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Microstrip Line Low Pass Filters Based on Metamaterial Component

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Abstract: Stepped impedance microwave low pass filters (LPFs) are presented. The conventional stepped impedance LPF with cut off frequency of 1. 9 GHz is proposed. Replacing split ring resonator (SRR) instead of low impedance line in conventional design is presented to get compact, low insertion loss (IL), sharp cutoff, and high selectivity LPF. The proposed filter have better result compared to conventional counterpart. The simulated results indicated that the proposed filter achieved flat pass-band without ripples, corresponding to numbers of unit cells of SRR structure. Numerical result for the stepped impedance microwave LPFs are obtained. The filters are simulated by the computer aided design software (Ansoft HFSS) tool.

Keywords: Microstrip, metamaterial, selectivity, split ring resonator, stepped impedance.

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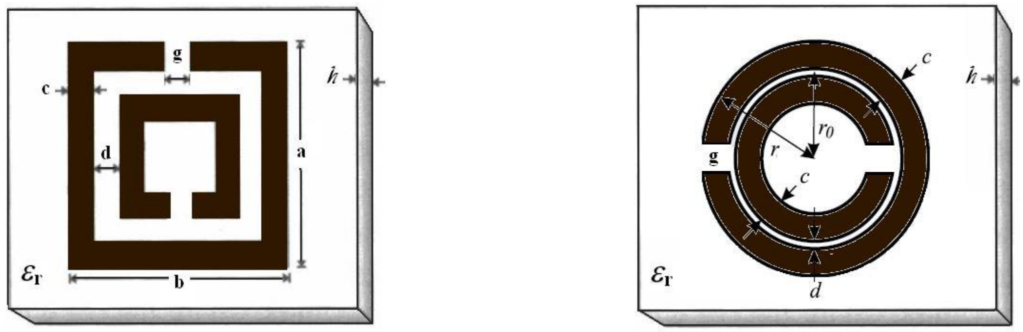
I. INTRODUCTION

In microwave wireless systems, different filters are available for different applications. The miniaturizations of microwave filters have been one of the challenges for microwave communication devices. Low pass filters are often an important component in RF circuits and microwave communication systems. Conventional implementation of a LPF involves the use of stepped impedance microstrip lines (D. Ahn *et al.,* 2001), however, these structures have a gradual cut off response which is not sharp. Therefore, the rejection characteristics has limitations in such traditional LPFs. This limitation can be improved by increasing the pass-band insertion loss (*IL*) by adding new sections. However, this increasing does increase the size of overall structure. In order to overcome these problems there has been an increasing interest for the use of metamaterial structures such as SRRs or other structures (W. Tu & K. Chang, 2005) in the development of compact microwave components using printed circuit boards and MMIC technologies (N. Engheta & R. Ziolkowsky, 2006). So, Metamaterial filters at high frequencies are the best studied for microwave wireless where miniaturization of filters provides reduction in size, light weight and low cost. Left-handed materials (LHMs) are first introduced by (V.G. Veselogo ,1968), which created a new research in the area of microwave circuit design. Several equivalent terminologies have been used as MTMs, such as left-handed (LH), double-negative (DNG), negative-refractive-index (NRI), backward-wave (BW), Veselago medium, or negative phase velocity medium (NPV) (C. Caloz and Itoh. Tatsuo, 2006) Split ring resonators (SRRs) are one of the first particles proposed for metamaterial construction.

Metallic metamaterials comprising double SRRs are the main artificial structures to realize magnetic responses at an electromagnetic spectrum above gigahertz frequencies (J. Pendry, 1999). The realization of backward wave propagation using SRR and thin wire (TW) and several other electrically small resonators are considered by (J. Pendry *et.al* ,1996). Figure.1 shows the SRR structures which are used to obtain a negative value of effective permeability over a desired frequency range. This negative permeability can prevent wave propagation at the resonant frequency (Ho. Lim *et.al*,2007).In this paper, stepped impedance microwave lowpass filters (LPFs) are presented. The cutoff frequency of the conventional LPF design is 1.9GHz. The other designs of LPFs based on metamaterial property is using SRR rectangular structure.



