SRR BASED TRI-MODE RESONANT MICROSTRIP BANDPASS FILTER FOR WLAN APPLICATIONS

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Abstract

This paper delivers a miniaturized tri-mode resonating microstrip bandpass filter having SRR unit cells in the center of the transmission line. The proposed filter having the center frequency of 2.4 GHz, 4.5 GHz and 5.2 GHz which have been used for WLAN technology. By the implementation of the SRR unit cells in the middle of the transmission line the performance of the filter was improved. The proposed filter with 3 SRR unit cells having the minimum insertion loss less than 3 dB. Filter parameters like return loss, insertion loss, phase response, group delay, quality factor, bandwidth, and efficiency also evaluated using ANSYS Electronic desktop. Theoretical results, simulated results, and measured results are of good agreement with minimum error values. The Real-time application of the filter also performed by integrating the fabricated filter in the WLAN system. The proposed filter with 3 SRR unit cell having the minimum transmission coefficient of -0.7 dB, -1.27 dB, and -2.1 dB across 2.4, 4.5 and 5.2 GHz, reflection coefficient of -22.7 dB, -23 dB, and -16.5 dB across 2.4, 4.5 and 5.2 GHz, group delay value of 1.52 ns, 1.38 ns and 0.58 ns across 2.4, 4.5 and 5.2 GHz with minimum nonlinear phase response and the quality factor value of 14.1, 18.7, 13.7 across 2.4, 4.5 and 5.2 GHz. The equivalent circuit of the proposed filter was designed with the order of 5 using The Chebyshev type 1 approximation technique having a ripple factor value of 0.01 dB. Surface current distributions of the proposed filter are also evaluated. Fabricated microstrip bandpass filter results are measured and validated using ANRITSU-MS2037C combinational analyser.

Keywords: Band pass filter, Group delay, Quality factor, SRR unit Cell, WLAN application.
1. Introduction

In modern communication system to meet the requirement of high selectivity, low insertion, high return loss, narrow band width and compact size planar microstrip bandpass filter are implementing [1]. To improve the selectivity and reduction in insertion loss order of the filter must be increased. The fetching feature of the multi-mode filter is its compactness, as the addition of resonators needed for a given degree of the filter is decrease by half. Moreover, the multimode filter exhibits quasi elliptical or elliptical frequency response which results in high selectivity [2]. The most used multi-mode microstrip structure consist of DGS [3, 4], crossed slots [5], right crossed slots [6-9], and loaded crossed slots in the square patch. Nevertheless, the structures proposed above possess a genuinely enormous circuit territory.

To lessen the circuit size, various types of filter structures are implemented like split ring resonator [10-13], in the literature. Metamaterial structure such as split ring resonator reported in 1999 [14]. These structures are used for enhancing the microwave and millimetre wave devices which improve the performance and reduce the radiation losses. Various types of artificial resonator [15], are placed in the antenna or filter to improve their performance by varying the with, gap distance, split width, number of rings of the SRR and SRR [16]. Split ring resonators are mainly used for the improvement of reflection and insertion losses in low cost, light weight and compact filter [17, 18].

A work has been reported with the integration of parallel step impedance resonator and MTM structure to attain triple passband filter in addition in TZs. A compact triple band bandpass filter has been proposed using Koch fractal shape transmission line and complementary split ring resonator. By the design and implementation of the multi-mode resonator electromagnetic characteristics of multiband filter are enhanced [19]. In a triple-band BPF to improve passband and filter performance two identical square open loop resonator has been designed [20]. Design compliance are required for triple bandpass filter to offer different pass bands with different bandwidths in communication system [21].

In this paper, narrow bandpass microstrip filter with 3 SRR unit cells which operation in S and C band is proposed. The proposed band pass filter was designed using FR-4 as the substrate which having the thickness of 1.6mm. The proposed bandpass filter showing the minimum insertion loss and high reflection coefficient by using Chebyshev type -1 analog approximation technique with the stopband attenuation of -40 dB having the ripple factor value of 0.01 dB. The proposed filter having the high-quality factor value with minimum group delay and linear phase repose.

