CHAPTER 9

DESIGN AND ANALYSIS OF MICROSTRIP LOW PASS FILTER USING ANN AND METAMATERIAL FOR PERFORMANCE IMPROVEMENT

Summary- This Chapter proposes two Chebyshev type third order microstrip LPFs - one using artificial neural network (ANN) and another using MTM substrate. Firstly the conventional Pi type and ANN trained LPFs have been designed using HFSS simulation tool. In one case the design and analysis of microstrip LPF at cut-off frequency of 2 GHz on a FR4 substrate has been initially performed using HFSS and then the necessary filter design parameters were trained with an ANN optimization technique using MATLAB. The performance comparison of the conventional filter designed has been executed with the ANN model. The best possible design dimensions of the filter could be obtained with the help of ANN. The reflection ($S_{11}$) and transmission ($S_{21}$) properties have been obtained in a satisfactory level. Secondly an investigation report on the superior performance of another 2 GHz Chebyshev type T section microstrip LPF loaded with MTM as an additional plane between ground and filter sections is reported. The MTM is an array of SRR consisting of new V shaped structures. The existence $\mu$ negative and $\varepsilon$ negative properties using were verified using NRW method. The LPF loaded with the verified MTM structure was simulated using HFSS 3D simulation tool and analyzed. On comparison it is observed that the SRR loaded LPF provides improved performance over the conventional type.
9.1 OPTIMIZATION OF FILTER DESIGN USING ANN FOR PERFORMANCE IMPROVEMENT

Microstrip filters gain attracting popularity among researchers because their day to day improvement in designs and their needs in many microwave systems including satellite communication (Daniel Swanson and Wolfgang Hoefer 2003). They are most widely preferred for selecting or confining the microwave signals within specified spectral ranges. The challenges on the microwave filters with requirements such as improved performance, miniature size, light weight and low cost are ever increasing with the emerging applications of wireless communications. Depending on the need and application, either the Butterworth or the Chebyshev type of low pass, high pass, band pass or band stop filter configurations can be used. The conventional LPFs can be synthesized using equivalent circuit model provided by Jia-Shen Hong and Lancaster (2001). However, this type of synthesis methods suffer from some limitations such as mathematical complexity and time consuming computational efforts in determining the best possible designs.

This section provides an ANN based LPF design for a 2 GHz cut-off frequency. The improvement in the filter design was made possible with the help of ANN (Robert Callan 1999). The artificial neural networks are proposed because they offer a fast and fairly accurate design before going for fabrication. There are different kinds of ANN used (Vivek Singh Kushwah et al 2011) in the recent years for overcoming limitations found in synthesis and analysis of microstrip components. ANNs are crude model of many engineering systems describing the analogy of neural structure of the brain. In terms of technical perspective they are viewed as parallel information computing systems consisting of large number of interconnected processing systems called neurons, working together to provide a solution to complicated
variables based problems. The attracting feature of ANN is that it possesses the ability to learn through trainings and provide best decision (Thiruvalarchelvan and Raghavan 2009).

To learn the neuron, two main learning schemes such as supervised learning and unsupervised learning are available. In the supervised learning, an external supervisor called output set corresponding to the input set is provided. However, in the unsupervised learning there is no such defined output set to compare with the obtained outputs set after training. Hence, it needs some kind of regularities to make decisions. Generally, for decision making after applying the learning algorithm various activation functions (Praveen Kumar Malik et al 2011) are used. The various inputs given to the neuron are processed with the weights of some neuro-cells. Finally the output from the neuro model is compared with the fixed threshold set of values by using any of the activation functions and decision is made for the best. Hence, they are found described as yield prediction and optimization (Kabir et al 2007) methods in microstrip based components designs. In this work the back propagation algorithm (BPA) is used to train the data set. Many ANN models adapt supervised learning since it is a popular learning algorithm and has the ability to classify the input data patterns and relate with the output patterns and provide accuracy. It mainly compares the outputs produced from the neural network with the specified outputs and then the error in the calculation is back propagated to the network for making a modification in the weights.