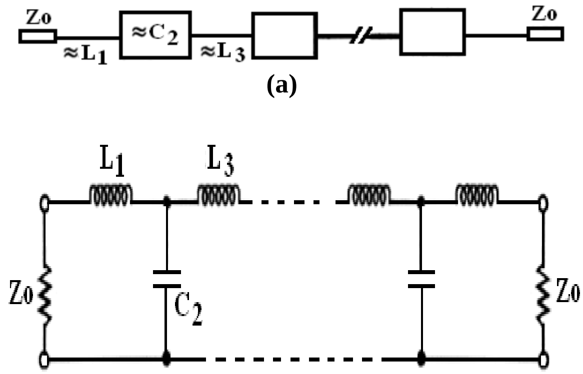
(a) **(b)**

Figure 1.SRR topology (Unit cell), (a) Square shape, (b) Circle shape. The relevant dimensions are indicated. The designed filters are used in RF and microwave wireless applications.All proposed filters are simulated by using Ansoft HFSS simulator tool and implemented on FR-4 substrate. This substrate has a dielectric constant εr = 4.4, loss tangent tan α = 0.002, substrate height *h* = 1.6 mm and thickness of microstrip conductor *t* =0.035mm.

II. LOW PASS FILTER DESIGN

2.1. Stepped impedance LPF Structure

Figure. 2(a) shows, the general structure of the stepped impedance microstrip LPF is shown in Figure. 2 (a), which uses a cascaded structure of alternating high- and low- impedance transmission lines. The high-impedance lines act as series inductors and the low-impedance lines act as shunt capacitors. Figure. 2 (b) shows the equivalent circuit representation of LPF.



(a)

(b)

Figure.2. Stepped impedance Low pass microstrip line Filter (a) Structure, (b) Equivalent circuit representation.

2.2. **Characterization, specifications, and design of the stepped impedance LPF**

Insertion loss (IL or L_A) and return loss (L_R) are the two important losses in the filter characterization. The losses and voltage standing wave ratio (VSWR) are related to scattering parameters (S_{mn}) and

$$L_A = -20\log|S_{mn}| \text{ dB} \quad (1)$$ Where $m=n=1,2$ $(m \neq n)$

$$L_R = 20\log|S_{nn}| \text{ dB} \quad (2)$$ Where $n = 1,2$

$$VSWR = \frac{1+|S_{11}|}{1-|S_{11}|} \quad (3)$$

The specifications of the stepped impedance microstrip LPF source and load impedances at $Z_o = 50\Omega$ are listed in Table 1.

Table1. Specifications of stepped impedance microstrip LPF

Filter Design	Cu at off Frequency 3dB (GHz)	Return Loss (dB)
1	1.9	-39.94
2	2.9	<-39.94

The filters are to be implemented on a substrate with a relative dielectric constant (εr) of 4.4 and a substrate height (*h*) of 1.6 mm. The characteristics impedance (Z_O) of the high (*L*) and low (*C*) impedance lines are chosen as 95Ω and 26Ω, respectively with accurate microstrip width (W). The normalized cutoff Ωc = 1, using the element transformations is as given by Sheng and Lancaster [23]. Thus the evaluated values of inductors and capacitors are listed in Table 2.

