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A NEW METAMATERIAL BANDPASS FILTER FOR WIRELESS APPLICATIONS

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ABSTRACT

The wireless communication systems are developing and gaining a wide interest in designing RF components like antennas and filters with special features. Here a concept of creating materials with new functionalities and properties by achieving size reduction is discussed. The known concept metamaterial is the one which inculcates all the above mentioned features. In this paper a CPW bandpass filter is proposed by introducing the negative refraction effect in the normal substrate. It was named as novel because of achieving negative effects from the normal substrate material with a compact circuit size of the structure. A coplanar waveguide transmission line is loaded with complementary split ring resonators for providing the structure with negative effects. The proposed filter is simulated and characterized using Method of Moments based IE3D simulator. The designed filter covers the band of 4 to 6.8 GHz with the return loss of ≤ -40dB and the -0.2dB insertion loss. The size of the filter is about 12 x 10 mm^2. With the above properties the proposed negative indexed so called metamaterial filter can be used for the Fixed Wi-max application, IEEE 802.16-2004.

Key words : Bandpass Filter, metamaterial, Wi-Max, CPW feed, CSRR, SIR.

1. INTRODUCTION

In the latter years, the possibility of taking advantage of the unusual properties of the so-called metamaterial technology has led to a great deal of research activity. For instance, many efforts have been aimed at reducing the size and improving the performances of, among others, phase shifters, baluns, couplers, power dividers and filters [1]. In the above cases the achievement of both negative permittivity and permeability in a given frequency range by an appropriate engineering of the dispersion characteristics [2]. At microwave frequencies, a medium that supports backward wave propagation can be fabricated from a transmission line loaded with split-ring resonators (SRRs) [1]-[3] and/or reactive elements [4],[5]. Such loading elements enable one to efficiently control the response characteristics simply by adjusting its dimensions and the position.

These structures generally incorporate resonant particles such SRRs, open SRRs (OSRRs), and their dual counterparts [i.e., complementary split-ring resonators (CSRRs) or open CSRRs] [6],[7]. Due to the resonant nature of these transmission lines, special efforts have been made to the synthesis of artificial lines exhibiting improved (i.e., wider) bandwidths. A broadband response can be obtained when the right- and left-handed behaviour coincide. This is known as the balanced composite right/left-handed (CRLH) response [8].. The frequency selectivity of a coplanar transmission was improved using the split ring resonators with a higher rejection level, increasing the Q factor[10].

A coplanar transmission line with split ring resonators exhibited a high bandpass response with right handed characteristics [9]. An improved lumped model of split ring resonators with a pi-network , and implemented an improved left-handed behavior[13]. The structure model of complementary split ring resonators were discussed with both circular and rectangular complementary split ring resonators demonstrating the left-handed behavior[16].

The right handed behavior was analyzed with split ring resonators connected in series, shunt wired and were demonstrated to operate on C-band. It had a effective control on phase and magnitude responses [12]. An edge-coupled SRR's and broadside coupled SRR's were demonstrated for measuring the polarisabilities of split ring resonators[15]. Generally, this kind of periodically loaded line has compact dimensions, due to the electrically small size of the resonators used. It also yields low insertion loss characteristics and a broad fractional bandwidth.

In this paper a bandpass filter is proposed using the coplanar waveguide (CPW) transmission line. The CPW bandpass filter is simulated using IE3D simulator. The CPW transmission line is loaded with complementary split ring resonators(CSRR's). Since the CPW transmission line has ground plane and conducting plane on the same side of the substrate, there is no need of via holes for connecting to the ground.

2. PROBLEM FORMULATION

When analyzing all the designs proposed in all these years for the WLAN application, it is evident that the size of the components play a major role in deciding the operating frequency. This size reduction field is gaining a wider interest among the researchers. Eventhough there are a lot of techniques followed for miniaturizing concept, Metamaterial gained a wider interest. This paper proposes a bandpass filter for the Wi-Max application (4-6.8GHz), in a miniaturized size and well improved performance using the negative indexed materials concept.

3. METAMATERIAL CPW BANDPASS FILTER

A CPW bandpass filter is proposed here. Two stepped impedance resonators are used in either sides of the conducting plane. These resonators are useful in getting a better resonance at the desired frequency.