9.1.1 Conventional Microstrip Low Pass Filter Design

This section considers the design aspects of third order Chebyshev type Pi section LPF. The design steps involved in this filter synthesis are presented in a simplified way in Chapter 3 under the Section 3.6. Hence referring to those described Equations (3.42) to (3.65), the filter components have been designed for the preferred input data:
Recent research on ANN applications imply that the ANNs are knowledge based structures which combine the existing empirical formulae and equivalent circuit models with the networks for providing optimum results. For fixing an accurate model for the problem defined it is necessary to have a sufficient number \((k)\) of neurons. However, it depends on the degree of non-linearity and dimensionality involved in the synthesis. For highly non-linear components, the number of neurons required is more. Hence adaptive processes are also used which can add or discard neurons as per the necessity at the time of training. The BPA based ANN model used in this paper is shown in Figure 9.1. The complete coding for ANN has been developed in MATLAB using ANN tool box. There are three layers- input layer, output layer and hidden neuron layer. However in the hidden layer, the input data or output data is not directly associated but through the actual as well as the weighted functions relationship as mentioned in Equation (9.4).

\[ f_c = 2 \text{GHz}, \ f_s = 4 \text{GHz}, \ r_{sba} = 20 \text{dB}, \ r_{pba} = 0.5 \text{dB} \]

\[ \varepsilon_r = 4.4, \ h = 1.6 \text{mm}, \ L_{T_X} = \frac{\lambda_o}{8} \text{ and } Z_o = 50 \Omega \]
9.1.2.1 ANN Input, Ranges and Output Data Set

The number \((m)\) of input parameters set \((x)\) planned for the design of proposed filter and the number \((n)\) of output parameters set \((y)\) expected are seven and the output set depends on the input set. This is represented in Equations (9.1) and (9.2).

\[
x = \{ f_c, f_s, r_{sba}, r_{pba}, \varepsilon_r, h, Z_o \}
\]  \hspace{1cm} (9.1)

\[
y = \{ W_{TX}, W_{OL}, W_{OC}, L_{TX}, L_{L2}, L_{LC1}, L_{LC3} \}
\]  \hspace{1cm} (9.2)

\[
y = f(x)
\]  \hspace{1cm} (9.3)

However, for ANN training a weight parameter associated with the interconnections in the neural network must be included. The training for data set is decided based on the actual relationship between the input and output parameters. Thus, Equation (9.3) becomes modified as below.

\[
y = f(x, w)
\]  \hspace{1cm} (9.4)

9.1.2.2 The Data Range

The data range in conventional and ANN model are shown below. This ANN is applied for design accuracy of the filter and hence the parameters which describe the filter characteristics are simulated using HFSS simulator. The input data range for ANN is given by

\[
f_c = 2GHz \ (1:0.1:2GHz), \quad f_s = 4GHz \ (2.8:0.1:4.5GHz),
\]

\[
r_{sba} = (20:2:40dB)
\]

\[
r_{pba} = 0.5dB \ (0.1,0.2,0.5dB),
\]

\[
\varepsilon_r = 4.4 \quad h = 1.6mm,
\]

\[
L_{TX} = \left( \frac{\lambda_s}{8}, \frac{\lambda_s}{16}, \frac{\lambda_s}{32} \right); \quad Z_o = 50\Omega
\]
9.1.2.3 Synthesized Filter Dimensions

The MATLAB codings for ANN and LPF design are listed in Appendix 5. The synthesized filter dimensions (impedance in ohms, wavelengths, lengths and widths in millimeter) are listed in Table 9.1 and the shape of the microstrip version of LPF is shown in Figure 9.2.

9.1.3 Simulation

Both the conventional as well as ANN designed filter parameters have been taken to HFSS software where the layout and simulations have been performed. The filter components have been drawn using copper conductor on a double side printed FR4 substrate (42.63mm x 16.3mm) of thickness 1.6 mm and permittivity 4.4. The ground plane has been laid at the bottom of the substrate. The filter has been set up for a sweep frequency of 2 GHz in a sweep range of 1 - 6 GHz with lumped port input fed to two ports and simulated.

9.1.4 Results and Discussions

The simulation results obtained for the reflection ($S_{11}$) and transmission ($S_{22}$) properties are analyzed and compared in the in the following sections.

