Microstrip Wideband Bandpass Filters Using Step Impedance Resonator Techniques

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Abstract: In this paper, microstrip wideband pass filter in various topologies viz. open stubs, short stubs and via holes are presented. The microstrip bandpass filter is designed with 6.85 GHz resonant frequency and return loss (>70 dB) at resonant frequency is proposed. The designed wideband bandpass filter has insertion loss of (< 1 dB) in its passband. The filter is implemented employing SIR techniques. The SIR based bandpass filter is implemented on Roger RO3010 substrate with fractional bandwidth recorded to be 109.5%. The Agilent ADS software is used to carry out the design and simulation of S-parameters for proposed design. The proposed wideband filter can be employed in various wireless systems due to its ease of design and compactness.

Keywords: Bandpass Filter (BPF), Insertion loss, Microstrip, Return loss, Step Impedance resonator, Wideband

1. INTRODUCTION

Microstrip filters plays vital role in modern wireless communication systems to attain desired frequency spectrum passage and to reject undesired ones. We can design lowpass, high pass, bandpass or band reject filters subject to requirements of communication systems. Wideband bandpass filters are highly employed in microwave systems and antenna design. The function of a band pass filter is to pass a band of frequency components with regard to their defined lower & higher cutoff frequencies. The design and analysis of microstrip filters can be carried out using high frequency softwares. The approach of design depends on its application. Firstly the filter can be realized in lumped components for analysis purpose. Although these design are not feasible at ultra wideband frequencies. To eradicate this issue we need to transform the design into its distributed equivalent circuits. A numerous of techniques available in literature to design and fabricate microstrip wideband bandpass filters due to its compactness and ease of fabrication. These microstrip filters works well at microwave frequencies ranging from few MHz to 10's of GHz. While implementing these filters certain loop holes needs to be fixed viz. size of filter, dielectric losses, etc. To obtain elegant performance from these filters various techniques can be used e.g. defected ground structure, photonic band gap, step impedance resonator etc. The selection of technique varies from application perspective or systems requirements. In order to achieve the ripple free passband characteristics, spurious free out of band characteristics, sharp transition bands and skirt factor, multiple poles in passband and zeros at lower and upper cut-off frequency, the filter design must be carried out with proper selection of topology and techniques. A large number of techniques and design procedures can be implemented to obtain desired characteristics of proposed filter. More specifically the filters can be designed from available standard low pass design procedures and later can be refined to bandpass equivalent circuits to ease the design methodology. Finally to implement the filter in microstrip transmission line configuration, various structures can be incorporated viz. open stubs, short stubs, step impedance resonator, ring resonators etc. The deployment of these techniques enhanced the performance of designed filters and make it suitable for various applications like microwave systems, wireless communication systems, antennas etc. In this paper microstrip wideband bandpass filter is implemented using step impedance resonator approach. Various SIR topologies are combined in the form of short stubs and open stubs. The combination of these half/quarter wavelengths stubs produces desired bandpass filter response. In order to design proposed filter the stubs are incorporated in different configuration. The filter is designed at resonant frequency of 6.85 GHz. The filter design is carried out in high frequency Agilent ADS software. The filter response is simulated to in ADS as S-parameters which reveals good results in pace with defined objective. The analysis and design of step impedance resonator based wideband bandpass filter is accomplished. The optimization while design of the proposed filters is carried out using high frequency software Agilent ADS in order to attain desired filter characteristics.