2. Design of Triple Bandpass Filter with SRR Unit Cell

In this paper a compact metamaterial inspired band pass filter are proposed and characterized using ANSYS electronic desktop. The dimension of the filter along with SRR unit cells have been optimized and placed in Figs. 1, 2 and 3, also the width and length values of the filter and SRR unit cell are placed in Table 1. The band pass filter having the impedance value of 50ohm using fr-4 as substrate with the dielectric constant of 4.3 and having the thickness of 1.6mm. The order and LC equivalent model of the proposed band pass filter along with its iterations have been designed using Chebyshev type 1 approximation with the ripple factor value of 0.01 dB.

The center frequency of the filter is calculated using the formula

$$f_c = \frac{c}{2L\varepsilon_r}$$  \hspace{1cm} (1)

The width and length of the proposed microstrip filter was calculated using Eq. (2). Width of the microstrip band pass filter was calculated using the expression

$$W = \frac{c}{2f_c\sqrt{(\varepsilon_r+1)/2}}$$ \hspace{1cm} (2)

By using Eq. (2), the width of the microstrip band pass filter was calculated having the value of 30mm. The effective dielectric constant of the of the microstrip bandpass filter was evaluated using Eq. (3)

$$\varepsilon_{eff} = \frac{(\varepsilon_r+1)}{2} + \frac{(\varepsilon_r-1)}{2} \left[1 + 12 \frac{h}{W} \right]^{-0.5}$$ \hspace{1cm} (3)

By using Eq. (3), the effective dielectric constant of the microstrip band pass filter was calculated having the value of 6.3. Length of the microstrip band pass filter was calculated using the expression

$$L_{eff} = \frac{c}{2f_c\sqrt{\varepsilon_{eff}}}$$ \hspace{1cm} (4)

By using Eq. (4), the length of the microstrip band pass filter was calculated having the value of 23.3mm. To calculate the feed line width, the expression is given by,

$$W_f = \frac{1}{2f_c\sqrt{\varepsilon_r\mu_0}} \sqrt{\frac{2}{\varepsilon_r+1}}$$ \hspace{1cm} (5)

From Eq. (5), the width of the feedline is obtained a value of 2mm. $f$ is the resonance frequency, $W$ is the width of the patch, $L$ is the length of the patch, $h$ is the thickness, $\varepsilon_r$ is the relative permittivity of the dielectric substrate and $c$ is the speed of light: $3\times10^8$.

![Fig. 1. Microstrip bandpass filter.](image)

Figure 2 represents the microstrip band pass filter having the slot in the center of the microstrip transmission line which improve the performance of the filter and also resonates at tri-band frequency modes.
2.1. Metamaterial element construction

Split ring resonators having the widths of W4, W5, W6, W7, W8, W9 and lengths of L4, L5, L6 and L7 is consider at 3 rectangular slots having the gaps of G1, G2, G3. In Fig. 3, we can observe the unit cell setup with the SRR. In SRR unit cells, the gap causes the magnetic response the magnetic response considers as the gap capacitor. In the SRR case, each gap develops the series capacitance where in the second SRR which is having split pointed opposite towards the first SRR is to generate the large capacitance by considering the small gap between the two SRR’s. Similarly, third SRR which is having split point opposite to the second SRR is to generate large capacitance by considering the small gap between the three SRR’s. Series capacitances are developed and further the inductance which will appear in the loop is considered for the development of equivalent circuit.
The total capacitance of the SRR can be calculated by
\[ C_t = \frac{1}{C_s + C_G + C_c} \]  \hspace{1cm} (6)

The inductance in the loop of the rectangular SRR is calculated by
\[ L_T = 0.0002 l(2.303 \log_{10} \frac{4d}{\gamma}) \mu H \]  \hspace{1cm} (7)

where, the constant \( \gamma = 2.853 \) for a wire loop of rectangular geometry.

The resonating frequency of the SRR is calculated by
\[ \omega_0 = \frac{1}{\sqrt{(L_S + 4LM)(C_s + C_G + C_c)}} \]  \hspace{1cm} (8)

where \( L_S = \) self-inductance, \( LM = \) mutual inductance, \( C_S = \) surface capacitance, \( CC = \) coupling capacitance, \( CG = \) gap capacitance.

The negative permittivity of the metamaterial structure is expressed using Eq. (9),
\[
\varepsilon_p = 1 - \frac{\omega_p^2}{\omega^2}
\]  

where \(\omega_p\) is the plasma frequency and \(\omega\) is the frequency of the propagating electromagnetic wave. If the frequency below the plasma frequency the effective permittivity is negative from the above equation.