Table 9.1 Synthesized Pi Section LPF Dimensions

<table>
<thead>
<tr>
<th>Filter</th>
<th>$Z_o$</th>
<th>$Z_{oL}$</th>
<th>$Z_{oC}$</th>
<th>$\lambda_{go}$</th>
<th>$\lambda_{gL}$</th>
<th>$\lambda_{gC}$</th>
<th>$W_{Tx}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conv</td>
<td>50</td>
<td>99.78</td>
<td>18.43</td>
<td>82.39</td>
<td>88.99</td>
<td>77.36</td>
<td>3.06</td>
</tr>
<tr>
<td>ANN</td>
<td>50.088</td>
<td>103.4861</td>
<td>18.4452</td>
<td>81</td>
<td>84.9</td>
<td>76.2</td>
<td>3.059</td>
</tr>
<tr>
<td>Filter</td>
<td>$W_{oL}$</td>
<td>$W_{oC}$</td>
<td>$L_{Tx}$</td>
<td>$L_{L2}$</td>
<td>$L_{C1}$</td>
<td>$L_{C3}$</td>
<td>-</td>
</tr>
<tr>
<td>Conv.</td>
<td>0.7008</td>
<td>12.256</td>
<td>10.3</td>
<td>7.55</td>
<td>7.24</td>
<td>7.24</td>
<td>-</td>
</tr>
<tr>
<td>ANN</td>
<td>0.7092</td>
<td>12.2428</td>
<td>2.5745</td>
<td>10.099</td>
<td>7.079</td>
<td>7.079</td>
<td>-</td>
</tr>
</tbody>
</table>
9.1.4.1 Simulation Results

The simulated $S$ parameters of the conventional LPF as a function of frequency are shown in Figure 9.3(a). The reflection loss $S_{11}$ value lies well below $-10$ dB with a deep upto $-31$ dB at $1.43$ GHz indicating a good matching at the port. From the transmission properties it can be found that the passband ripple varying between $-1$ and $-4$ dB and a roll-off takes place after cut-off frequency ($1.9$ GHz) and is found as $14.16$. The attenuation is $-20$ dB at $3$ GHz. A transition of $-15$ dB per $1$ GHz is noticed in the stopband after $1.9$ GHz. Though, there is an increase in attenuation after $3$ GHz, the insertion loss is not sufficient beyond $f_s$.

The S parameters obtained for ANN trained filter are shown in Figure 9.3(b) - (c). In Figure 9.3(b), the reflection loss quantities are compared with various strip lengths $L = \left( \frac{\lambda_{go}}{8}, \frac{\lambda_{go}}{16}, \frac{\lambda_{go}}{32}, \frac{\lambda_{go}}{64} \right)$ as per ANN outputs. For $\frac{\lambda_{go}}{8}$ the reflection($S_{11}$) parameter is well upto $-45$ dB but there is dip in attenuation noticed at $2.6$ GHz in the stop band. Similarly the attenuation for other two consecutive strip lengths are found providing reflection loss of around $-30$ dB but there is a dip noticed at $3.6$ GHz and $4.4$ GHz respectively. However, the $\frac{\lambda_{go}}{64}$ length strip provides constant stop band attenuation in addition to sufficient passband reflection level.
In Figure 9.3(c), the insertion loss characteristics for the said four strip lengths are shown. The stop band insertion loss is appreciably good for $\frac{\lambda_{g0}}{64}$ when compared to other three strip lengths. Insertion loss of upto -68 dB is provided by this structure. A sharp transition occurs after cut-off frequency and a roll-off rate of 12.14 is also achieved. Also the maximum stopband attenuation occurs well within 4.2 GHz in advance when compared to the specified maximum value in the input data. This remains comparatively better than that of the conventional filter. There is a downshift in frequencies corresponding to various strip lengths in the increasing order. The $S_{22}$ and $S_{12}$ parameters appear same as $S_{11}$ and $S_{21}$ and hence they are not shown here.

9.1.4.2 Comparison of the Characteristic Parameters of the Proposed Filter

The filter parameters designed from conventional method and from the artificial neural networks are compared and produced in Table 9.1. It lists the values of conventional filter elements obtained for the stated input data. The size of the substrate board is $0.517\lambda_{g0} \times 0.197\lambda_{g0}$ in the conventional filter. The ANN trained optimum dimensions for better reflection and transmission properties are different from the calculated ones. The transmission strip length is also very small compared to that of the conventional filter. Hence the size of the substrate board is $0.295\lambda_{g0} \times 0.197\lambda_{g0}$ showing size reduction possibility with ANN approach. From the comparison is found that the ANN has produced optimized dimensions using best possible combinations of the supplied input data set.
Figure 9.3  Simulated Results of $S_{11}$ and $S_{21}$ (Inset: Filter Structure)
(a) Conventional Filter (b) $S_{11}$ After ANN (c) $S_{21}$ After ANN
9.1.5 Concluding Remarks

The application of ANN in the design of microstrip LPF has been verified in this Chapter. The optimum method of synthesis of microstrip LPF has been performed using BPA based ANN model. The designed filter has been simulated for both conventional as well as ANN trained data sets separately and then compared. From the simulated results it is evident that the design accuracy can be achieved using ANN. A filter size reduction has also been achieved considerably with the help of ANN.