2. LITERATURE SURVEY

Wideband bandpass microstrip filter employed in wireless communication systems to pass a desired band of frequencies with specific lower-upper cut off frequency and at certain centre frequency a signal inside a specific bandwidth while rejects out of band frequency components, i.e. as stop band [1]. As revealed in [2] that ultrawide band BPF plays vital role in selection of desired frequency components in passband and rejection of undesired frequencies or out of band frequencies. A wideband UWB BPF using combination of low pass and high pass filter topology with controlled lower & upper stopbands is presented in [3]. Parallel coupled filters reveal attractive design for UWB filter; however the requirement of higher fractional bandwidth upto 100% of more is difficult to accomplish with these structures as the size of filter increases tremendously [4]. At centre frequency 6.85 GHz along with the fractional bandwidth of 110%, a compact UWB filter is discussed in [5] for high data rate applications upto 500 Mbps. A novel microstrip ultrawide band bandpass filter implemented by connecting stub-loaded circular ring resonators is presented in [6]. A variety of topologies with improved pass band, stopband with low insertion loss and high return loss are presented in [7-9]. A dual notched band rejected ultrawide band BPF implemented using short circuited stubs was presented in [7]. A compact ultrawide band BPF incorporated with two mushroom type electromagnetic bandgap (EBG) coupled line structure was presented in [8]. Another compact ultrawide band BPF with three notched bands implemented by step impedance resonator techniques with adjustable resonant frequency is presented in [9]. A microstrip stub loaded and ring resonator has been investigated with two attenuation poles is presented in [10]. A microstrip line based UWB filter is implemented on lossy composite substrate to suppress the out of band frequencies at insertion loss (> 6.0 dB). A ring based compact filter with sharp selectivity and low insertion loss designed with multiple stages in proposed in [9]. Estimated group delay of 0.5 ns and insertion loss upto 0.6 dB was recorded in the passband. The proposed has various loopholes regarding bulkier size; lower & upper stopbands are narrower with unwanted passbands at lower frequency regions (< 3.1 GHz). Coplanar waveguide based ultrawide band BPF is proposed with adjustable cut-off frequencies in [12]. Due to its larger size as the topology has long dimension which makes it unfit for use in UWB systems. Although a coplanar waveguide (CPW) based bandpass filter designed considering low pass prototypes design yet large fractional bandwidth cannot be achieved [13]. The design and implementation of bandpass filter with matched impedance networks, coupled line structure, time delay structures etc. promises with low power consumption was proposed in [14]. For ultra wideband applications; large fractional bandwidth is need which in turn needed tight coupling between coupled sections and hence coupling tolerances are difficult to attain. A hybrid microstrip with coplanar waveguide structured UWB BPF is designed with three resonant modes at 6.85 GHz centre frequency is presented in [15]. A compact bandpass filter with low insertion loss and high return loss plays a vital role in the microwave communication systems at transceiver side to recognize and transmit the desired frequency components [16]. UWB BPF with notched band characteristics is designed by incorporating step impedance multimode resonators consisting of quarter wavelength stubs [18]. Parallel coupled microstrip lines topology can be employed in various microwave communication systems, RF systems, filters, resonators, amplifiers etc. To accomplish the wideband operation in band pass filter, parallel coupled line microstrip filters needed several stages between input-output ports which in turn raise its fabrication tolerance [19]. Besides passband in ultrawide range; this filter also notched out 5.5 GHz WLAN frequency in order to avoid interference with existing technology.

3. Wideband BPF: DESIGN AND ANALYSIS

In this paper a 5th order bandpass filter at 6.85 GHz resonant frequency with matched impedance of 50 ohm and return loss (> 70 dB) is implemented in different topologies. The lower cut-off frequency is 3.1 GHz and higher cut off frequency is 10.6 GHz which gives the approximate bandwidth of 7.5 GHz. Roger RO3010 substrate with conductor thickness 0.017 mm and dielectric constant of $\varepsilon_r = 10.2$ is chosen for implementation. Conventionally the proposed wideband filter design starts with standard low pass prototype and then converted into its equivalent bandpass filter configuration. Later using SIR transformation filter will be moulded into various structures in order to attain desired characteristics. The lumped parameters of LPF can be obtained from following equations:

$$L = \frac{Z_0 g}{\omega_c} \quad \text{and} \quad C = \frac{g}{Z_0 \omega_c} \qquad (1)$$

