Stepped Impedance Design Of Butterworth Microstrip Low Pass Filter With Split Ring Resonator For N=3 And N=5

Navita, Pravesh, Vibhav Kumar Sachan

Abstract— This paper presents the designing and comparison of 1.0-2.0 GHz Butterworth low pass filter with cut-off frequency 1.3GHz and pass band ripple of 3.01db using conventional stepped impedance and split ring resonators in a multilayer configuration for digital broadcasting applications. Initially, the proposed conventional structure is considered for Stepped Impedance Low Pass Butterworth filter of order n=3 and n=5 [1]. Afterward the modified split ring is introduced in low impedance micro strip line of the filter to obtain the better roll-off factor, low insertion loss and improved selectivity [10]. The geometry is simulated using IE3D Mentor Graphics. The FR-4 substrate with dielectric constant, εr of 4.4 and substrate height h=1.6mm has been used as a core material in the design. The simulated results have a good agreement with the metamaterial structure. Insertion loss, return loss with respective frequency for both the design has been analyzed and the results shows that metamaterial structure obtain much better miniaturization at microwave frequencies for a given physical cell size. The designing equations are solved using MATLAB code and the results are simulated using IE3D simulator.

Index Terms— Return loss, Substrate, Impedance Matching, MATLAB, Split Ring Resonator, Roll-off factor, Metamaterial

1 Introduction

Micro strip transmission line low pass filters show a vital role in numerous radio frequency wireless Communication Systems. A low-pass filter (LPF) that allows signals having a frequency lower than a designated cutoff frequency and attenuates signals having the frequencies more than the cutoff frequency. The precise frequency curve of the filter depends on the designing of filter. A Micro strip LPF having compressed size, sharp roll-off factor and good attenuation is greatly required. There are two main points in the conventional design, first selecting an appropriate low pass prototype and secondly finding a micro strip realization [I]. But this type of structure designing provide gradual cut-off, which is not suitable for practical application. So to overcome with this problem, the low impedance micro strip line is replaced by a modified split ring resonator (SRR). In this paper, designing of 3rd order and 5th order stepped impedance Butterworth LPF and modified split ring resonator (SRR) is approximated and the simulated results are compared on the basis of S-Parameter i.e. insertion loss and Return loss. For proposed conventional design work, Butterworth Approximation is assumed which exhibits the monotonically decrease behavior in the passband and stopband and for modified SRR the structure

uses the main metamaterial designing process Metamaterials are basically modelled as artificial materials and offers the properties that are not available freely in nature.

The Metamaterial properties are usually explained from newly modelled structure rather than from the properties of the base materials. In Metamaterials, the vital property is their unfamiliar and preferred qualities that appear because of their specific design & structure. Electromagnetic waves intermingle with the inclusions in specific composite media which produce electric & magnetic moments and in result it affects the macroscopic effective permittivity & permeability of the bulk composite medium. Its defined structure and arrangement provides various properties capable of transforming electromagnetic waves by blocking, absorbing, enhancing, or bending waves, to attain assistances that go beyond what is possible with conventional materials [4][5]. In these the shape of the inclusions is one that offers an original prospect for metamaterial processing. In this paper, conventional stepped impedance micro strip LPF of 1.3 GHz is simulated and then after modified SRR for N=3 and N=5 has been introduced to overcome the drawback of conventional structure. The designing equations are solved using MATLAB code and the results are simulated using IE3D simulator

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2 Design Procedure for Low Pass Filter

2.1 Designing Steps

Firstly, considering the specifications required in the designing of microstrip low pass filter

Cut-off Frequency = 1.3 GHz
Source/Load Impedance Z_0 = 50 ohms
Normalized frequency Ω_c = 1 GHz
Loss Tangent tan δ = 0.002

Butterworth Low Pass Prototype filter for maximally flat low pass prototype filters with an insertion loss L_{Ar} = 3.01 dB at the cut-off Ω_c = 1, the element values may be computed by

$$g_0 = 1.0$$

$$g_i = 2\sin\left(\frac{(2i-1)\pi}{2n}\right) = 1\ to\ n$$

$$g_{n+1} = 1.0$$

The normalized elements are then changed to L-C components for the given cut off frequency fc and normally 50Ω source impedance is use for micro strip filter [4][5]. The LC ladder type stepped impedance low pass micro strip line filter and general arrangement is shown in figure 1.