The CPW transmission line is loaded with circular shaped complementary split ring resonators. Here a pair of complementary split rings are used for producing a good negative effect in the structure. Here FR-4 substrate is used for designing the bandpass filter. The value of the dielectric constant (ε_r) used is 4.4. The thickness of the substrate is chosen as 0.8mm. The designed bandpass filter was analyzed by considering the filter characteristic parameters like insertion loss and return loss.

Here a coplanar transmission line is considered because of non-requirement of via-hole grounding in the structure. Moreover, the coplanar transmission line encourages less dispersion effect in the structure and enhances the filter's efficiency. Metamaterials are characterized by a negative effective permeability and negative effective permittivity. Continuous media with negative parameters, are those media with negative dielectric constant "ε", and magnetic permeability "μ". Wave propagation in media with simultaneous negative ε and μ, is called as left- handed media[1].

The coplanar line has an advantage , is the ability to connect active and passive circuit components in shunt from the conducting strip to the ground plane on the same side of the substrate. The structure was formed on the FR-4 material since , it is lossy at high frequencies, absorbs less moisture, has greater strength and stiffness and is highly flame resistant compared to its less costly counterpart. The FR-4 has a loss tangent (δ) = 0.019 , and the conductor thickness was considered to be t=0.035mm.

The designed filter is estimated to have a circuit size of (12 x 10)mm^2 . Here the signal plane was divided into two sections on the top and bottom side of the upper portion of the conducting material (Fr4). The circular shaped CSRR's were placed on top layer[1]. The simulated structure of the proposed filter with their design considerations are discussed below. The designs were simulated using Method of Moments based IE3D simulator

A. Design and Simulations

The design was considered to have two divisions in the strip and it was exited with a full port impedance(Z_c) of 50Ω. Since the design was simulated using a coplanar transmission line, there was no necessity of separate wiring for grounding the components. The design is shown in figure 2. The circuit size of the structure was (12x10)mm^2. Here the strip was composed of a stepped impedance resonator (SIR) . The dimensions of each resonator was of length 4.6mm and the width(W_1) of the SIR was of 0.2mm and the width (W_2) is 0.4mm. The width and the spacing between the SIR and the strip is also considered as 0.2mm. The effective dielectric constant was calculated using

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} \qquad (1)$$

The value of ε_{eff} of the substrate was found to be 2.7. The split ring resonators used here was of the following measurements

(i) inner radius 1.1mm ,
(ii) the outer radius is 1.2mm.

The width of the split ring resonator was considered as 0.1mm. The second ring is placed with a spacing of 0.1mm and the measurements were

(i) inner radius is 0.9mm,
(ii) outer radius is 1mm.

In the structure all the width and the spacing between the split ring resonators and the SIR wereconsidered to be equal. These equal spacing helped in increasing the capacitive effect in the structure.

The split ring resonators (SRR) were considered in complementary form,ie., the copper part of the rings which were placed on the ground plane were etched from it. They were known as Complementary Split Ring Resonators (CSRR's) , which are capable of performing ex-or operation in the structure [1],[6]. These are the dual counterparts of the split ring resonators.

The design offered a return loss (RL) greater then -40dB and insertion loss (IL) of -0.2dB. The output of the above discussed design is shown in figure 3. It covered operating frequency of 5.8GHz, and thebandpass response obtained was found to satisfy the wireless application named fixed Wi-max.

B. Analysis Of the Proposed Design

The proposed design is analysed using a various number of complementary split rings in the ground plane. The dual counterpart of the split ring resonator is called the complementary split ring resonator, shown in figure 1.

The creation of new components with new functionalities and properties has a wide concentration in these years. Moreover, realizing a component for practical applications in a miniaturized size plays a vital role in communication. So dealing with these considerations, metamaterial gained its importance in the field of design of RFIC , RFID components. The above designed filter is designed using the metamaterial concept. It was tested for the metamaterial effect using MATLAB. The achievement of negative permeability and permittivity values were found to be in the obtained simulated band. These were plotted and is shown in figure 4 and 5.

