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Performance Comparison of Micro strip Band pass Filter Topologies On Different Substrates

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ABSTRACT— This paper presents the design of five pole microstrip bandpass filters with hairpin and combline configurations with a center frequency of 4.8 GHz The simulation is performed using ADS simulation tool. The filters are designed for different substrates like FR4, RT/Duroid 6010, and RO3010. The filter performance is compared for these substrates in terms of insertion loss and return loss. The simulated results show that both filters are operating well for the desired specifications and the substrate with higher dielectric constant provides higher return loss and lower insertion loss for both filter configurations.

KEYWORDS— Bandpass filter, microstrip, dielectric constant, fractional bandwidth, hairpin, combline, substrate, insertion loss, return loss.

I. INTRODUCTION

A filter is a network which allows the transmission of signal frequencies within the pass band and rejects at the stop band region. Mobile communication market which is developing very fast needs huge compact and inexpensive communication devices such as microwave filters and antenna. Microwave/RF filters are widely used in the wireless communication systems in order to discriminate between the desired and undesired signal frequencies. Microstrip bandpass filters confine the Radio Frequency signals within the assigned spectral limits since the electromagnetic spectrum is limited by various reasons such as licensing issues.

There are many filters available in market but due to some reasons it has certain disadvantages. The lumped-element filter will not be good choice if a sharp rejection is needed because of its limited 'Q' value. Helical filters are the best, as they provide excellent rejection profile but suffer from big size, assembly and tuning problems. Surface acoustic wave filters provides excellent performance but their shortcoming is lossy [1].

Return loss and insertion loss are considered to be the performance measurement parameters for any high frequency filter design. Our proposed work focuses on the design and performance comparison of different microstrip bandpass filter topologies such as hairpin and combline configuration. Though the physical realization of filters varies, the circuit network topology remains the same.

Hairpin filter is a 'U' shaped filter obtained from parallel coupled resonator. The resonator is bent at both the ends so it gets the shape of 'U' and length of resonator is reduced to half of its original length. Hairpin structure is compact in size and it does not require grounding. Combline filter is widely used type of coaxial filter. It consists of array of coupled resonator structures. Each resonator has a direct ground connection at one end and grounded with capacitor at other end.

To design these filters and to perform simulation results, EM simulation tools can be used. The filter design frequency is chosen in C band frequency segment and the simulation is done for different substrates using ADS simulation tool. The filter performance parameters are simulated in terms of insertion loss and return loss. Simulation results are represented in terms of S-parameters such as transmission coefficient (S_{12}) and reflection coefficient (S_{11}).

II. DESIGN METHODOLOGY

Generally filters are of two types, one is with lumped elements and another one is with distributed elements. The performance of distributed element is effective at microwave frequencies. Due to this reason, most of the microwave bandpass filters are based on distributed elements (e.g. waveguides, microstrip lines, and coplanar waveguides) [2].

Microstrip bandpass filters can be designed by two methods: Image parameter method and insertion loss method. In this proposed work, insertion loss method is used since it provides high degree of control over passband and stopband amplitude and phase characteristics [3].

For design of microstrip bandpass filter, low pass prototype elements are calculated for Chebyshev fifth order response. Initially low pass filter is designed and it is converted to the same order bandpass filter. By using J-inverters and impedance values, parallel coupled filters have been designed. From the dimensions of parallel coupled filter, hairpin and combline configurations are designed.

A. Design Steps

Based on the design specifications given in Table I, prototype values are calculated for lowpass filter. The following steps are generally involved in the design of filter topologies.

- Design of fifth order low pass filter using filter prototype element values.
- Transformation of lowpass to bandpass.
- Design of parallel coupled filter based on even and odd mode impedances.
- Design of hairpin and combline filter from the parallel coupled filter.