Figures 7, 8 and 9 represent the negative permeability value of the SRR unit cell which was simulated using ANSYS electronic desktop. Figure 7 represents the negative permittivity value of the outer ring which operates at 2.4 GHz. Figure 8 represents the negative permittivity value of the outer ring with combination of inner ring which operates at 2.4 GHz and 4.5 GHz. Figure 9 represents the negative permittivity value of the outer ring with combination of two inner rings which operates at 2.4 GHz, 4.5 GHz and 5.2 GHz.

Fig. 7. Single SRR cell negative permittivity at 2.5 GHz.

Fig. 8. Two SRR cell negative permittivity at 2.5 GHz and 4.5 GHz.
Fig. 9. Tripe SRR cell negative permittivity at 2.5 GHz, 4.5 GHz and 5.2 GHz.

Figures 10, 11 and 12 represent the negative refractive value of the SRR unit cell which was simulated using ANSYS electronic desktop. Figure 10 represents the negative refractive index value of the outer ring which operates at 2.4 GHz. Figure 11 represents the negative refractive index value of the outer ring with combination of inner ring which operates at 2.4 GHz and 4.5 GHz. Figure 12 represents the negative refractive index value of the outer ring with combination of two inner rings which operates at 2.4 GHz, 4.5 GHz and 5.2 GHz.

Fig. 10. Single SRR cell negative refractive index at 2.5 GHz.
Fig. 11. Double SRR cell negative refractive index at 2.5 GHz and 4.5 GHz.

Fig. 12. Triple SRR cell negative refractive index at 2.5 GHz, 4.5 GHz and 5.2 GHz.

Figures 13, 14, and 15 represent the negative permeability value of the SRR unit cell which was simulated using ANSYS electronic desktop. Figure 13 represents the negative permeability value of the outer ring which operates at 2.4 GHz. Figure 14 represents the negative permeability value of the outer ring with combination of inner ring which operates at 2.4 GHz and 4.5 GHz. Figure 15 represents the negative permeability value of the outer ring with combination of two inner rings which operates at 2.4 GHz, 4.5 GHz and 5.2 GHz.

Fig. 13. Single SRR cell negative permeability index at 2.5 GHz.
2.2. Evaluation process of the proposed filter

Figures 16 and 17 represent the evaluation process of the microstrip band pass filter and prototype models of filters. The first iteration of the process showing the tri-mode frequency with high reflection coefficient and minimum insertion loss. As the iteration of the process increases by the placement of SRR unit cells in the middle of the slotted microstrip bandpass filter the performance values like reflection coefficient and insertion loss also improved with high quality factor value, linear phase response and minimum group delay.
2.2.1. Order of the filter

The order of the filter was calculated using Chebyshev type 1 filter approximation having the ripple factor value of 0.01 dB having stopband attenuation 40 dB. The order of the filter was calculated using the formula (11).

$$n = \frac{\cosh^{-1}\left(\sqrt{(10^G-1)/\sqrt{(10^G-1)}}\right)}{\cosh^{-1}\left(\frac{L}{f_c}\right)}$$  (11)

where $n$ is the order of filter which was calculated with the reflection coefficient value at the centre frequency($L$) and having the ripple factor value of $G = 0.01$ dB. $f_c$ is the centre frequency of the bandpass filter and $f$ is the resonating frequency of the bandpass filter.

The normalized frequency of the filter was calculated using the formula

$$f = \sqrt{f_1 * f_2}$$  (12)

where $f_1$ and $f_2$ the lower cut off and upper cut off frequency of the particular centre frequency.

The proposed microstrip bandpass filter with 3 SRR unit cell having tri band frequencies which operates at 2.4, 4.5 and 5.2 GHz. The normalized frequency of the three band are 2.3, 4.4 and 5.1 GHz. from the equation 3 and 4 the order of the filter was calculated which having the value of 5.
2.2.2. Calculation of the lumped values of the bandpass filter

Now we can calculate $L$ and $C$ component values as following parameter. The lumped values of the bandpass filter can be calculated using the formulas

For series $L$ and $C$ values,

$$L_K = \frac{K K_1 z_0}{f_0 \Delta}$$

$$C_K = \frac{\Delta}{f_0 L_K z_0}$$

(13)

(14)

For shunt $L$ and $C$ values,

$$L_K = \frac{\Delta z_0}{f_0 C_K}$$

$$C_K = \frac{C K_1}{f_0 \Delta z_0}$$

(15)

(16)

where $\Delta$ is the fractional bandwidth which can be computed using Eq. (17):

$$\Delta = \frac{f_2 - f_1}{f_c}$$

(17)

From Figs. 18 to 29, all the lumped values of the microstrip bandpass filter based on its iteration process are mentioned which having an order of 5.
Fig. 21. Equivalent circuit of the iteration 2 filter at 2.4 GHz.