9.2 COMPACT SRR EMBEDDED MICROSTRIP LOW PASS FILTER

The miniature size better performing LPF are of great demand in the applications of microwave circuits. Though the LPFs (David Pozar 2005) designed using microstrip technology provides low profile, improvement in the filter characteristics are still investigated intensively with different alternatives (Jia-Shen Hong and Lancaster 2001). Recently MTMs play important role in the performance improvement of microstrip components such as antennas, filters etc. MTMs are artificial materials obtained from their physical structures and not from their chemical composition. They are attracting researchers because of their negative medium properties which influence the performances of MIC components. Ekmekci and Turhan-Sayan (2009) mentioned that the ENG and MNG media aided in improving the performance of band pass filter due to good coupling between strips. There are mainly resonator and transmission line approaches for preparing the artificial substrates. Researchers have been contributing a variety of SRR and CSRR structures (Li et al 2009, Ching-Wen Tang and Shih-Chin Yang 2010, Sudhakar Sahu et al 2011) for such investigations. The SRR or CSRR embedded on or in the substrate disturb (Dal Ahn et al 2001) the shield current distribution in the ground plane and changes the properties of inductor
and capacitor. The proposed microstrip LPF is based on resonator approach. This makes use of a novel SRR consisting of V shaped metallic structures arranged to form an array on a plane embedded between the filter on the top and the ground at the bottom giving rise to change in the effective inductance and capacitance of the microstrip line laid as filter. The filter properties are influenced by the presence of the embedded MTM and also the gap distance between the unit cells.

### 9.2.1 Conventional Microstrip Low Pass Filter Design

The conventional LPF of order three has been designed using the empirical equations provided in Chapter 3 under the Section 3.6 and the procedure of design remains same as described already in Section 9.1.1 except for the capacitor and the inductor realizations. This section considers the design aspects of third order Chebyshev type T section LPF. The input parameters considered for the design are the cut-off frequency \( f_c \), the stop band frequency \( f_s \), the stop band attenuation \( r_{sdb} \), the pass band ripple level \( r_{pba} \), the dielectric permittivity of the substrate \( \varepsilon_r \), the thickness of the substrate \( h \) and the characteristic impedance \( Z_0 \) for matching.

### 9.2.2 Design and Simulation

This section deals with the conventional T section LPF design, the MTM preparation and negative medium property verification through NRW method and the MTM loaded filter simulation.

#### 9.2.2.1 Conventional LPF Synthesis

After inputting the specified set of data: 
\[
\begin{align*}
    f_c &= 2 \text{ GHz}, \quad f_s = 4 \\
    g_{db} &= 25 \text{ dB}, \quad r_{pba} = 0.5 \\
    \varepsilon_r &= 4.4, \\
    h &= 1.6 \text{ mm}, \quad l_{\tau} = \frac{\lambda_0}{8} \quad \text{and} \quad Z_0 = 50 \Omega.
\end{align*}
\]
The calculated filter dimensions are
as listed in the Table 9.2. The corresponding filter section is shown in Figure 9.7(a). For the design and simulation of MTM and filter structures the HFSS software was used. Simulations were performed for both the conventional T section LPF as well as SRR embedded LPF. The filter components were designed using copper conductor on a double side printed FR4 substrate of thickness 1.6 mm and permittivity 4.4 with dimensions (47.54mm x 16mm). The ground plane was laid at the bottom of the substrate.