B. Design Equations

Low pass prototype element values are given in Table II. Using $g_0, g_1 \ldots g_6$, lumped element values for lowpass filter have been calculated. For lowpass to bandpass transformation, all capacitors in low pass are replaced by parallel resonators in bandpass and all inductors in low pass are replaced by series resonators in bandpass.

TABLE I
DESIGN SPECIFICATIONS

Filter type	Chebyshev
Order of filter (n)	5
Center frequency (f_0)	4.8 GHz
Fractional bandwidth (FBW)	0.1%
Dielectric constants (ε_r)	4.4 (FR4) 10.2 (RT/Duroid 6010) 11.4 (RO3010)

TABLE II
LOW PASS PROTOTYPE ELEMENT VALUES

Filter Order (n)	g_0	g_1	g_2	g_3	g_4	g_5	g_6
5	1	1.146	1.371	1.975	1.371	1.146	1

Parallel coupled filter uses half wavelength line resonators. These resonators are placed parallel to each other along half of their wavelength. This parallel arrangement gives large coupling between the resonators than end coupled filter configuration.

For designing parallel coupled bandpass filter, J-inverter method is used to convert low-pass filter to bandpass filter by making using low pass prototype element values. Inverters have the ability to shift impedance or admittance levels depending on the choice of impedance inverter 'K' or admittance inverter 'J' parameters. Making use of these inverters enables us to convert a filter circuit into an equivalent form that would be more convenient for microwave structures. The inverter constants are found using equations (1) & (2) [4]:

$$Z_O J_1 = \sqrt{\frac{\pi\Delta}{2g_1}} \tag{1}$$

$$Z_O J_n = \frac{\pi\Delta}{2\sqrt{g_{n-1}g_n}} \quad \text{n=2,..,5} \tag{2}$$

where $g_0, g_1, \ldots g_n$ are coefficients of Chebyshev filter design, $J_1, J_2 \ldots J_n$ are the characteristics admittance of J-inverters and Z_0 is the characteristic impedance of input and output lines. From the obtained results, the even and odd impedances can be calculated using equations (3) & (4) [4].

$$Z_{0e} = Z_0[\,1 + JZ_0 + (JZ_o)^2\,] \tag{3}$$

$$Z_{0o} = Z_0[\,1 - JZ_0 + (JZ_o)^2\,] \tag{4}$$

III. HAIRPIN FILTER

Hairpin filters are obtained by folding the ends of parallel coupled resonators on both the sides and it becomes 'U' shape. This type of U shaped resonator is called hairpin resonator [4]. So its length reduced to half of its original length. Hairpin filters are compact in size and it does not require any grounding, this makes the design simpler. The external quality factor and coupling coefficients are found using equations (5), (6) & (7) [4].

$$Q_{e1} = \frac{g_0 g_1}{FBW} \tag{5}$$

$$Q_{en} = \frac{g_0 g_{n+1}}{FBW} \qquad (6)$$

$$M_{i,i+1} = \frac{FBW}{\sqrt{g_i g_{i+1}}} \quad \text{for i=1 to n-1} \qquad (7)$$

where Q_{e1} and Q_{en} are the external quality factors of the resonators at the input and output, and $M_{i,i+1}$ are the coupling coefficients between the adjacent resonators.

IV. COMBLINE FILTER

Combline filters are the most widely used types of coaxial filters. This filter consists of array of coupled resonator structures depending upon the number of prototype element values. Each resonator is directly grounded at one end and grounded with capacitor at the other end. The capacitive loading at one end reduces the size of the filter but by choosing proper value of capacitor, the length of the resonators can be kept small. It uses quarter wavelength resonators. Quality factors and coupling coefficients can be obtained from equations (5), (6) & (7) [4].

Combline filters generally have compact structure with excellent stopband performance and also better coupling can be maintained between the resonators. Using LineCalc tool in ADS, the dimensions of the microstrip lines such as length, width and spacing are calculated for different substrates. Table III specifies the dimensional values of hairpin and combline filters over different substrates from even and odd mode impedances using ADS.