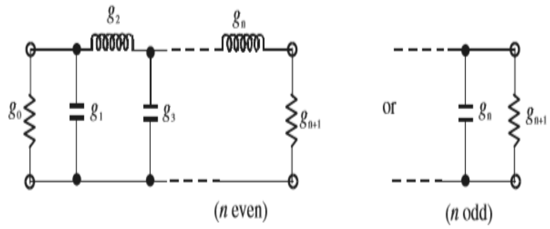


Fig. 1. Ladder Network Arrangement for Low Pass Prototype.

p Using Element Transformation for normalized cut-off frequency, we can have

$$L_1 = L_3 = \left(\frac{Z_0}{g_o}\right)\left(\frac{\Omega_c}{2\Pi f_c}\right) g_1$$

$$C_2 = \left(\frac{g_o}{Z_0}\right)\left(\frac{\Omega_c}{2\Pi f_c}\right) g_2$$

The fabrication of a filter is done on a substrate having relative dielectric constant of 4.4 and height of about 1.6mm. The characteristic impedance of high impedance line is chosen as Z_{0L} = 93 Ω and of low impedance line is chosen as Z_{0C} = 17 Ω for N=3. Now we have calculated the relevant design parameters of microstrip line by using the designing formulas [1][2]. Firstly, calculating the microstrip line width and guided wavelength for the given impedance by using, [3].

$$\frac{W}{h} = \frac{8\exp(A1)}{\exp(2A) - 2}$$

where

$$A1 = \frac{Z_c}{60}\left\{\frac{\varepsilon_r+1}{2}\right\}^{0.5} + \frac{\varepsilon_r-1}{\varepsilon_r+1}\left\{0.23 + \frac{0.11}{\varepsilon_r}\right\}$$

Now calculating the effective dielectric constant by using following expression [3], since $W_0/h \geq 1$

$$\varepsilon_{re} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(1 + 12\frac{h}{W}\right)^{-0.5}$$

At the cut-off frequency f_c = 1.3 GHz, Guided wavelength is calculated as follows,

$$\lambda_{g0} = \frac{300}{f(GHz)\sqrt{\varepsilon_{re}}} \text{ mm}$$

As W/h ≤ 1, we use

$$\varepsilon_{re} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left\{\left(1 + 12\frac{h}{W}\right)^{-0.5} + 0.04\left(1 - \frac{W}{h}\right)^2\right\}$$

$$\varepsilon_{re} = \frac{4.4+1}{2} + \frac{4.4-1}{2}\left\{\left(1 + 12\frac{1.2}{0.4}\right)^{-0.5} + 0.04\left(1 - \frac{0.4}{1.2}\right)^2\right\}$$

Also, the calculation of physical length for high-impedance and low-impedance line is done by using following expression.
Physical length of the high impedance line is calculated by using,

$$l_L = \frac{\lambda_{gL}}{2\Pi}\sin^{-1}\left(\frac{\omega_c L}{Z_{0L}}\right)$$

low impedance line physical length is calculated as,

$$l_C = \frac{\lambda_{gC}}{2\Pi}\sin^{-1}(\omega_c C Z_{0C})$$

The modified length of high-impedance line and low-impedance line is considered by using following expressions. We have to select their length in such a way that the following expressions must be satisfied [3].

$$\omega_c L = Z_{0L}\sin\left(\frac{2\Pi l_L}{\lambda_{gL}}\right) + Z_{0C}\tan\left(\frac{\Pi l_C}{\lambda_{gC}}\right)$$

$$\omega_c C = \frac{1}{Z_{0C}}\sin\left(\frac{2\Pi l_C}{\lambda_{gC}}\right) + 2 \times \frac{1}{Z_{0L}}\tan\left(\frac{\Pi l_L}{\lambda_{gL}}\right)$$

For convenience, we have designed a Matlab code to calculate, generalized value for the order of filter N and to solve the various designing equation from order of Filter to the physical length of stepped impedance Microstrip line, Matlab software is used.

