# Design of Low Pass Filter for Ultra Wide Applications Using Metamaterial Structures

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***Abstract:*** This paper presents the design of low pass filter by using metamaterial structure. The metamaterial structure is used for size reduction purpose. The proposed filter covers whole ultra wide band hence it can be used for front end device for UWB components. The characteristics of low pass filter are analyzed by S-parameter graph and VSWR graph which is obtained by simulating the design in CST simulation software. One of the types of unit cell in metamaterial structure that is uni-planer complementary split ring resonator is used in this paper and it is etched on top plane of microstrip line.

***IndexTerms - Metamaterial, Low pass filter, Ultra wide band, Uni-planer CSRR,S-parameter, VSWR.***

## I.INTRODUCTION

Metamaterials are materials that are not found in nature. They are made by artificial structures of unit cells which are arranged in periodic way. Some metamaterials are the combination of resonator cells and wires [7]. This materials are made by arranging pattern of cells repeatedly which are at the scale smaller than wavelength of operating frequency. Metamaterials derive their properties according to their shape of structure instead of their base material. Metamaterials have some smart properties which are responsible for guiding electromagnetic waves and these smart properties are achieved by their precise shape, size, orientation, geometry and arrangements [8]. The benefits like blocking, absorbing, enhancing, or bending of electromagnetic waves which are not possible in conventional material are achieved by metamaterials. The metamaterials which have both permittivity and permeability are negative also called as left handed metamaterials (LHMs). This type of metamaterials is employed on top plane of microstrip line for designing of low pass filter and whose properties are depends on value of capacitor and inductor which gives negative permittivity and permeability. The filter with compact size and new configuration of complementary split ring resonator is proposed which is flexible design for operating frequency. The left handed properties are realized by etching CSRR cells on top plane of microstrip line. Such configurations are proposed in number of microwave applications [1]. The new configuration of split ring resonator has negative refractive index profile. The filter performance is investigated using CST simulation software. Now this filter is designed for ultra wide band applications [9]. The federal communication commission (FCC) assigned frequency band from 3.1GHz to 10.6GHz in 2002. FCC also assign low power spectral density around -41.3dBm/MHz for UWB transmitters so there is very big challenge of designing front end devices with low power loss for UWB band. The size reduction is also another challenge for UWB components [9]. So in this paper we proposed design of low pass filter which covers whole ultra wide band with compact size.

## II.FILTER DESIGN CONCEPT AND PROCEDURE

### 2.1 Design Of Conventional CSRR cell

The general CSRR cells are used many applications. The CSRR cell means complementary split ring resonators which is counter part of simple split ring resonator. The conventional CSRR cell is used in previous paper [1] has some drawback like difficult to design. Now we will see how to design conventional CSRR cell.

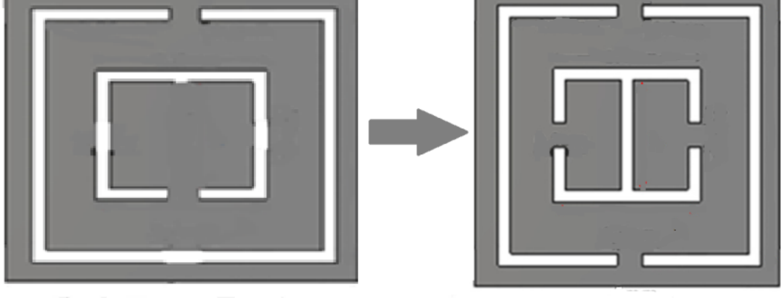

***Fig.1: Conversion of General form of CSRR cell into conventional CSRR cell***

 

The conversion of general form of CSRR cell is shown in Fig 1 which can be converted into conventional CSRR cell. The conventional CSRR cell consists of outer split ring and inner split ring. The inner split ring is subdivided into two split ring by substituting slotted strip in the middle side which increases capacitance value in equivalent circuit.

### 2.2 Design of new configuration CSRR cell

The conventional CSRR cell is modified in this paper into new configuration of CSRR cell which is shown in Fig 2.