TABLE III
DIMENSIONAL VALUES FOR HAIRPIN AND COMBLINE FILTER

Substrate Materials	Width (mm)		Length (mm)		Spacing (mm)	
FR4 (ε_r=4.4)	W_1	0.34892	L_1	8.00556	$S_{0,1}$	0.25520
	W_2	0.46093	L_2	7.79779	$S_{1,2}$	0.26404
	W_3	0.46830	L_3	7.77775	$S_{2,3}$	0.34930
	W_4	0.46830	L_4	7.77775	$S_{3,4}$	0.34930
	W_5	0.46093	L_5	7.79779	$S_{4,5}$	0.26404
	W_6	0.34892	L_6	8.00556	$S_{5,6}$	0.25520
RT/ Duroid 6010 (ε_r =10.2)	W_1	0.16132	L_1	5.61158	$S_{0,1}$	0.18440
	W_2	0.22014	L_2	5.62679	$S_{1,2}$	0.29541
	W_3	0.22381	L_3	5.61184	$S_{2,3}$	0.37320
	W_4	0.22381	L_4	5.61184	$S_{3,4}$	0.37320
	W_5	0.22014	L_5	5.62679	$S_{4,5}$	0.29541
	W_6	0.16132	L_6	5.61158	$S_{5,6}$	0.18440
RO3010 (ε_r =11.4)	W_1	0.14226	L_1	5.34813	$S_{0,1}$	0.18806
	W_2	0.19583	L_2	5.20689	$S_{1,2}$	0.29908
	W_3	0.19916	L_3	5.19316	$S_{2,3}$	0.37606
	W_4	0.19916	L_4	5.19316	$S_{3,4}$	0.37606
	W_5	0.19583	L_5	5.20689	$S_{4,5}$	0.29908
	W_6	0.14226	L_6	5.34813	$S_{5,6}$	0.18806

V. DESIGN AND SIMULATION RESULTS

ADS simulation tool is used to simulate the schematic and layout of microstrip hairpin filter for the calculated design values in different substrates. The simulated results show that the substrate with higher dielectric constant gives better performance than the one with the lower dielectric constant. Fig. 1 and Fig. 2 show the schematic view and layout view of hairpin filter.