2.2 Calculated Results and Layout

TABLE 1

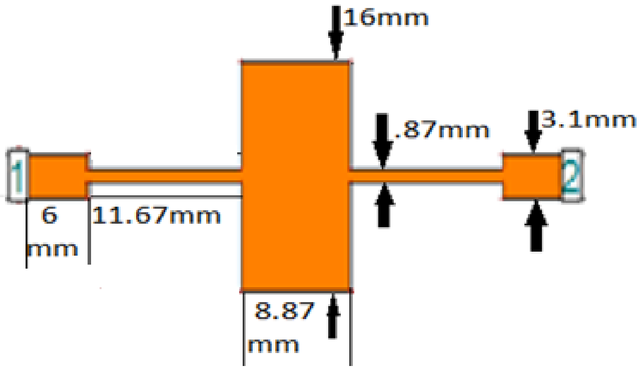
N=3

s.no	Source Impedance/low Impedance /High Impedance	Guided Wavelength	Width	Physical Length
01	50(source)	163.01 mm	3.1mm	6mm
02	93(high)	171.30 mm	.87mm	11.67mm
03	17(low)	98.17mm	16 mm	8.87mm

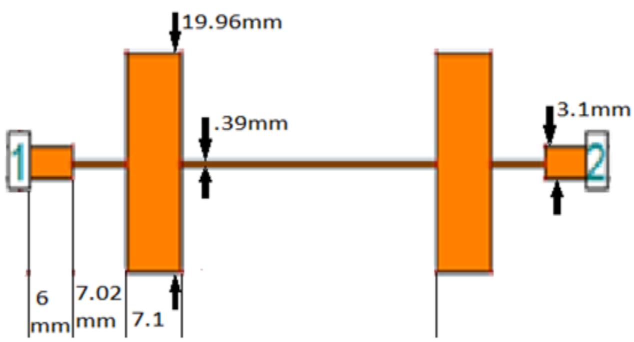
The layout of the conventional Stepped impedance LPF is shown in fig (2) for N=3 and N=5 and its simulated frequency response in fig (3). Output results shows the simulated values of Insertion Loss and Return loss of about -6.65 dB and -55.49 dB respectively for N=3 and for N=5, it is about -7.23db and -16.01 dB respectively. From fig 3(a) and 3(b), it can also be concluded that we have improved value of insertion loss as the order of the filter increase

TABLE 2
N=5

s.no	Source Impedance/low Impedance /High Impedance	Guided Wavelength	Width	Physical Length
01	50(source)	163.01 mm	3.1mm	6mm
02	120(high)	173 mm	.39mm	7.02mm(l1 and l5) and 30mm(l3
03	15(low)	83.61mm	19.96mm	7.1mm(c2 and c4)

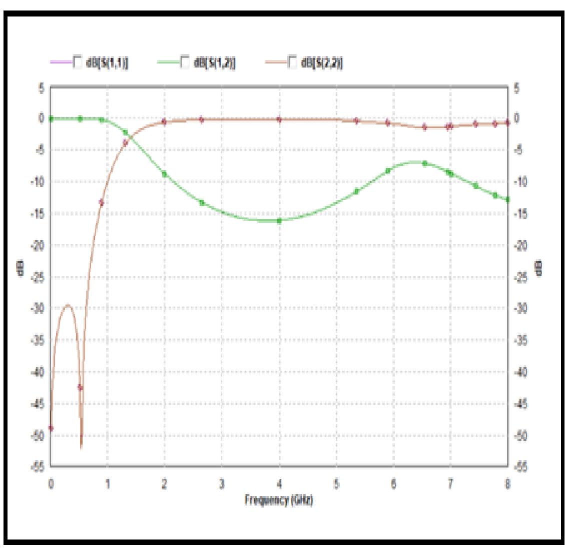


(a)