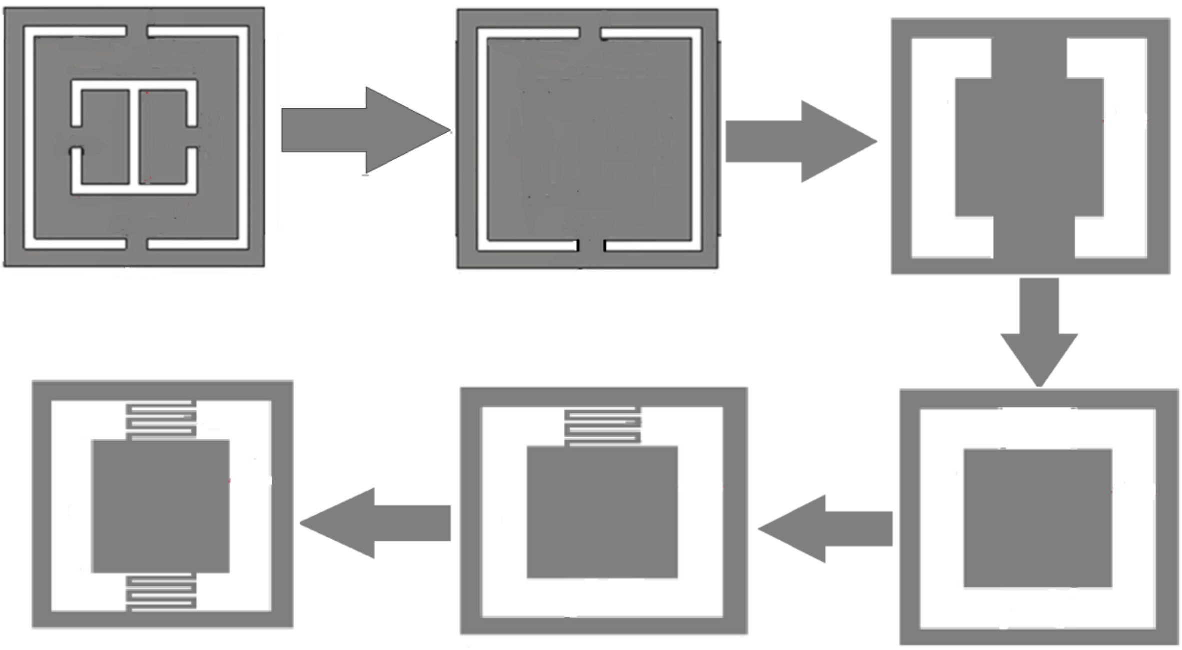

*Fig .2: Modification Of Conventional CSRR cell to new configuration of CSRR cell*

The conventional CSRR cell is modified into new configuration of CSRR cell in stepwise manner. The steps are given below:
Step 1: The inner sub rings in conventional CSRR cell are removed.
Step 2: The outer ring has some size which has been increased to increase cell capacitance which reduces the resonance frequency.
Step 3: The continuous slot is obtained for adding inter digital capacitors.
Step 4: The addition of inter digital capacitors in upper and lower air gap of outer ring for increasing cell capacitance.
In this way we have designed the new configuration of CSRR cell in stepwise manner.

### 2.3 Design of inter digital coupled lines

We have seen design of CSRR cell in step wise manner. In step 4 we have added inter digital coupled lines or it is also called as inter digital capacitors are added in CSRR cell [11]. These inter digital coupled lines are used for raising value of cell capacitance. The structure of inter digital coupled lines is shown in Fig 3.

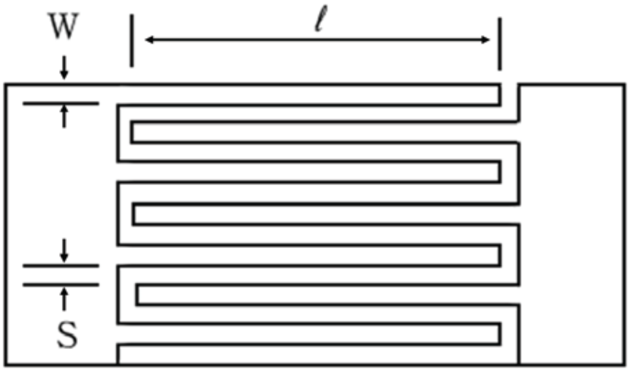


*Fig.3: The structure of inter digital coupled lines*

 

The value of capacitance is increase when this structure is added to any type of structure. When the value of capacitance is increases the resonance frequency is decreases. Resonance frequency means the frequency at which the value amplitude or gain is suddenly changes (increase or decrease). This type of structure is mostly used in metamaterial structure design. In fact metamaterial structure consists of periodic pattern of strips or it can be periodic pattern of cells which are arranged on microstrip. The value of capacitance of given structure can be given by following formula:

$$C(pF) = \frac{\epsilon_{rg} 10^{-3}}{18\pi} \frac{K(k)}{K'(k)} (n_{IDF} - 1)$$

Where,

$$k = tan^2\left(\frac{a\pi}{4b}\right), a = \frac{W}{2}, b = \frac{W+S}{2} \qquad (2)$$