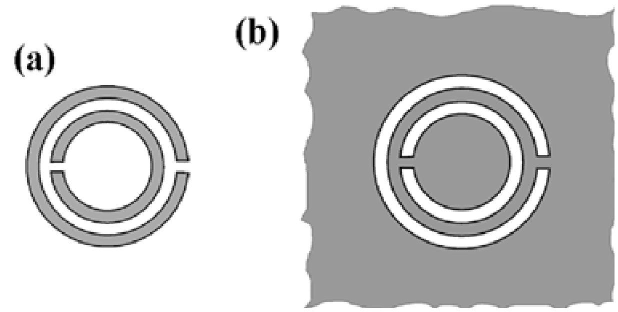

Figure1: (a) Split ring resonator (SRR), (b) Complementary Split Ring Resonator(CSRR).

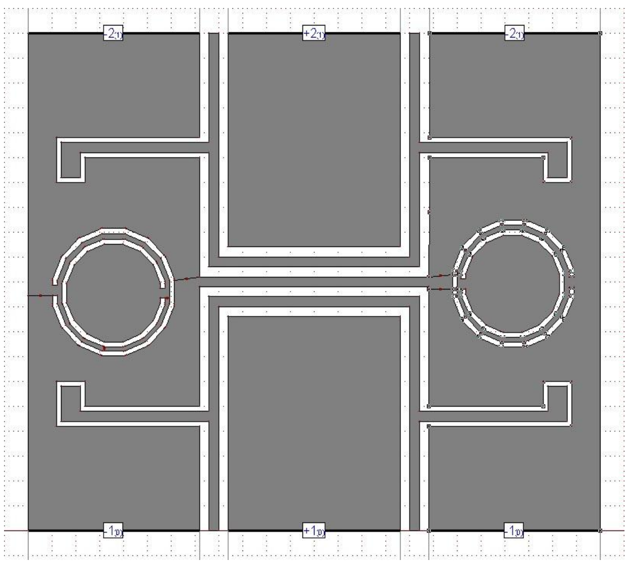

Figure 2: Proposed Structure of CPW Bandpass Filter

The dual counterparts of the split rings helps in achieving the required band with a good S_{11} parameter value. The numerical analysis of the structure was done by using the Method of Moments based IE3D simulator. The SIR's were placed in the structure accordingly that they were made to face each other (refer figure 2). The use of stepped impedance resonator in the structure enhances the resonance frequency due to varying impedances. The structure was tested for the negative effects. The negative refraction is tested by using the formula given below

$$n = -(\mu\varepsilon) \quad (2)$$

where μ is the permeability,
ε is the permittivity.

The above mentioned structure was tested for its negative effects by using the formula given below

$$n= (1/1.6)\{acos/2S_{21}(1-S^2_{11}-S^2_{21}\ )\} \quad (3)$$

$$z=\sqrt{}\{((1+S_{11})^2-S^2_{21})/((1-S^2_{11})-S^2_{21})\} \quad (4)$$

where z is the impedance value.

The impedance values available in the stepped impedance resonators used are calculated as follows. Since the widths of the resonators vary, at the portion of higher width the impedance will be less than the impedance value with less width. The width (W_1) is considered as 0.2mm and the width (W_2) is considered as 0.4mm (refer the dimensions of figure 2). The height (h) of the structure is assumed as 0.8mm. So by using the values mentioned , the characteristic impedance (Z_1) is found to be 105Ω , and the characteristic impedance (Z_2) is calculated as 86.83Ω.

The impedance values Z_1 and Z_2 are calculated for the corresponding values of the widths $W_1$and W_2 , respectively. From the calculated values it is evident that the impedance values varies in the stepped impedance resonators ($Z_1>Z_2$) as mentioned before.

The negative permittivity (ε) and permeability (μ) values were achieved at the frequency covered . The results shown in the figures 4 and 5, stands as the proof for the negative refractive effect , is possessed by the structure proposed. Hence from the results it is evident that the designed coplanar waveguide bandpass filter exhibited the negative effect so-called the metamaterial effect.

The guided wavelength (λ_g) is calculated as 45.7mm. The fractional bandwidth was calculated from the simulated band, and it was found to be 51%. The electrical size is calculated from the overall circuit size $(12x10)mm^2$, and was found to be ($0.26\lambda_g$ x 0.21 λ_g) offered a good performance with better return loss and insertion loss characteristics.