<table>
<thead>
<tr>
<th>Filter</th>
<th>$Z_o$</th>
<th>$Z_{oL}$</th>
<th>$Z_{oC}$</th>
<th>$\lambda_{go}$</th>
<th>$\lambda_{gL}$</th>
<th>$\lambda_{gC}$</th>
<th>$W_{Tx}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>T sec</td>
<td>50</td>
<td>99.78</td>
<td>18.43</td>
<td>82.39</td>
<td>88.99</td>
<td>77.36</td>
<td>3.06</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Filter</th>
<th>$W_{OL}$</th>
<th>$W_{OC}$</th>
<th>$I_{Tx}$</th>
<th>$I_{C2}$</th>
<th>$I_{L1}$</th>
<th>$I_{L3}$</th>
<th>$W_{Tx}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>T sec</td>
<td>0.7008</td>
<td>12.256</td>
<td>10.3</td>
<td>4.98</td>
<td>10.98</td>
<td>10.98</td>
<td>-</td>
</tr>
</tbody>
</table>

### 9.2.2.2 Metamaterial Preparation and Negative Medium Verification

There are a number of MTM structures proposed by previous researchers. The proposed SRR type MTM preparation is based on the V shaped structure. This is arranged in duals to make an array of MTM structure. The governing dimensions and few such combinations of dual and array MTMs are illustrated in Figure 9.4. It is interesting to note that there can be varieties of patterns that can be generated from the basic, dual and array structures.

![Figure 9.4 V Shaped MTM Structures](image-url)

(a) Basic V MTM (b) Dual MTM 1 (c) Dual MTM 2 (d) Dual MTM 3
The single V structure is responsible for providing self inductance effect. When arranged in duals due to coupling the mutual capacitance and mutual inductance are getting added. These combinations of capacitances and inductances are responsible for resonances when excited through wave ports. This structure is used along with the conventional substrate appropriately for realizing negative medium properties and thus behaves as new MTM.

The following dimensions of the proposed MTM such as strip width ($w_1$), flaring width ($w_2$), flaring angle ($\theta$), side length ($l_1$), inner length ($l_2$) and side of mitered corner ($l_3$) are depicted in the Figure 9.5(a). However, the array of MTMs adds two more parameters such as spacing between adjacent element ($s$) and gap between adjacent array ($g$) as marked in Figure 9.5(b). The unit followed for the dimensions are in millimeters. The position where the MTM is placed on or in the original substrate can be changed to obtain the desired results. Also the above said dimensional parameters mentioned above may be varied appropriately to acquire better MTM performance. This array structure is embedded as copper strips between filter section and ground at a distance of 0.8mm from the top in the FR4 substrate of 1.6mm thick. After creating the said MTM structure, the PE and PM boundaries and waveports has been set up appropriately with appropriate sweep frequency range as outlined in the Section 3.4.7 in Chapter 3 and then simulated.

(a)                                                          (b)
Figure 9.5 Proposed SRR Structures (a) Single Unit Structure (b) Array of V Structures Placed Underneath the Filter Section Inside the Substrate
Figure 9.6  Negative medium property verification of the MTM medium
(a) Permeability and Permittivity  (b) Refractive Index
Hence the S parameters data obtained from the simulation have been used in the equations provided in Chapter 3 under the Section 3.4.8 for verification of negative medium property. One set of S parameters ($S_{11}$ and $S_{21}$) have been exported to MATLAB and medium property has been retrieved using coding developed for NRW method. The obtained $\varepsilon_r$, $\mu_r$, and refractive index $n$ are drawn as a function of frequency as depicted in Figure 9.6.

![Figure 9.6](image)

(a)

![Figure 9.7](image)

(b)

**Figure 9.7** MTM and LPF Structures (a) T Section LPF (Filter Component Length in x-axis and Width in y-axis) (b) MTM Loaded LPF in Simulation

### 9.2.2.3 MTM Loaded LPF Simulation

The synthesized LPF is shown in Figure 9.7(a). MTM has been inserted between the filter and the ground as shown in Figure 9.7(b). The filter simulation has been set up for a solution frequency of 2 GHz in the
sweep range of 1 - 6 GHz with lumped port input fed at two ports and simulated to obtain the filter properties. The dimensions of gap and spacing between adjacent elements and the array respectively have been treated equal in the simulation and varied simultaneously while simulated for various values.