Where 'W' is width of slotted strip and 'S' is width of copper strip respectively which is shown in Fig 3. The new configuration of CSRR cell and its equivalent circuit is shown in Fig 4. Here the value of 'W' and 'S' is taken as 'g/11' where 'g' is the size gap between inner loop and outer loop. The slot in the CSRR cell represent the value of capacitance and slotted strips in inter digital coupled lines causes increase in value of capacitance. The copper area represents value of inductor.

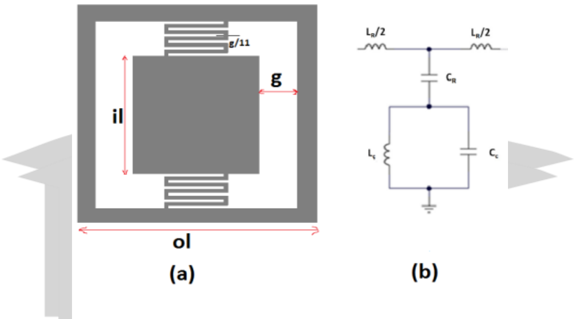


*Fig.4 (a) Structure of unit cell (b) Equivalent structure of unit cell when etched on microstrip*

### 2.4 Design of proposed low pass filter

The simple microstrip line is described by series inductor LR and Capacitor CR and equivalent circuit of CSRR is parallel tank circuit of inductor Lc and capacitor Cc. The shunt inductance gives the effect of negative permittivity and CSRR cell when loaded with microstrip line gives the realization of left handed properties of metamaterial. The proposed CSRR metamaterial filter is shown in Fig 5. The uni-planer CSRR cell [2] is etched on top plane of microstrip line and hence the total equivalent structure is shown in Fig 4 (b).

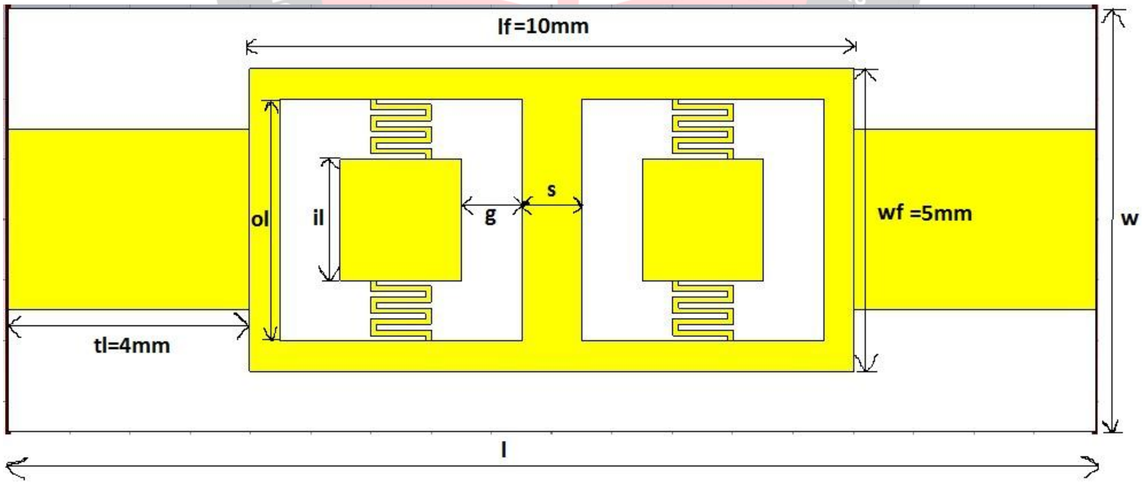


*Fig.5: Structure of proposed filter.*

**Table 1**: Dimension of Proposed Filter

| Name | Value | Description |
|---|---|---|
| ol | 4 mm | Length of outer loop |
| il | 2.5mm | Length of inner loop |
| l | 18 mm | Length of substrate |
| w | 7 mm | Width of substrate |
| t | 1.52mm | Thickness of substrate |
| g | ol/2-il/2 | Gap between outer and inner Loop |

| | | |
|---|---|---|
| ct | 0.035mm | Thickness of copper |
| $\varepsilon_r$ | 3 | Relative permittivity of Rogers 3003 |
| lf | 10 mm | Length of filter |
| wf | 5 mm | Width of filter |
| s | 1 mm | Spacing between two cells |
| tl | 4 mm | Length of transmission line |
| tw | 2.98mm | Width of transmission line |