Fig. 22. Equivalent circuit of the iteration 2 filter at 4.5 GHz.

Fig. 23. Equivalent circuit of the iteration 2 filter at 5.2 GHz.

Fig. 24. Equivalent circuit of the iteration 3 filter at 2.4 GHz.

Fig. 25. Equivalent circuit of the iteration 3 filter at 4.5 GHz.
3. Results and Discussion

From Figs. 30 and 31, it was observed that the microstrip bandpass filter with slotted centre performing three different modes of frequency like 2.4, 4.5 and 5.2 GHz with reflection coefficient value of -22 dB, -22 dB and -15.1 dB in ANSYS software and -27 dB, -23 dB and -14.8 dB in measured across 2.39, 4.49 and 5.18 GHz. From the both measured and simulated results it was observed the they are
having an error values of 0.4 which was acceptable in range. Transmission zeroes are also occurred which was used to improve the selectivity of the frequency.

![Graph](image1.png)

**Fig. 30.** Simulated s-parameter values of iteration 1 filter.

![Graph](image2.png)

**Fig. 31.** Measured s-parameter values of iteration 1 filter.

From Figs. 32 and 33, it was observed that the microstrip bandpass filter with slotted centre with one SRR unit cell performing three different modes of frequency like 2.4, 4.5 and 5.2 GHz with reflection coefficient value of -21 dB, -22 dB and -16 dB in ANSYS software and -28 dB, -26 dB and -15.2 dB in measured across 2.4, 4.38 and 5.2 GHz. From the both measured and simulated results it was observed the they having an error values of 0.4 which was acceptable in range. Transmission zeroes are also occurred which was used to improve the selectivity of the frequency.

![Graph](image3.png)

**Fig. 32.** Simulated s-parameter values of iteration 2 filter.
From Figs. 34 and 35, it was observed that the microstrip bandpass filter with slotted centre with two SRR unit cell performing three different modes of frequency like 2.4, 4.5 and 5.2 GHz with reflection coefficient value of -23 dB, -22.5 dB and -16.5 dB in ANSYS software and -27 dB, -22 dB and -13 dB in measured across 2.4, 4.38 and 5.2 GHz. From the both measured and simulated results it was observed they are having an error values of 0.4 which was acceptable in range. Transmission zeroes are also occurred which was used to improve the selectivity of the frequency.

From Figs. 36 and 37, it was observed that the microstrip bandpass filter with slotted centre with two SRR unit cell performing three different modes of frequency like 2.4, 4.5 and 5.2 GHz with reflection coefficient value of -22 dB, -23 dB and -16 dB in ANSYS software and -27 dB, -22 dB and -14.5 dB in measured across
2.4, 4.5 and 5.2 GHz. From the both measured and simulated results it was observed the they are having an error values of 0.4 which was acceptable in range. Transmission zeroes are also occurred which was used to improve the selectivity of the frequency.

![Simulated s-parameter values of iteration 4 filter.](image)

**Fig. 36. Simulated s-parameter values of iteration 4 filter.**

![Measured s-parameter values of iteration 4 filter.](image)

**Fig. 37. Measured s-parameter values of iteration 4 filter.**

### 3.1. Bandwidth

Iteration 1 microstrip band pass filter with slot in centre having the bandwidth value of 180, 250 and 500 MHz at 2.4, 4.5 and 5.2 GHz. Similarly, iteration 2 microstrip band pass filter with one SRR having the bandwidth value of 180, 360 and 340 at 2.4, 4.5 and 5.2 GHz. laterally, iteration 3 microstrip band pass filter with two SRR having the bandwidth value of 170, 230 and 380 at 2.4, 4.5 and 5.2 GHz. Finally, iteration 4 microstrip band pass filter with three SRR having the bandwidth value of 170, 240 and 390 at 2.4, 4.5 and 5.2 GHz. Minimum the bandwidth occurs due to narrow band in the pass band filter.