Table2. Design parameters of stepped impedance LPF

Parameters	C	O	L
Zo(mm)	26	50	95
W(mm)	8.22	1.1	0.815
Λg(mm)	102.45	113.67	114.65

The physical lengths of the high- and low- impedance lines are expressed, as given by Sheng and Lancaster [23]

$$l_L = \frac{\lambda_{gL}}{2\Pi} Sin^{-1} \frac{(\omega_c L)}{(Z_{oL})} \qquad (4)$$

$$l_C = \frac{\lambda_{gC}}{2\Pi} Sin^{-1} (\omega_c C Z_{oc}) \qquad (5)$$

The lengths of the high- and low- impedance lines are suggested by Sheng and Lancaster [23]

$$\omega_c L = Z_{oL} Sin\left(\frac{2\Pi l_L}{\lambda_{gL}}\right) + Z_{oc} \tan\left(\frac{\Pi l_C}{\lambda_{gC}}\right) \qquad (6)$$

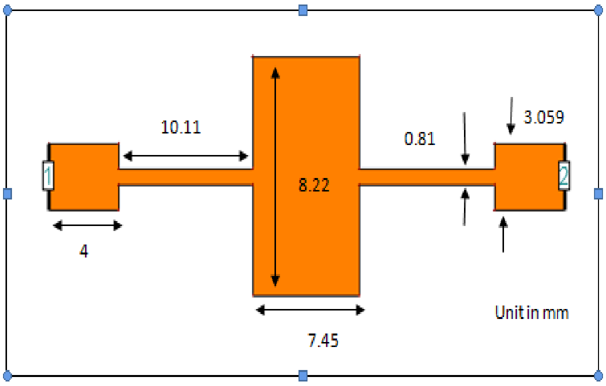
$$\omega_c C = \frac{1}{Z_{oC}} Sin\left(\frac{2\Pi l_C}{\lambda_{gc}}\right) + \frac{2}{Z_{oL}} \tan\left(\frac{\Pi l_L}{\lambda_{gL}}\right) \qquad (7)$$

The overall results after approximation are listed in Table 3.

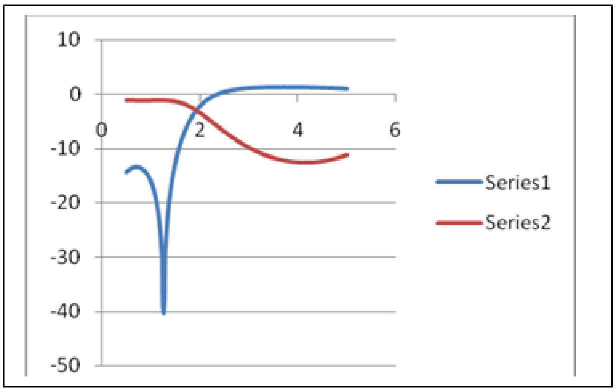
Table3. Design parameters (approximate)

L1=L3 (nH)	C2(pF)	Physical Length(mm)	Adjusted Length(mm)
5.307	2.436	l 1= 10.00 l 3= 0.181	l 1=10.11 l 3= 7.45

A layout of conventional microstrip LPF after approximation (to get better results) is shown in Figure. 3(a). The simulated transmission (S21) and reflection (S11) parameters as frequency response for conventional LPF is shown in Figure.3 (b). It is obtained by simulation using Ansoft High Frequency Structure Simulator (HFSS) Simulator.



(a)



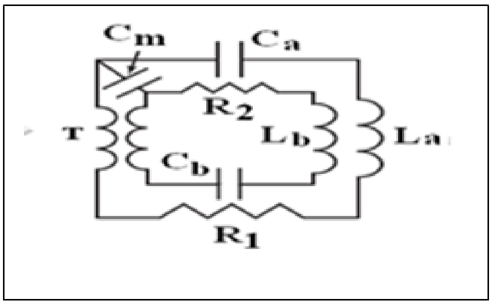
(b)

Figure.3. Conventional stepped impedance microwave LPF, (a) layout, (b) S21 and S11 frequency response using HFSS simulator (Design 1).