Since there is nothing etched in ground plane for good housing purpose. The cut-off frequency of low pass filter can be varied according to variation in gap. The inter digital capacitor can be added in gap for lower operation of frequency as well as for increasing left handed properties without increasing the size of CSRR cell. Also it is noticed that in conventional CSRR cell there are two split rings are present but in case of this CSRR cell only one ring is present and inter digital capacitors are added in the gap. The inter digital capacitors are described by zigzag pattern of copper strips which increase the cell capacitance as well as left handed properties of metamaterial. The filter is loaded with 50 ohm transmission line. The overall filter size is around 18×7 $mm^2$ which is very compact size. The CSRR cell is formed by employing only one ring instead of two rings for size reduction. The addition of inter digital capacitors is done for reducing resonance frequency. If we studied response of filter when filter is operating at lower frequency at that time impendence of parallel tank circuit is low or it can be short circuited and hence there is maximum power transfer is occurred and there is pass band characteristics at lower frequency. When the frequency goes on increasing the impendence of parallel tank circuit goes on increasing. When frequency reaches near to cut off frequency the impendence become highly inductive load and there minimum transfer of power is occurred and stop band characteristics are observed after cut off frequency. The amount of attenuation is based on number of cells etched on top plane of microstrip line. The characteristics of low pass filter can be analyzed by single cell but two cells are etched on top plane for good attenuation in stop band. The substrate used for filter is Rogers 3003 with relative permittivity of 3 and thickness is around 1.52 mm. The cut off frequency is taken as 10.6GHz so that it can be used for ultra wide band applications. The value of inductor 'Lc' is taken as 0.2254uH and value of capacitor 'Cc' is taken as 0.001pf.The resonance frequency can be calculated by following formula.

$$f0 = \frac{1}{2\pi\sqrt{LcCc}} \quad (3)$$

The design formulae are shown below:

$$Cc = [l - 1.5(2 + g)] \quad (4)$$

$$Lc = \frac{4.86\mu 0}{2}(lf - wf - g)[\ \ln\left(\frac{0.98}{\rho} + 1.84\rho\right)\ ] \quad (5)$$

$$\rho = \frac{wf + g}{lf - wf - g} \quad (6)$$

Where 'lf' is length of filter, 'wf' is the width of filter and 'g' is the gap between outer loop and inner loop.

### III. RESULTS AND DISCUSSION

The filter performance can be extracted by CST simulation software. The simulated s-parameters are extracted which are shown in Fig 6.