The calculated values of the components can be tabulated as:

Table 1: *Low pass prototype calculations*

Parameters	Computed Values
L1	0.618 nH
C2	1.618 pF
L3	2.000 nH
C4	1.618 pF
L5	0.618 nH

A. Lumped wideband bandpass filter

To design the wideband bandpass filter from its low pass prototype, the computed values from above table can be used in the formulas as follows:

a) Parallel connections of LC

$$L_1 = \frac{g_1 \Delta Z_0}{\omega_0} \quad \text{and} \quad C_1 = \frac{1}{\omega_0 g_1 \Delta Z_0} \qquad (2)$$

b) Series connections of LC

$$L_2 = \frac{Z_0}{\omega_0 g_2 \Delta} \quad \text{and} \quad C_2 = \frac{g_2 \Delta}{\omega_0 Z_0} \qquad (3)$$

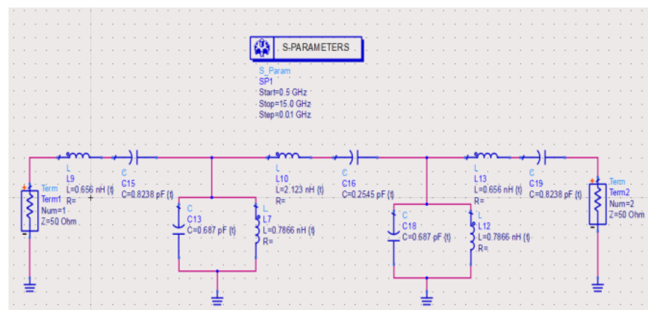

Figure 1. *Lumped components 5th order bandpass filter at f0=6.85 GHz*

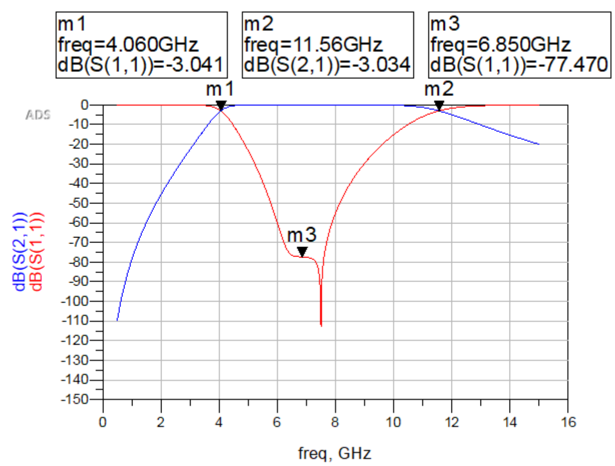

Figure 2*. Simulated S-Parameters S11 & S21 for 5th order bandpass filter*

Further the above shown lumped circuit of wideband bandpass filter is tuned to enhance its bandwidth and s-parameter response. The tuned schematic with its s-parameter response can be shown as:

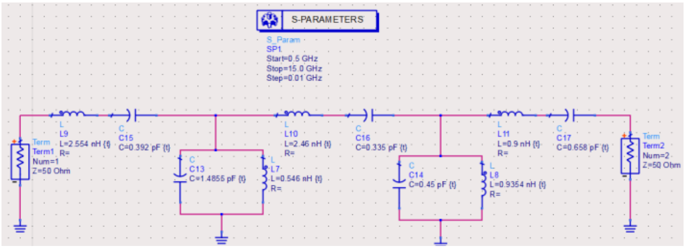

***Figure 3**. Tuned lumped wideband bandpass filter at f_0=6.85 GHz*

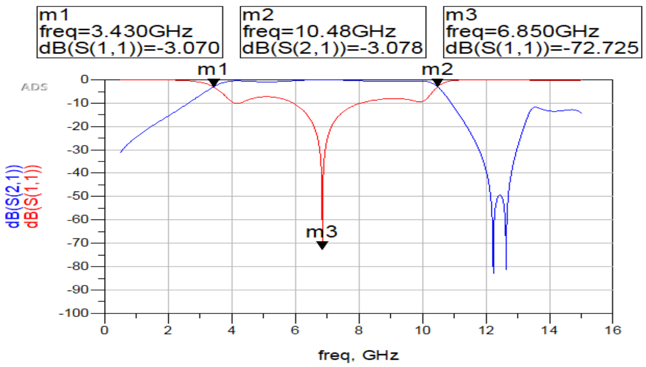

***Figure 4**. Simulated S-Parameters for tuned wideband bandpass filter*

B. Microstrip wideband bandpass filter

To ease the implementation of proposed filter with its compact design, it is necessary to convert the lumped configuration into its equivalent transmission line structures i.e. microstrip structures. To accomplish this task, the width and length of L & C components needs to be calculated. This can be done using following transformation:

- Open stubs are used to implement capacitors with its impedance 1/C.
- Shorted stubs are used to implement inductors with impedance L and its length βl.

We can now find Z_l (low impedance) and Z_h (high impedance) by assuming βl< 45^0. This gives:

$$Z_l = 15\,\Omega \quad \text{and} \quad Z_h = 150\,\Omega \tag{4}$$

Finally, L and C electrical lengths can be calculated by the following relations:

$$\beta l = \frac{LR_0}{Z_h} \quad \text{and} \quad \beta l = \frac{CZ_l}{R_0} \tag{5}$$

a. Open and short stub implementation

The microstrip equivalent parameters for wideband filter as shown in figure 3 i.e. W, L values for lumped components are presented in following table.

***Table 2**. Transmission line dimensions*

Component Values (nH)	Transmission line specifications		Component Values (pF)	Transmission line specifications	
	W (mm)	L (mm)		W (mm)	L (mm)
L1=0.656	0.2	0.575	C1= 0.824	1.58	2.61
L2= 0.687	0.747	2.64	C2= 0.687	0.22	1.04
L3=2.123	0.2	1.69	C3 =0.254	1.58	1.24
L4=0.786	0.892	2.672	C4= 0.687	0.539	1.706
L5=0.656	0.2	0.575	C5= 0.824	1.58	2.61

Stepped impedance resonator implementation of transmission line circuit; in which L and C can be represented by different widths. The corresponding layout of SIR implementation is given as:

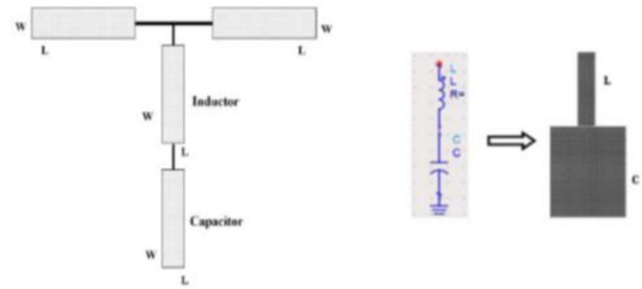

***Figure 5**. Layout of SIR from lumped topology*

Using Agilent ADS software, the stepped impedance resonator implementation of proposed wideband bandpass filter at resonant frequency f_o = 6.85 GHz is shown in figure 6.

