance has been improved in both pass band stop band. The new design has been compared with conventional microstrip low pass filter. The reflection coefficient s11 has been improved in proposed microstrip low pass filter.

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