### 3.2. Quality factor

Iteration 1 microstrip band pass filter with slot in centre having the quality factor value of 13.3, 18 and 10.4 at 2.4, 4.5 and 5.2 GHz. Similarly, iteration 2 microstrip band pass filter with one SRR having the quality factor value of 13.3, 12.5 and 15.2 at 2.4, 4.5 and 5.2 GHz. laterally, iteration 3 microstrip band pass filter with two SRR having the quality factor value of 14.1, 19.5 and 13.6 at 2.4, 4.5 and 5.2 GHz. Finally, iteration 4 microstrip band pass filter with three SRR having the quality factor value of 14.1, 19.5 and 13.6 at 2.4, 4.5 and 5.2 GHz. From the all above iteration’s it was observed that the
bandpass filter with 3 SRR slots having high quality factor values compare with the iterations because of its narrow frequency band.

### 3.3. Group delay

From Figs. 38(a) and (b), it was absorbed that iteration 1 microstrip band pass filter with slot in its centre having the group delay value of 1.6 ns, 1.52 ns and 0.81 ns across 2.4, 4.5 and 5.2 GHz which was simulated in ANSYS electronic desktop. The measured group delay values are also similar to the simulated with the value of 1.66, 1.54 and 0.82 ns across 2.4, 4.5 and 5.2 GHz. From the both measured and simulated results it was observed the they having an error values of <5 which was acceptable in range.

![Fig. 38(a), and (b). Simulated and measured group delay values of iteration 1 filter.](image)

From Figs. 39(a) and (b), it was absorbed that iteration 2 microstrip band pass filter with slot in its centre having the group delay value of 1.48 ns, 1.3 ns and 0.72 ns across 2.4, 4.5 and 5.2 GHz which was simulated in ANSYS electronic desktop. The measured group delay values are also similar to the simulated with the value of 1.56, 1.45 and 0.89 ns across 2.4, 4.5 and 5.2 GHz. From the both measured and simulated results it was observed the they are having an error values of <5 which was acceptable in range.

![Fig. 39(a), and (b). Simulated and measured group delay values of iteration 2 filter.](image)
From Figs. 40(a) and (b), it was absorbed that iteration 3 microstrip band pass filter with slot in its centre having the group delay value of 1.53 ns, 1.37 ns and 0.61 ns across 2.4, 4.5 and 5.2 GHz which was simulated in ANSYS electronic desktop. The measured group delay values are also similar to the simulated with the value of 1.73, 1.67 and 0.73 ns across 2.4, 4.5 and 5.2 GHz. From the both measured and simulated results it was observed the they are having an error values of <5 which was acceptable in range.

From Figs. 41(a) and (b), it was absorbed that iteration 4 microstrip band pass filter with slot in its centre having the group delay value of 1.52 ns, 1.38 ns and 0.58 ns across 2.4, 4.5 and 5.2 GHz which was simulated in ANSYS electronic desktop. The measured group delay values are also like the simulated with the value of 1.727, 1.58 and 0.78 ns across 2.4, 4.5 and 5.2 GHz. From the both measured and simulated results it was observed the they are having an error values of <5 which was acceptable in range. From all iterations it was observed that all the bandpass filter having good agreement of simulated and measured results having an error values of <5 which was acceptable in range. The occurrence of error is due to manufacture defeat while manufacturing the band pass filter.
3.4. Phase response

It was evaluated using the formula given below

\[ \tau_\phi(\omega) = -\frac{\phi(\omega)}{\omega} \]  

(22)

where, \( \tau_\phi(\omega) \) = phase delay, \( \phi(\omega) \) = total phase shift in radian, \( \omega \) = angular frequency in radians.

From Figs. 42(a), (b) and (c), it was observed that the filters are having linear phase shift.

![Phase response of iteration 1, 2, 3 and 4 filter at 2.4, 4.5 and 5.2 GHz.](image)

3.5. Surface current distribution

Surface current distribution represent the intensity of current in the device. Higher the current distribution values at operating frequency higher the performance value in term of its scattering parameters, i.e., return loss, insertion loss.