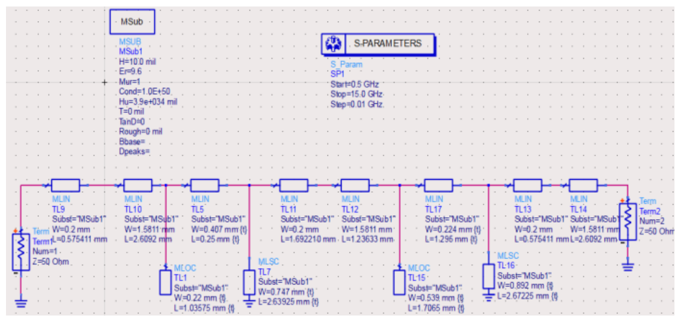

***Figure 6**. Layout of wideband BPF using SIR technique*

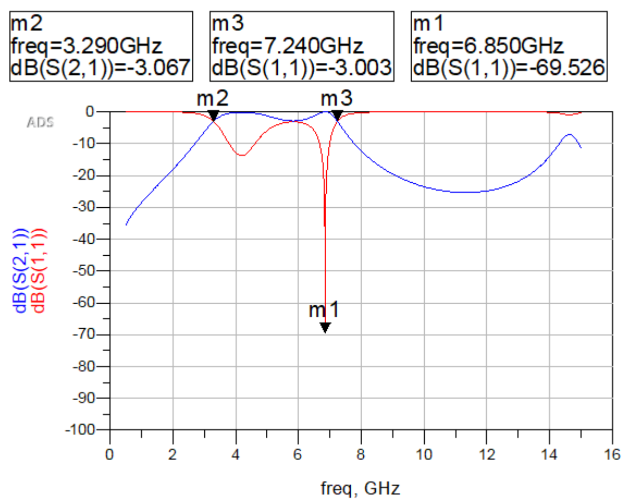

***Figure 7**. S-parameter representation for SIR based Wideband BPF*

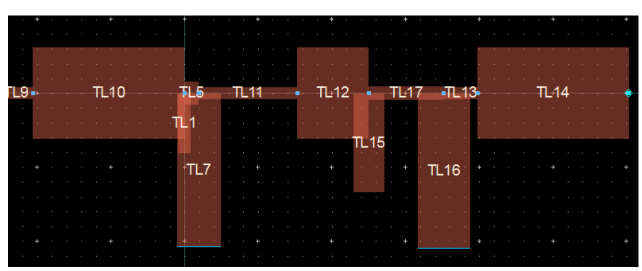

***Figure 8**. Layout of SIR based bandpass filter*

b. Short circuit stub implementation

Further the compact design of filter can be achieved by omitting two sections of MLOC thereby gaining the compactness and enhancing the passband characteristics of implemented filter as revealed in figure 9.

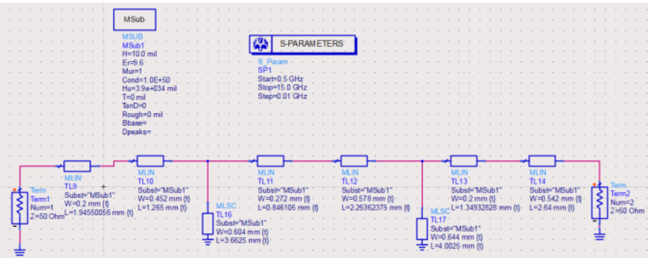

***Figure 9**. Short circuited stub Implementation of proposed BPF*

The simulated S-parameters of proposed wideband bandpass filter is shown in figure 10 while its layout of is shown in figure 11 as follows:

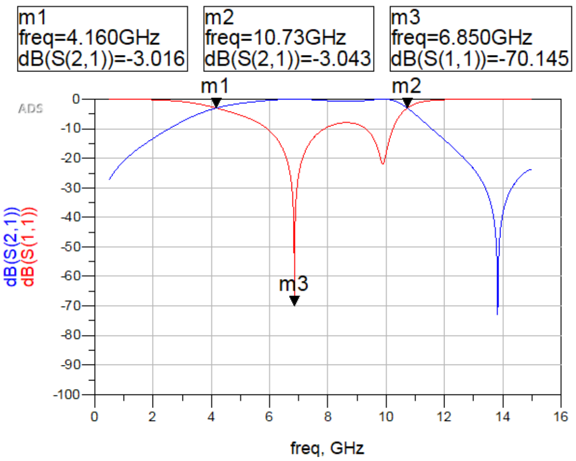

***Figure 10**. S- parameters representation for shorted stub BPF*

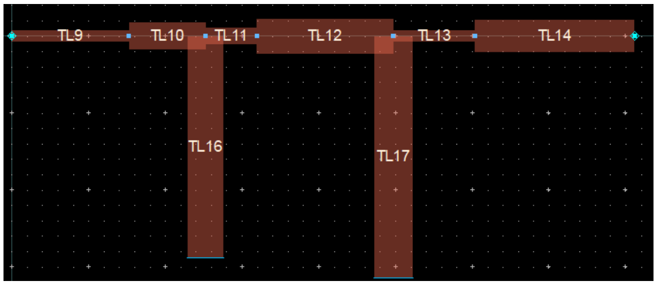

***Figure 11**. Short circuited stub bandpass filter layout.*

c. Tuned short-open circuited implementation

The shorted stub topology discussed in previous section can be modified by incorporating an open circuited stub which improves lower transition band upto some extent. The SIR implementation with its S-parameter simulation and layout are shown in figure 12, 13 and 14.

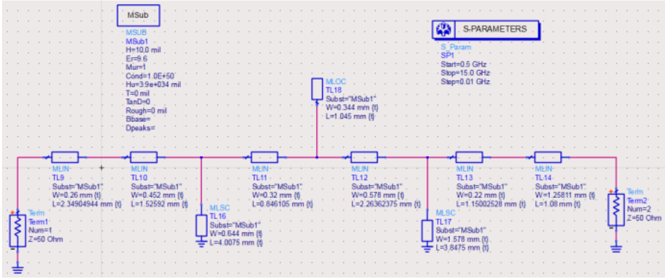

***Figure 12**. Shorted-open SIR Implementation of 5th order bandpass filter*

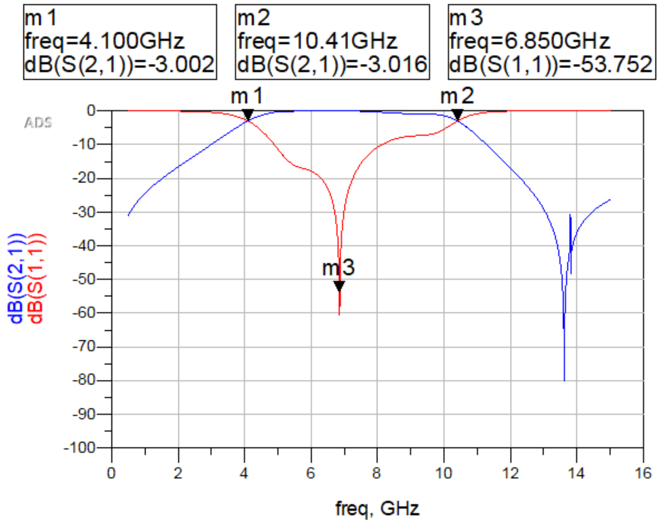

***Figure 13.** S- parameters representation for shorted-open stub proposed BPF*

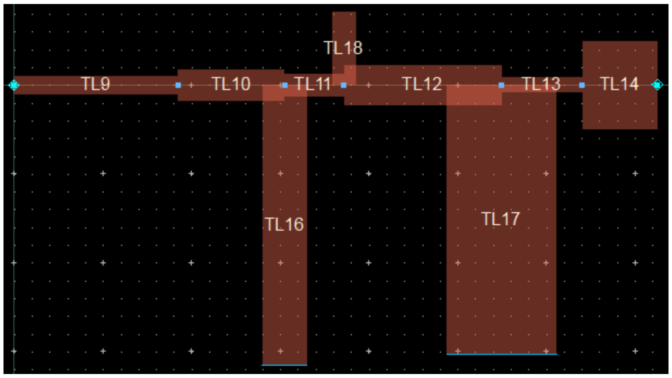

***Figure 14**. Shorted open stub BPF layout*

d. Short circuit implementation using via holes

To enhance the characteristics of the proposed filters, the SIR implementation is added with two via holes, which not only enhances the filter response but also imparts the compactness in filter.