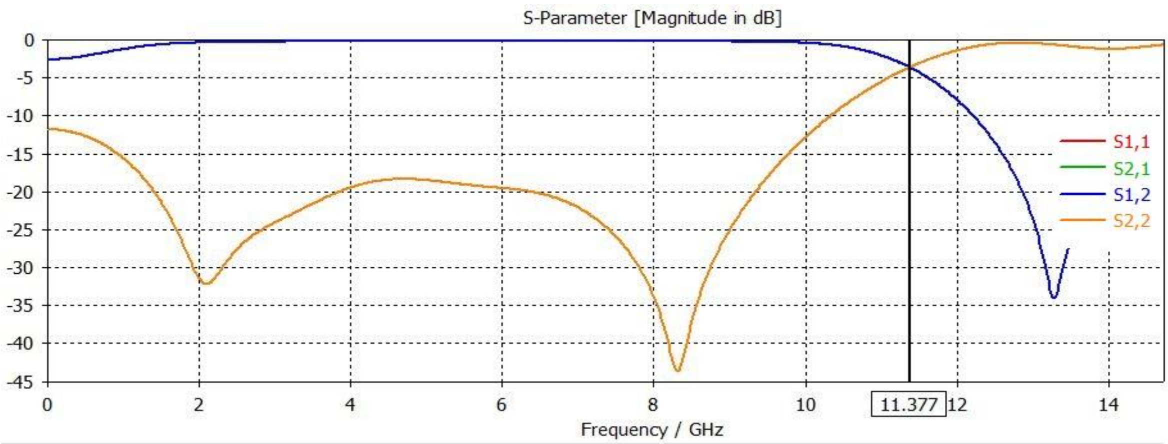


*Fig.6: Scattering parameters of proposed low pass filter*

The result shows that S-parameters graph in which S21 parameter is the ratio of output power to input power in which we give input power at port 1 and output power is measured at port 2 or it can be say that S12 parameter is the ratio of output power to input power in which input power is given at port 2 and output power is measured at port 1. Generally the values of S12 and S21 are same [6]. These parameters are measured in decibel unit. In Fig .6 we observed that S21 parameter is around 0dB from 0GHz to 11.377GHz. Now we know that S21 parameter is 0dB means input power is equal to output power hence there is maximum power transfer is occurred from 0GHz to 11.377GHz. The same concept can be described for S12 parameter. In case of S11 parameter which is ratio of output power to input power in which we give input power to port 1 and output power is measured at same port that is port 1 [6]. Now output power is appeared at port 1 also called as reflected power. The reflected power is appeared due to impendence mismatch in filter. Hence the value of S11 parameter should be as small as possible. The same concept is applicable for S22 parameter. The S-parameter graph show that the value of S11 and S22 is less than -10dB in pass band which is sufficient for maximum power transfer in pass band. The value of S11 and S22 is 0dB beyond cut-off frequency that means there is maximum reflection is occurred and hence less power is transferred at the output of filter. The characteristics of low pass filter can be described by VSWR graph which shown in Fig 7.

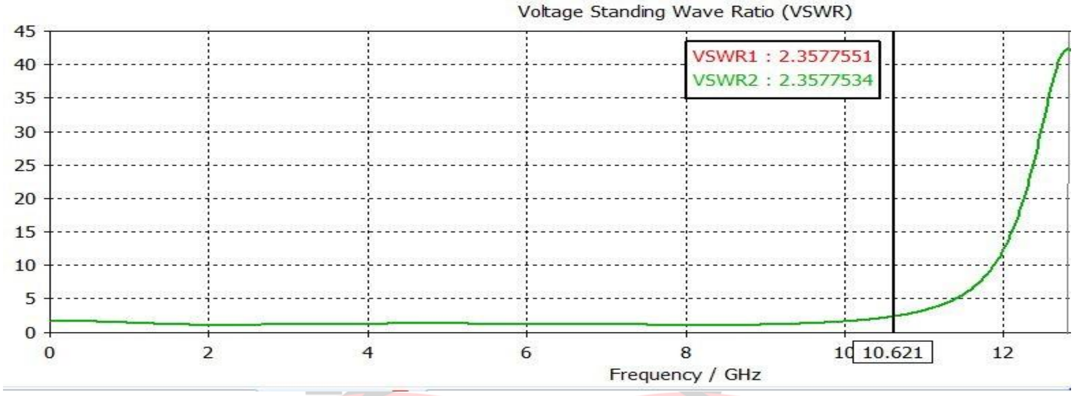


***Fig.7: Simulated VSWR graph of Low pass filter.***

The VSWR graph shows that the value of VSWR that means voltage standing wave ratio is less than 3 up to 10.6GHz which is sufficient for power transfer. We know that ideal value of VSWR is 1 which means that there is zero reflection power [10]. This graph as shown in Fig 4 consist of value of VSWR is around 1 to 3 which shows pass band characteristics from 0GHz to 10.6GHz that can be covers whole ultra wide band. We know that VSWR describes how much power is reflected or it can be say that VSWR is the function of reflection coefficient. When the value of VSWR is 1 at that time total power is transferred and zero power is reflected. When value of VSWR is around 3 there is 25% power is reflected and 75% power is transferred. The VSWR graph shows that the value of VSWR is around 3 at 10.6 GHz that means 25% power is reflected at that frequency which is sufficient for pass band characteristics.

## IV.CONCLUSION

The paper presents the use of metamaterial structure for designing of low pass filter with compact size. The concept of metamaterial is utilized for filter designing in which metamaterial has negative permittivity and permeability at resonance frequency. The propagation of signal is reversed at resonance frequency where value of permittivity and permeability is negative and this causes minimum transfer of power. Hence it shows stop band characteristics after resonance frequency. The CSRR cells are already used for filter designing purposes in previous papers but in this paper there is a use of new configuration of Uni-planer CSRR cell for designing of low pass filter. This cell consists of single ring in which inter digital capacitors are added in gap for size reduction purpose. Also this cell is very simple to design as compared to conventional CSRR cell. The proposed filter covers ultra wide band which can be characterized by S-parameter curve and VSWR curve.

## V.ACKNOWLEDGMENT

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