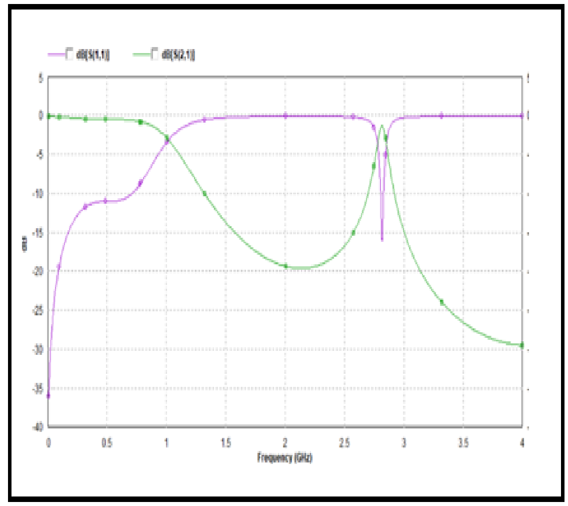


(b)

Fig 2. (a) Microstrip line filter layout for N=3 and (b) Microstrip line filter layout for N=5



(a)



(b)

***Fig. 3. (a)** Simulated Result for N=3 (b) Simulated Results for N=5.*

3 Metamaterial: SRR Structure

Metamaterials (MTMs) are artificial media characterized by constitutive parameters usually not originate in nature whose values can be analyzed to specified values [15]. They have been analyzed mostly as composite artificial media designed by periodic arrays of dielectric or metallic inclusions in a host substrate. The "meta" refers to the final effective properties whose electromagnetic responses are "beyond" those of their constituent materials [16] [17]. It can be explained that how the metamaterials can have counter intuitive properties in their relations with electromagnetic waves, e.g., [4] – [6]. They are considered for application in wide variety of guiding and radiating structures. Particular emphasis will be given to electrically small metamaterial-based resonant radiating systems that arise by designed pairings of conventional materials with metamaterials and that can be used to overcome conventional physical limitations. The structure response in the presence of Electromagnetic field is analyzed by the properties of the materials involved. These properties are defined by considering the macroscopic parameters permittivity and permeability μ of these materials. The classification of metamaterials on the basis of permeability and permittivity is shown in fig. 4

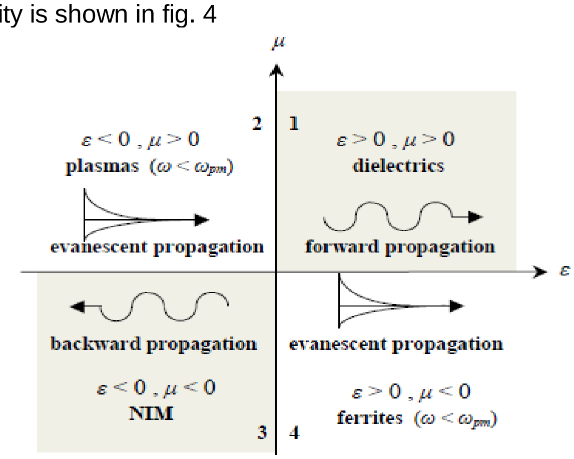


Fig.4. Permittivity(ε) and permeability(μ) diagram

A medium having both permittivity & permeability greater than zero (e > 0, μ > 0) are defined as double positive DPS medium. Most arising media (e.g. dielectrics) fall under this designation. A medium having permittivity less than zero & permeability greater than zero (e < 0, μ > 0) are defined as Epsilon negative (ENG) medium. In certain frequency ranges many plasmas exhibit this characteristic. A medium having both (e > 0, μ < 0) permittivity greater than zero &permeability less than zero are called as μ negative (MNG) medium. In some frequency regions some gyrotropic material shows this characteristic. Double negative (DNG) medium are defined as the having both permittivity & permeability less than zero (e < 0, μ < 0). These type of materials has been demonstrated only with artificial constructs. Important classification of metamaterial includes electromagnetic and acoustic metamaterial. Electromagnetic metamaterial bend and influence electromagnetic waves like visible light waves, microwaves, and infrared waves and these are transverse waves. Negative electric permittivity and negative magnetic permeability is utilized in Electromagnetic metamaterial to control wave propagation. The metamaterial has many different applications in antenna, filter, metamaterial absorber, terahertz modulators. In this paper, we have simulated rectangular structures which are used as metamaterial and frequency response is investigated for this shape.