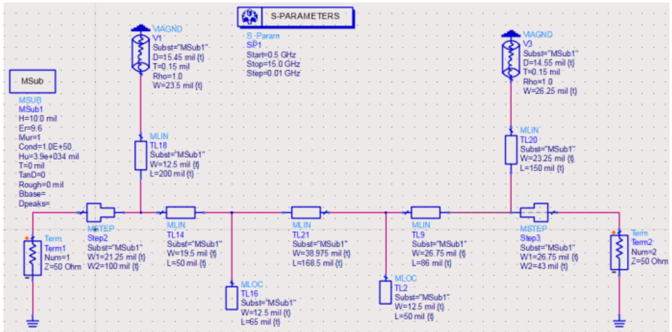

***Figure 15**. SIR-Via holes layout of proposed BPF*

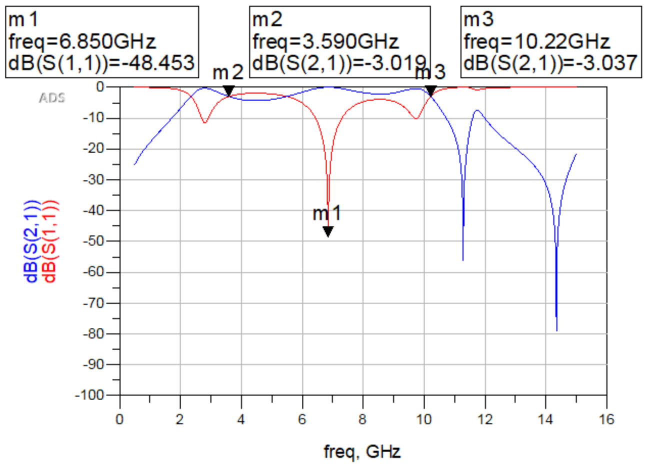

***Figure 16**. S- parameters representation for SIR-Via holes BPF*

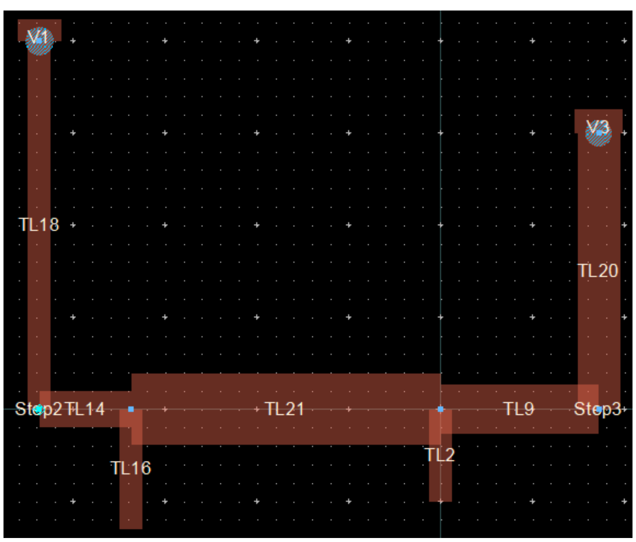

***Figure 17**. SIR-Via holes based BPF layout*

Further enhancement in the above design can be accomplished by adding an extra via hole between existing two via hole in previous implementation. This addition of extra via hole improves the insertion loss in passband, return loss at resonant frequency f_o=6.85 GHz and enhances bandwidth of the proposed filter upto a greater extent. The modified wideband bandpass filter can be shown as:

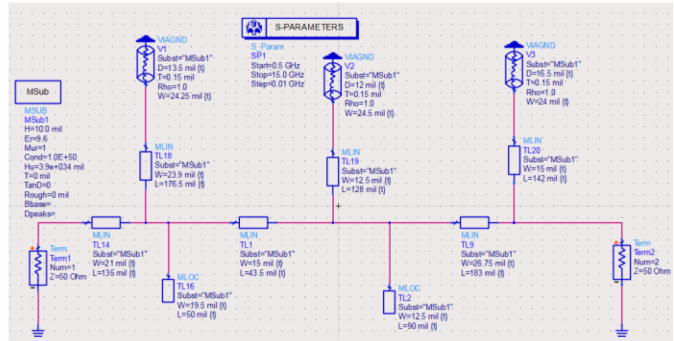

***Figure 18**. Modified 3-Via holes SIR based 5th order bandpass filter*

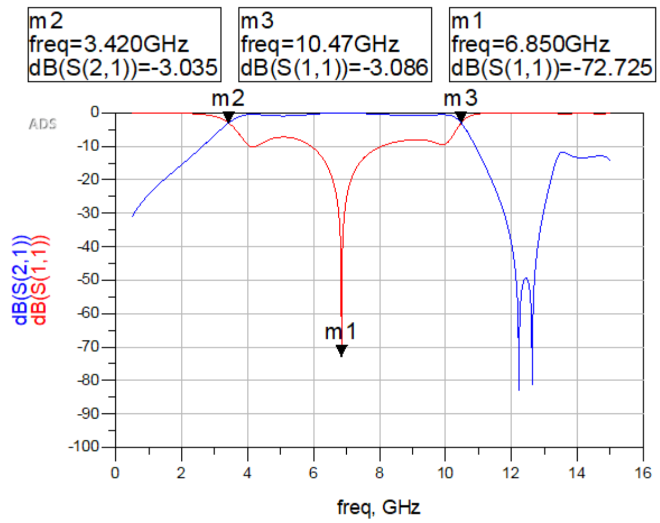

***Figure 19**. Simulated S11 and S21 parameters for 3 Via-holes SIR based BPF*

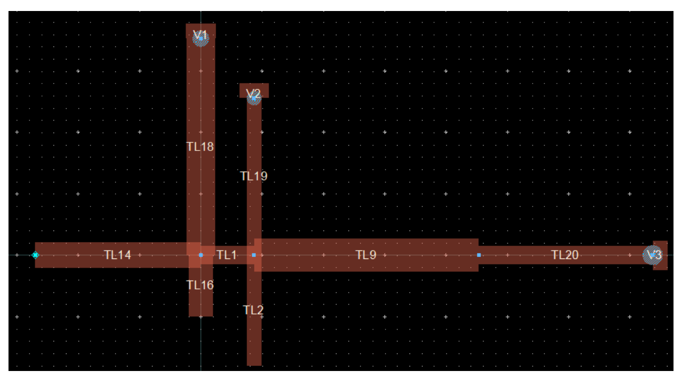

***Figure 20**. Layout of 3 Via-holes SIR based bandpass filter*

4. CONCLUSION

The microstrip wideband bandpass filters are analyzed and designed employing high frequency Agilent ADS software. The lumped and step impedance resonator based wideband bandpass filter at resonant f_o= 6.85 GHz is designed with return loss of more than 70 dB at resonant frequency. The fractional bandwidth of proposed filter is estimated as 109.5%. The via holes are introduced in design of wideband bandpass filter using step impedance resonator techniques which enhances the vital parameters of proposed filter viz. bandwidth, insertion and return loss in passband of the filter. The bandwidth of the filter i.e. ultrawide bandwidth using via-holes recorded as 7.0

GHz at resonant frequency 6.85 GHz and return loss nearly 73 dB and insertion loss (< 1.0 dB). The design results revealed that the efficiency of filter can be enhanced by incorporating SIR techniques. This not only eases the design procedure but also imparts compactness to filter size. Due to these elegant features; the proposed filter can be employed in numerous of microwave and modern wireless systems.

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