4. ANALYSIS OF THE PROPOSED CPW BANDPASS FILTER

The above shown structure in figure 1 is simulated using IE3D simulator and the output obtained by simulating the structure is shown in figure 2. IE3D is an integral full-wave electromagnetic simulation and optimization packages for analysis and design of 3D and planner microwave circuits MMIC, RFIC,RFID, antennas ,digital circuits and high speed printed circuit broads(PCB). IE3D has been adopted as industrial standard in planner and 3D electromagnetic simulation.

The bandpass filter so designed is found to operate and can also be applicable for Fixed Wi-max application and it was found that the bandwidth exhibited by the filter was 259 MHz. The return loss being the superficiary factor in deciding the performance of a RF/microwave component, the return loss is found to be of higher value, ie., the designed filter achieved an acceptable return loss of -43dB, with the consideration of compact size. The overall circuit size is estimated to be $(12x10x0.8)mm^3$.

The height of the substrate is so chosen that it helps in avoiding spurious response in the structure. The thickness of the substrate plays a major role in deciding the performance of the RF components.

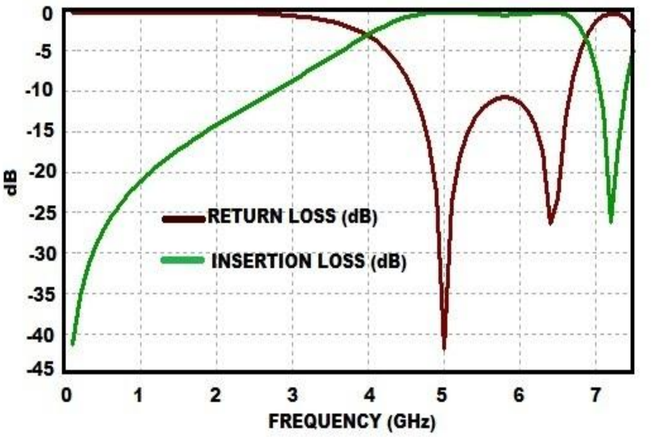

Figure 3: Simulated result of the proposedbandpass filter, simulated using IE3D simulator. It shows that it achieved a RL < -40dB.

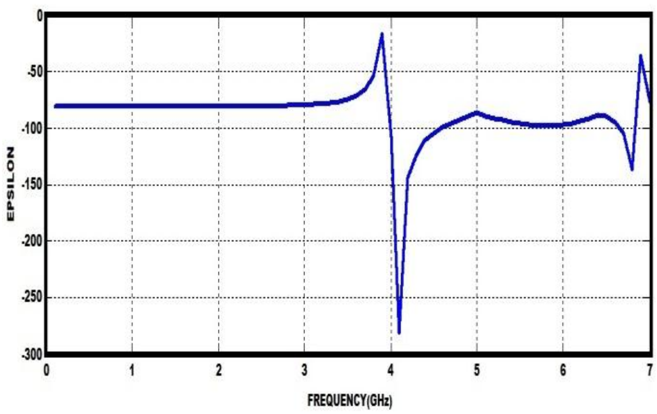

Figure 4: Negative value of epsilon (permittivity) plotted using MATLAB, in consideration of the $S_{11}$and S_{12} values from the simulated result.

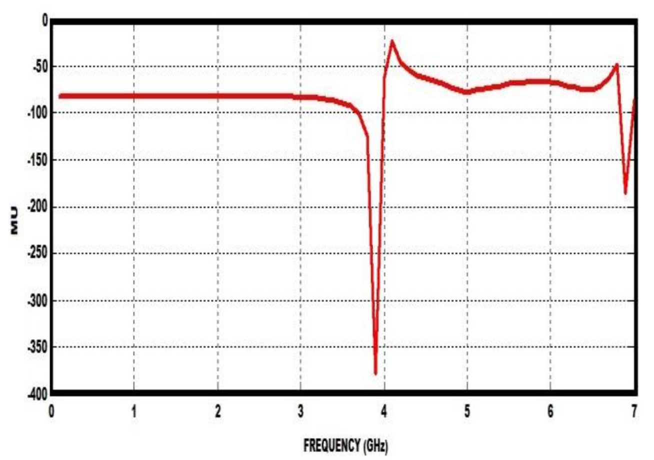

Figure 5: Negative value of mu (permeability)plotted using MATLAB, in consideration of the $S_{11}$and S_{12} values from the simulated result.

