L- Band Multilayered Microstrip Low -pass Filter Based on Split – Ring Resonators

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Abstract— Size reduction, lower cost and improved performance are the keen interest in the field of Microwave components in recent years. In this paper a new multilayered Microstrip low pass filter is designed keeping all above factors in mind. To improve the performance of the filter, square split ring resonators are fabricated on the top layer while low pass filter is designed in middle layer. In this work a new multilayered Microstrip low pass filter based on SRR with cut off frequency 2GHz is presented .The Metamaterial has the advantage of compact size with ability to provide improved performance. A comparison between a simple Microstrip low pass filter with a new modified design of multilayered Microstrip low pass filter based on split ring resonator has been done. The return loss has improved significantly both in pass band and stop band.

Key words: Split – Ring Resonators, L- Band Multilayered Microstrip Low -pass Filter

I. INTRODUCTION

An ideal filter is a linear 2-port network that provides perfect transmission of signal for frequencies in a certain pass band region, infinite attenuation for frequencies in the stop band region and a linear phase response in the pass band (to reduce signal distortion). The goal of filter design is to approximate the ideal requirements within acceptable tolerance with circuits or systems consisting of real components. The Metamaterial or artificial electromagnetic materials are those materials that do not have any natural occurrence in nature [1-3]. They offer special and distinct qualities that natural materials do not have. Metamaterial is a material which gains its properties from its structure. Materials have simultaneously negative permittivity and negative permeability [4]. These Metamaterial were first introduced by Veselago in 1967[5, 6]. In the year 1999, Professor John Brian Pendry proposed his design of thin wire structure that exhibits the negative value of permittivity and split ring resonator with a negative permeability. Dr.Albert Smith from Duke University combined the two structures and became the first to fabricate the metamaterial [7, 8], it has been shown that both negative permeability and negative permittivity can also be obtained by means resonant element CSRR introduced by Falcone et at in 2004[9]. These resonator can be considered as quasi lumped elements and are, very important for reduction of size of planar Microwave devices such as filters and duplexers and for improving their performance. Metamaterials in filter application are based on resonant type metamaterial transmission line. A low pass filter is a filter that passes low frequency signals and attenuates higher frequency signals above a cut off frequency [10].The proposed filter is applicable in L-band which varies from 1 GHz to 2GHz. The main objective of this paper is to demonstrate that by using periodic structure of sub wavelength order dimensions, the performance of the filter can be improved both in pass band and stop band.

II. FILTER DESIGNING

The dimensions of Microstrip lines and characteristic impedance depend upon the dielectric constant of the material used. To design a low pass filter, there are two steps. In first step appropriate low pass filter prototypes which are normalized in terms of impedance and frequency are selected and then these Low pass prototypes are scaled to the desired frequency and impedance to get the desired result. Normally source impedance is 50 ohms for Microstrip filters. In second step the lumped-element components are replaced with distributed circuit elements for implementation at microwave frequencies [11].

A. Design specifications for the filter under consideration are

Relative Dielectric Constant, \( \varepsilon_r = 4.3 \)
Cut-off frequency, \( f_c = 2GHz \)
Height of substrate, \( h = 1.6 \text{ mm} \)
\( Z_0 = 50 \Omega \)

Fig. 1: Low pass prototype network with five components

The parameters of the Microstrip filter are calculated from the formulas proposed below:

For \( w/h<=1 \)
\[
Z_o = 60 \cdot \frac{60}{\varepsilon_r} \ln\left(\frac{\beta h}{w} + \frac{w}{4h}\right) \quad \text{(1)}
\]

For \( w/h>1 \)
\[
Z_o = \frac{120\pi}{\sqrt{\varepsilon_r \left(\frac{w}{h} + 1.393 + 0.667 \ln\left(\frac{w}{h} + 1.444\right)\right)}} \quad \text{(2)}
\]

With
\[
\varepsilon_r = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \frac{1}{\sqrt{\frac{1+12h}{w}}} \quad \text{(3)}
\]

The \( w/h \) ratio to determine Microstrip line impedance:

For \( w/h<2 \)
\[
w = \frac{\varepsilon_r A}{\pi} \quad \text{(4)}
\]

With
\[
A = \frac{Z_o}{60} \sqrt{\frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{\varepsilon_r + 1} \left(0.23 + \frac{0.1}{\varepsilon_r}\right)} \quad \text{(5)}
\]