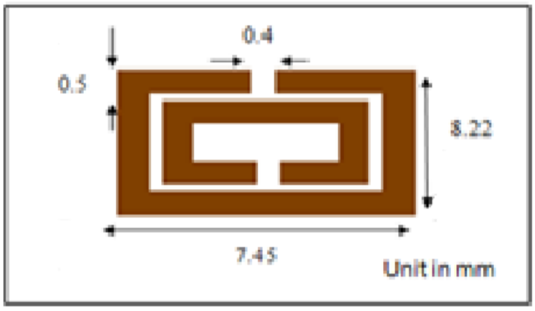
III. SIMULATION AND VERIFICATION OF SRR AS METAMATERIAL STRUCTURE

3.1. Split Resonator Ring (SRR) Structure

The equivalent circuit of an SRR shown in Figure. 4(a) is replaced instead of the shunt capacitor in the equivalent circuit of the conventional design to get better results such as sharp roll-off response. In the double ring configuration, capacitive coupling (Ca, Cb) and inductive coupling (La, Lb) between the larger and smaller rings are modeled by a coupling capacitance (Cm) and a transformer that has transformed ratio (T) [11]. In the Figure. 4(b), the double split rings are rectangular copper with a thickness of 0.035mm and the geometric parameters (a, b, and c) are 8.22mm, 7.45mm and 0.5mm, respectively. The gap between the inner and outer rings (d) is 0.4mm, and each of the splits in the inner and outer rings has the same width (g) of 0.4mm.



(a)

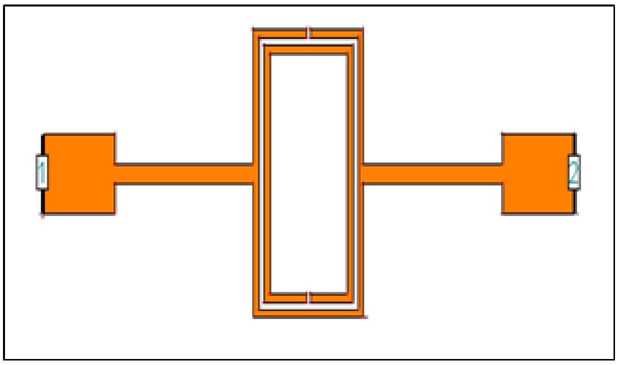


(b)

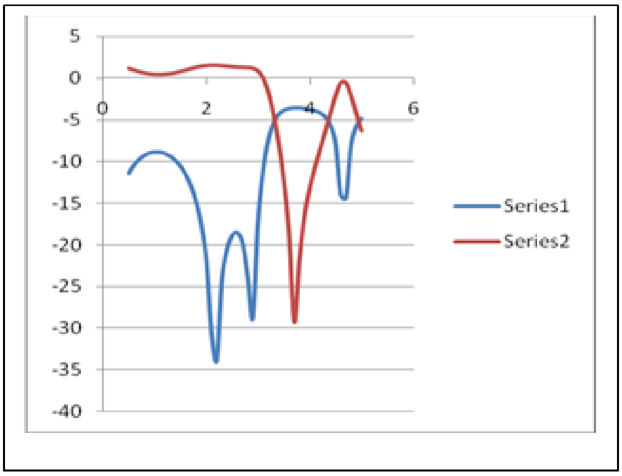
Figure.4. Double SRR (a) Equivalent circuit model, (b) Structure [11].

3.2. Improvement of stepped impedance LPFs design

To get improved electrical performance of the proposed filters, the design parameters are tuned and optimized using HFSS software. The layouts of proposed filters with its results are shown in Figures. 5 (a) and 5(b). From Figure. 5(b) it is observed that the roll off of LPF becomes sharper and there is better matching in the pass-band with the SRR structure than the conventional structure. The response of the conventional LPF shows a lowpass characteristic with a 3dB cutoff frequency of 1.9 GHz. The insertion loss reaches –2.79dB at 1.88GHz and return loss reaches -39.94dB at 1.25 GHz where as for two ring SRR LPF insertion loss reaches 1.23 dB at 2.9 GHz and return loss reaches -33.92 dB at 2.2 GHz using HFSS simulator .



(a)



(b)

Figure.5. Low pass Filter contains rectangular SRR,(a) layout, (b) S21 and S11 frequency response using HFSS simulator (Design 2).