3.1 Split Ring Resonator Structure

Different metamaterial structures are available for the simulation like circular and rectangular SRR, as shown in fig (5). The split ring resonator (SRR) structure is very common to achieve negative effective permeability and is used widely in designing of metamaterials. They have been widely studied in [13] and [14]. Another different form of the SRR is the Square SRR (S-SRR) which has more degrees of freedom from the design aspect. The SRRs possess large magnetic polarizability and exhibit negative effective permeability for frequencies close to their resonance frequency [14]

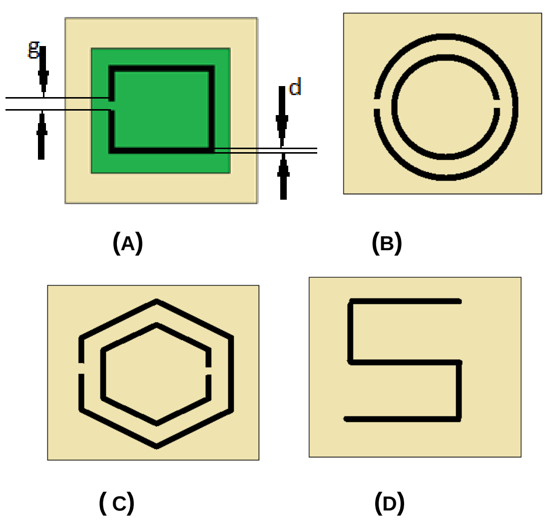


Fig.5. Different Configuration of SRR (A) Rectangular (B) Circular (C) Hexagonal (D)S-Shaped

Many investigators have analyzed the different shapes of split ring resonator (SRR) i.e. circular SRR (C-SRR), square SRR (S-SRR), hexagonal SRR (H-SRR), S-shape SRR (S-SRR) etc. for understanding artificial magnetic material or using the SRR as perturbations for different planar circuit design. Circular and square split ring resonators have been widely studied by [1]- [7]. These different structure like C-SRR, S-SRR and H-SRR has various applications in passive planar circuit design i.e. filter, power divider, duplexers and phase shifter [7]- [11]. The split ring resonators(SRR) has a structure smaller than conventional structure due to this property when SRR is used for planar microwave structures shows low radiation losses and also verifies very high quality factors. One more characteristic of this split ring resonator(SRR) shows strong magnetic coupling when compared with other materials found in nature. And this strong magnetic coupling indicates inhomogeneous fields inside the material. This result in large local field compared to free space in some manner.

3.2 Proposed SRR Structure and Simulated Results

The dimensions of the structure shown in fig (6) are optimized in such a way that it produces the desired frequency response fig (7). The Conventional design for both N=3 and N=5 has been modified using SRR structure. The modification is done in low impedance line by providing the slit gap g=0.5mm and width(d) =0.5mm, as shown in fig (6), fig5(a). The geometric calculation for the modified structure is done manually and simulated using IE3D Mentor Graphics. The simulated frequency response shows the improved values of insertion loss and return loss of about -15.7 dB at 3.1 GHz and -30 dB at 1.97 GHz respectively for N=3, similarly -9.499 at 2.25GHz and -40.76Db at 0.8347 GHz respectively for N=5. This can also be observed from fig (7) that steep roll of factor is obtained. The cut-off frequency for the proposed SRR filter also has been shifted from 1.3 GHz to 3.1 GHz for N=3 and to 2.25 GHz for N=5. The important parameter, roll of factor or selectivity of a low pass filter can be determined using the equation

$$\xi = \frac{\alpha_{min} - \alpha_{max}}{f_s - f_c}$$

Where α_{min} and α_{max} are the -3dB and -20 dB attenuation points respectively and f_s and f_c are the -20 dB stopband and -3db cut-off frequencies respectively. For N=3 the roll off factor is 6.13dB/GHz can be observed from the simulation results fig3(a), and by using the SRR structure for the same, it is improved by 15.45dB/GHz