Figure 9.8 (Continued)
9.2.3 Results and Discussions

The difference between the conventional LPF and the SRR embedded LPF is visible from the characteristics shown in Figure 9.6. The Figure 9.6(a) shows the dominating negative epsilon medium upto 4.2 GHz and dominating negative mu medium after 5 GHz. The double negative property is noticed between 4.2-5 GHz range. The Figure 9.6(b) indicates the negativeness of the refractive index of the artificially prepared substrate medium. The simulated $S$ parameters of the conventional LPF as a function of frequency are shown in Figure 9.8(a). The reflection loss is -28 dB initially at 1 GHz and rises uniformly as the frequency increases. It remains high after 3 GHz and continues up to 6 GHz. However, the transmission curve is nearly flat in the passband and it starts decreasing after the cut-off frequency of
2 GHz corresponding to -3 dB. It reaches -15 dB only at 4.4 GHz and again it rises. Hence this filter is able to provide a poor roll-off rate only because this curve does not even cross -15 dB whereas the specification planned is 25 dB in the stop band at 4 GHz which is not achieved by this filter.

The Figure 9.8(c) shows the transmission ($S_{21}$) values of the metamaterial loaded LPF for various gap distances between adjacent V structures. The transmission band is flat without any ripples and the cut-off frequency occurs at 1.95 GHz corresponding to -3 dB and then decreases to nearly around -34 dB for all the gap distances. However, for each gap distance reduction from 1mm to 0.2mm, it is seen that the stop band frequency reduces and hence improving to good roll-off rate. This rate is low for 1mm gap distance and becomes appreciably lower when it is 0.2mm. The 25 dB attenuation point is reached at 3.6 GHz whereas for the rest of the gap distances, it occurs after 4 GHz only. Similarly the reflection characteristics curves for various gap distances are shown in Figure 9.8(d). As the distance decreases the reflection loss varies between -18 dB and -20 dB initially and then rises uniformly. Also in the stop band, this $S_{11}$ is better for the gap distance of 0.2mm when compared to other values. Hence, as the gap between the MTM structures is reduced, more coupling takes place between strip lines and yielding better performance of the filtering action when compared to the conventional filter. The Table 9.3 represents the comparison of the proposed filter performance with that of the previous researcher Sudhakar Sahu et al (2011).
Table 9.3 Comparison of MTM Loaded LPF Performance

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Proposed</th>
<th>Sudhakar Sahu et al (2011)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type and size</td>
<td>MTM (V array) sandwiched Chebyshev T section LPF; (46.75mm x 16.74mm)</td>
<td>MSRR (hex-omega structure) loaded Maximally flat T section LPF; (47.46mm x 17.53 mm)</td>
</tr>
<tr>
<td>Substrate</td>
<td>FR4, (ε = 4.4 ; thickness =1.6) 47.54mm x 20.3mm</td>
<td>RT – Duroid 5870 (ε = 2.4; thickness = 1.6)</td>
</tr>
<tr>
<td>Ground Plane and feed</td>
<td>Conventional rectangular, Microstrip feed</td>
<td>Defected MTM ground plane, Microstrip feed</td>
</tr>
<tr>
<td>Simulation and sweep frequency</td>
<td>HFSS, 1-6 GHz; NRW</td>
<td>HFSS,3 - 5.5 GHz; NRW</td>
</tr>
<tr>
<td>Filter specification</td>
<td>Order 3 ;, f_c =2 GHz, f_s =4 GHz, r_pba = 0.5 dB, r_sba =25dB</td>
<td>Order 5; f_r = 4.5 GHz, f_s =5 GHz, r_pba = 10 dB, r_sba =40 dB</td>
</tr>
<tr>
<td>Advantage</td>
<td>Good S_{11} and S_{21} at passband and stopband, roll-off 13.33 dB/ GHz in MTM filter and 7.096 dB/ GHz in conventional filter, order 3 but better performance, no via holes</td>
<td>Size reduction with MTM structure, roll-off reduction 19.68 dB / GHz with 5 unit cells of MTM conventional , no via holes</td>
</tr>
<tr>
<td>Applications</td>
<td>In wireless applications requiring frequency selective circuits</td>
<td>-</td>
</tr>
</tbody>
</table>
9.2.4 Concluding Remarks

This Chapter presented the investigation reports on improving the performance of a third order Chebyshev conventional T section microstrip LPF using MTM array structure in the substrate. The novel V shaped MTM structure was laid as performance improving cover between filter section and conventional ground layer. Better transmission and reflection characteristics have been obtained without compromising the size. The roll-off rate of 13.33 dB / GHz has been achieved with the proposed filter whereas in the conventional filter this was observed to be 7.096 dB / GHz only. Improved and fast roll-off, good reflection and transmission loss in the pass and stop bands are the advantages in this filter.