For \( w/h>2 \)
\[
w = \frac{2}{\pi} \left[B - 1 - \ln(2B - 1) + \frac{\varepsilon_r - 1}{2\varepsilon_r} \left[\ln(B - 1) + 0.39 - \frac{0.61}{\varepsilon_r}\right]\right] \quad \text{(6)}
\]
With
\[ B = \frac{377\pi}{2\mu_0 \nu_0} \]

The values of the components of low pass filter are determined by following equations.
\[ L_i = \left( \frac{Z_o}{g_o} \right) \left( \frac{W_c}{2\pi f_c} \right) g_i \]
\[ C_i = \left( \frac{g_o}{Z_o} \right) \left( \frac{W_c}{2\pi f_c} \right) g_i \]
Where normalized cut off \( w_c = 1.0 \)

The length of the line of inductors and capacitors are calculated with following formulas:
\[ l = \frac{(L/C)(3.10^8/\sqrt{\varepsilon_f})}{\text{Length (mm)}} \]
\[ l = \frac{(C/Z_c)(3.10^8/\sqrt{\varepsilon_f})}{\text{Width (mm)}} \]

L: Value of the inductance
C: Value of the capacitor

<table>
<thead>
<tr>
<th>Components</th>
<th>Length(mm)</th>
<th>Width(mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>11 = 0.765</td>
<td>0.6</td>
</tr>
<tr>
<td>L2</td>
<td>12 = 8.3</td>
<td>0.3</td>
</tr>
<tr>
<td>C3</td>
<td>13 = 8.4</td>
<td>0.7</td>
</tr>
<tr>
<td>L4</td>
<td>14 = 8.3</td>
<td>0.3</td>
</tr>
<tr>
<td>C5</td>
<td>15 = 0.765</td>
<td>0.6</td>
</tr>
</tbody>
</table>

Table 1: Dimensions for a stepped-impedance low-pass filter

Fig. 2: Layout of a stepped-impedance Microstrip low pass filter on a substrate with \( \varepsilon_r = 4.3 \) and height = 1.6 mm

The simulated S11 and S21 results of the stepped-impedance Microstrip low pass filter is shown in Fig.3.

Fig. 3: Simulated S11 and S21 results of the stepped-impedance Microstrip low pass filter

III. DESIGN AND SIMULATION RESULTS OF THE MICROSTRIP LOW PASS FILTER WITH SPLIT RING RESONATORS

In 2001, Shelby, Smith, and Schultz used arrays of wires (giving rise to negative permittivity) and split-ring resonators (giving rise to negative permeability) at Microwave frequencies [1]. Split ring resonator is a set of two set of concentric planar rings with splits in Them at opposite ends, printed on a thin dielectric substance. SRR demonstrates a quasi-static resonance by virtue of the distributed capacitance between concentric rings and overall rings inductance. This behaves as an LC resonator with distributed inductance and capacitance [12]. A CSRR is the negative image of a SRR etched on the ground plane of substrate. With adjustment of the size and geometric parameters of the SRR, the resonant frequency can be easily tuned to the desired value. Fig. 4(a) shows the Dimensional view of the split ring resonator. The proposed low pass filter is designed on Middle layer using CST software while the split ring resonator structures are fabricated on the Top layer. The Middle layer and transparent view is shown in fig. 4(b) and fig.4(c).

Fig. 4 (a): Top layer with SRR structure

Fig. 4 (b): Middle layer of low pass filter

Fig. 4 (c): Transparent view of Microstrip low pass filter with Middle and upper layers

The simulated results reflection coefficient S11 and transmission coefficient S21 of micro strip low pass filter with split ring resonator is shown in fig.5.

Fig. 5: Simulated results of S11 and S21 using split ring resonator
IV. COMPARISON BETWEEN SIMPLE MICROSTRIP LOW PASS FILTER AND MICROSTRIP FILTER WITH SRR

![Comparison of S11 with and without resonator](image)

Fig. 6: Comparison between S11 with and without resonator

It is clear from the above comparison (from fig. 6) that both reflection coefficient S11 and transmission coefficient S21 has been improved for new Microstrip filter with SRR as compared to conventional low pass filter.

V. CONCLUSION

This work has presented a study of Microstrip low pass filter by using metamaterial structures. The paper proposes improved performance low pass filter by using metamaterial structure. The new design has been compared to conventional microstrip low pass filter. The reflection coefficient of the proposed filter has been improved significantly both in pass band and stop band.

ACKNOWLEDGMENT

The authors would like to thank Professor Dr. P. K. Singhal, Head of department of Electronics and Communication, MITS, Gwalior and all the faculty members of, department of electronics and Communication for their helpful discussion.

REFERENCES