From Figs. 43, it was observed that from iteration to iteration the surface current distribution increases which showing that the microstrip band pass filter with three SRR’s having the current distribution value more which improves the performance of the filter compare with previous iterations. The values of surface currents are 87.4, 90, 120, 124 A/m. The comparison of simulated and measured results are presented in Tables 2(a) and (b) and Table 3, show the proposed work comparison with available literature.
Fig. 43(a), (b), (c), and (d). Surface current distributions of iteration 1, 2, 3 and 4 filter at 2.4, 4.5 and 5.2 GHz.
### Table 2(a). Comparison of simulated and measured results.

<table>
<thead>
<tr>
<th>Filter Iteration</th>
<th>Filter order</th>
<th>Central frequency (GHz)</th>
<th>Return loss (dB)</th>
<th>Insertion loss (dB)</th>
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<td></td>
<td>4.5</td>
<td>-22</td>
<td>-1.21</td>
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<td></td>
<td></td>
<td>5.2</td>
<td>-15.1</td>
<td>-2.17</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td>2.4</td>
<td>-21</td>
<td>-0.71</td>
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<td></td>
<td></td>
<td>4.5</td>
<td>-22</td>
<td>-1.26</td>
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<td>-2.16</td>
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<td>5.2</td>
<td>-14.5</td>
<td>-2.61</td>
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### Table 2(b). Comparison of simulated and measured results.

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<th>Filter Iteration</th>
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<th>Band width (MHz)</th>
<th>Group delay (ns)</th>
<th>Quality factor</th>
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<td>250</td>
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<td>18.0</td>
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<td>500</td>
<td>0.81</td>
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<td>2</td>
<td>5</td>
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<td>1.48</td>
<td>13.3</td>
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### Table 3. Comparison of proposed work with existing literature survey.

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<td>15<em>11.5</em>1.6</td>
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<td>-20 dB@2.4-7.02 GHz</td>
<td>-20</td>
<td>-12</td>
<td>-22 <a href="mailto:dB@2.4GHz">dB@2.4GHz</a>, -23 dB@4.5 GHz and- 16.5 dB@5.2 GHz</td>
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<td>S21</td>
<td>-0.75 dB@2.4-7.02 GHz</td>
<td>-0.6 dB@1.9-4.8 GHz</td>
<td>0.05@1.9-7.02 GHz</td>
<td>1.28@4.5 GHz and- 2.16@5.2 GHz</td>
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<td>-</td>
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<td>-</td>
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<td>13.7@5.2 GHz</td>
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</table>
4. Conclusion

The design of tri-mode microstrip bandpass filter with 3 SRR unit cells in the middle of the transmission line was developed. The filter performing tri mode frequency at 2.4 GHz, 4.5 GHz and 5.2 GHz which are used for WLAN applications. By the implementation of the SRR unit cells in the middle of the transmission line the performance of the filter was improved. The proposed filter with 3 SRR unit cells having the minimum insertion loss less than 3 dB. Filter parameters like return loss, insertion loss, phase response, group delay, quality factor, bandwidth and efficiency also evaluated using ANSYS Electronic desktop. Theoretical results, simulated results and measured results are of good agreement with minimum error values. Real time application of the filter also performed by integrating the fabricated filter in the WLAN system. The proposed filter with 3 SRR unit cell having the minimum insertion loss of -0.7 dB, -1.27 dB, and -2.1 dB across 2.4, 4.5 and 5.2 GHz, reflection coefficient of -22.7 dB, -23 dB, and -16.5 dB across 2.4, 4.5 and 5.2 GHz, group delay value of 1.52 ns, 1.38 ns and 0.58 ns across 2.4, 4.5 and 5.2 GHz with minimum nonlinear phase response and the quality factor value of 14.1, 18.7, 13.7 across 2.4, 4.5 and 5.2 GHz. The equivalent circuit of the proposed filter was designed with the order of 5 using Chebyshev type 1 approximation technique having a ripple factor value of 0.01 dB. Surface current distributions of the proposed filter are also evaluated. The fabricated microstrip bandpass filter results are measured and validated using ANRITSU-MS2037C combinational analyser.

Acknowledgements

DST through FIST grant of SR/FST/ET-II/2019/450. KLEF Internal funding project File no. KLEF/IF/SEP/2019/002

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