The plots shown in the figures 4 and 5, were plotted using MATLAB. The S-parameter values from the simulated filter were extracted and they were plotted to verify whether the structure exhibited the negative effect. In accordance with the proposed structure, it was found that the bandpass filter exhibited the negative refraction at the operating frequency of the filter proposed.

In the above mentionedfigures , the negative permittivity is plotted is plotted in figure 4. From the figure it is evident that the proposed structure exhibits negative permittivity (epsilon) values in the operating frequency band of the proposed filter. The plot shown in figure 5, stands as a proof for the achievement of negative permeability values in the operating frequency band of the filter.

The parameters that decide the performance of a filter are return loss (RL), insertion loss (IL) and group delay. The two parameters RL and IL were already analyzed and now group delay is to be analyzed. The group delay plays a major role in deciding the performance of the filter. It must be aminimum of <1ns. The group delay is always measured in nano seconds. The group delay is measured by considering the insertion loss parameter values. So by considering the phase values from the simulated structure, the group delay is plotted in figure 6.

The group delay being an important parameter for deciding a filter's performance, it was plotted using MATLAB software. The simulation was done by considering the phase of the filter which was considered from the s_{12} parameters. The group delay must be less than 1ns for an optimum filter. Hence by taking this in consideration, the filter was checked for the group delay value. The group delay is calculated by using the formula,

$$\tau_d = -(d\beta/d\omega) \qquad (5)$$

It was found that the filter achieved the minimum value of the group delay, < 1ns and it was plotted in the figure 6.

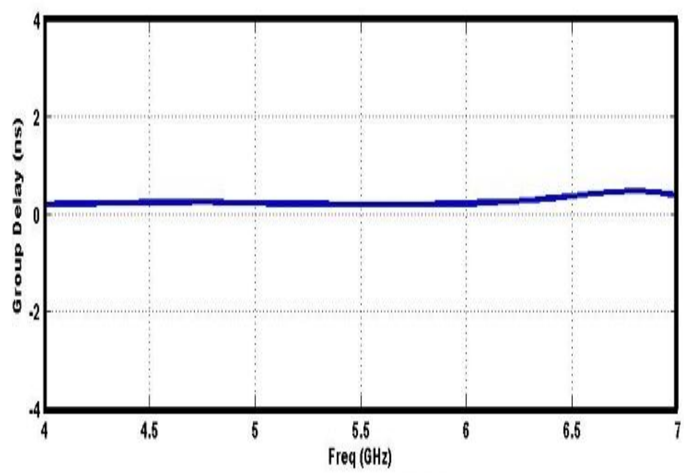

Figure 6: Group delay value plotted using MATLAB, considering the S_{12} values from the simulated result.

5. CONCLUSION

This paper proposes bandpass filter designed using a coplanar waveguide transmission line. It was found thatthey achieved the metamaterial effect and it had a wideband coverage. The proposed structure shown in figure 2 was simulated using Method of Moments based IE3D simulator and it was found to operate by covering the frequency band of (4-6.8) GHz, shown in figure 3, is suitable for Fixed Wi-max applications, which has the wireless standard IEEE 802.16-2004. The electrical size of the filter was found to be $(0.26\lambda_g \times 0.21\ \lambda_g)$ offered a good performance with better return loss and insertion loss characteristics. Specifically, the FBW of around 51% can be achieved with an acceptable return loss from the proposed filter design . It was found from the structure that it offered a good return loss (RL) greater than -40dB and an insertion loss (IL) of -0.2dB shown in figure 3 and had a minimum group delay less than 1ns, which is plotted in figure 6. The compact size (12x10x0.8) mm^3 of the proposed structure offered a wide passband coverage and made it suitable for the specified wireless application with the achievement of metamaterial effect ie., negative permeability and permittivity values at the operating frequency.

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