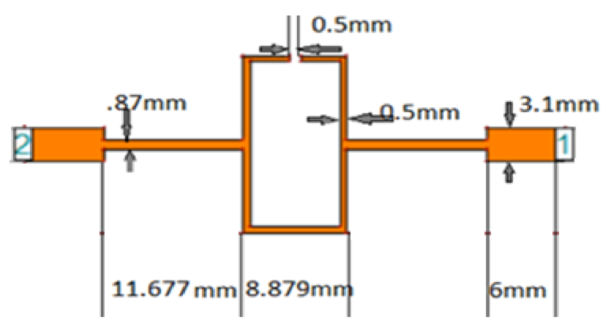


Fig.6.(a) Low Pass Filter Layout for N=3 using SRR Structure

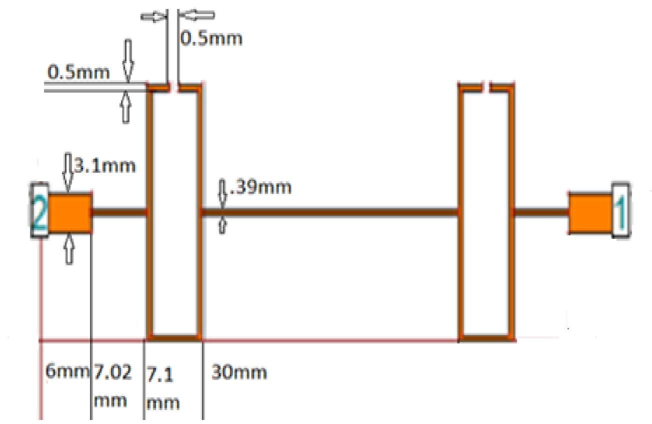


Fig.6.(b) Low Pass Filter Layout for N=5 using SRR Structure

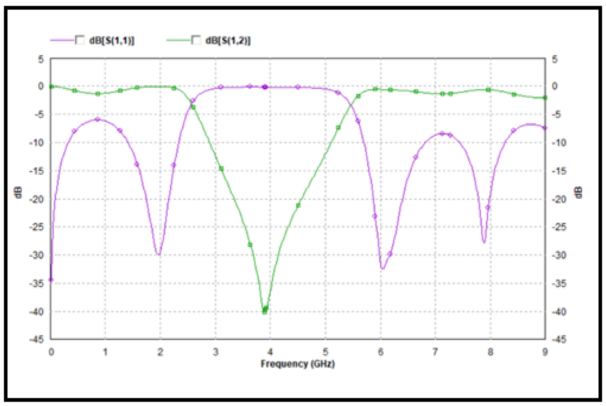


Fig. 7. (a) Simulated Result for SRR N=3

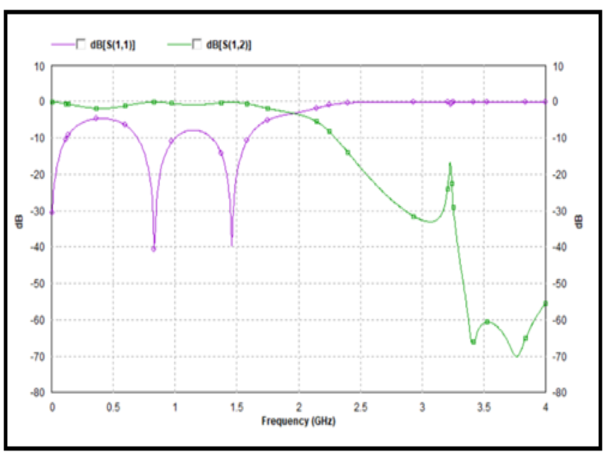


Fig. 7. (b) Simulated Results for SRR N=5

4 Conclusion and Discussion

In this paper a systematic process to study the family of planar structures having negative effective parameters, including left-handed behaviour, has been presented. The designed or proposed structures are based on the SRRs and conventional planar lines. Simulation results for N=3 and N=5 shows the insertion loss, return loss and selectivity for both conventional and SRR structure, and for SRR geometry it can be observed that the insertion loss and return loss has improvement of about -15.7 dB at 3.1 GHz and -30 dB at 1.97 GHz respectively for N=3, similarly -9.499 dB at 2.25GHz and -40.76dB at 0.8347 GHz respectively for N=5. So it can also be concluded that with increase in order of filter and also incorporating SRR geometry the roll off factor increase and thus we have improved selectivity.

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