From this, it is observed that the scattering parameters for the LPF incorporating SRR particles, illustrate a much steeper roll-off than the conventional one.

IV. RESULTS AND ANALYSIS

The prototypes of the proposed LPF were fabricated are using FR- 4 (εr = 4.4, thickness = 1.6 mm) using standard photo etching techniques as shown in Figures 6. An Agilent 8757E scalar network analyzer (1-20 GHz) is used to measure the response of the proposed filter and the results are shown in Figures 7 and 8. The measured response for the conventional low-pass filter shows a low-pass characteristic with a 3 dB cut-off frequency of 1.9 GHz. The insertion loss reaches -4.483dB at 1.82 GHz.

It is observed that the scattering parameters for the low-pass filter incorporating split resonator ring, illustrate a much steeper roll-off than the conventional one. It is also evident that incorporating SRR structures into a low-pass filter has not degraded pass-band performance.

(a)

(b)

Figure.6. Fabricated proposed low pass filter (a) Conventional low pass filter (b) Two ring SRR structure at top view.

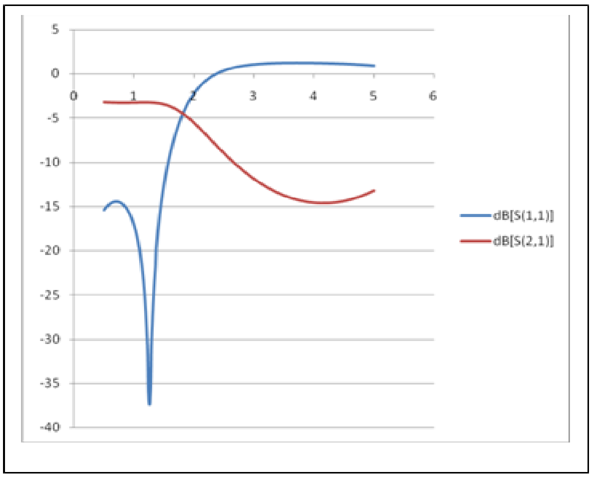


Figure.7. Measured S11 and S21 response for conventional low pass filter.

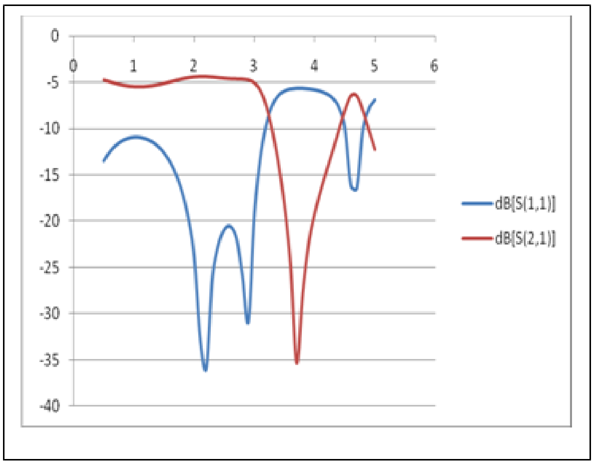


Figure.8. Measured S11 and S21 response for proposed low pass filter with two ring SRR.

The reason for the reduction in size of the proposed filter is due to sub wavelength dimensions of the SRR structure and frequency dispersion.

V. CONCLUSION

This paper proposed a conventional design of stepped impedance microwave low pass filter (LPF) with a cutoff frequency of 1.9GHz. Other designs depending on conventional design by using the SRR structures are presented. The proper design and using the rectangular SRR structures, several merits are achieved such as; low insertion loss (*IL*), sharp cutoff with high selectivity, and expand the bandwidth of pass-band in LPF performance. A size reduction of the filter is achieved by using SRR. Other advantages are improved selectivity, flat group delay over a large pass-band and ease of fabrication. The scattering parameters for the LPF incorporating SRR particles, illustrated a much steeper roll-off than the conventional one.

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