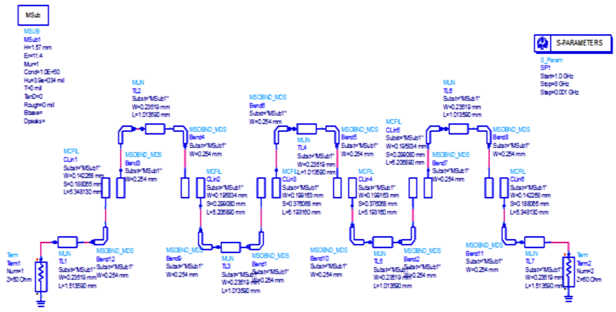

Fig. 1. Schematic view of hairpin filter

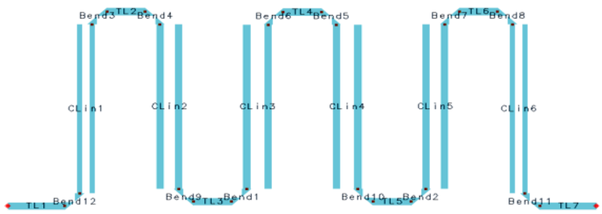

Fig. 2. Layout view of hairpin filter

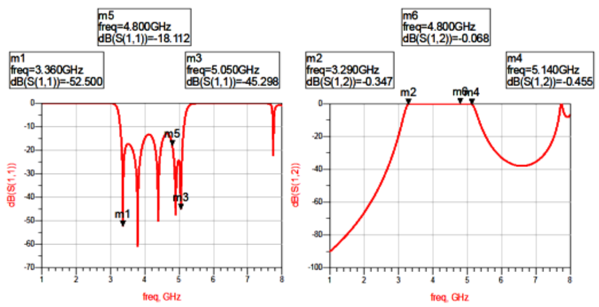

Fig.3. Simulated performance of hairpin filter in FR4

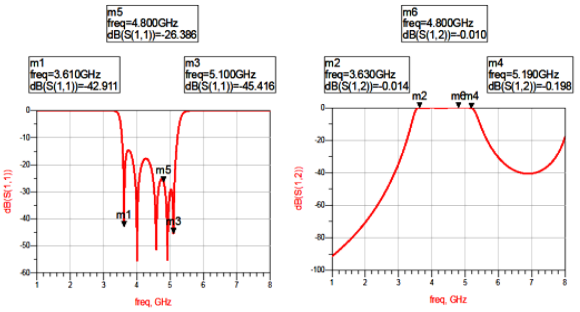

Fig.4. Simulated performance of hairpin filter in RT/Duroid 6010

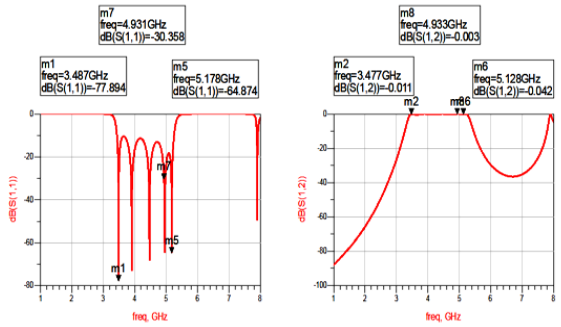

Fig.5. Simulated performance of hairpin filter in RO3010

Similar to hairpin filter design, the same ADS simulation tool is used to simulate the schematic and layout of microstrip combline filter for the calculated design values in different substrates. In this design also, the simulated results show that the substrate with higher dielectric constant gives better performance than the one with lower dielectric constant. Fig 6 & 7 shows the schematic and layout view of combline filter.

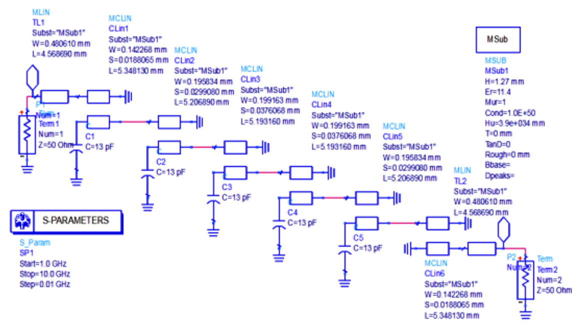

Fig.6. Schematic view of combline filter

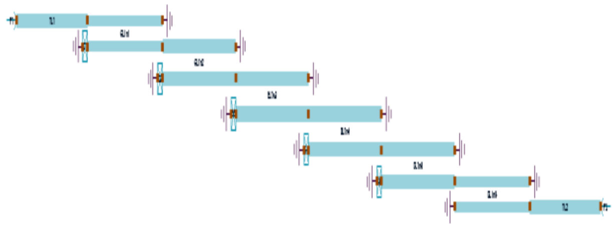

Fig.7. Layout view of combline filter

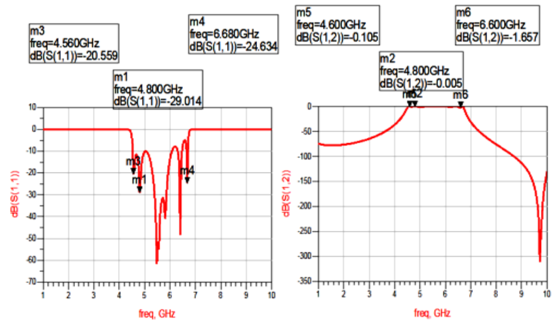

Fig.8. Simulated performance of combline filter in FR4

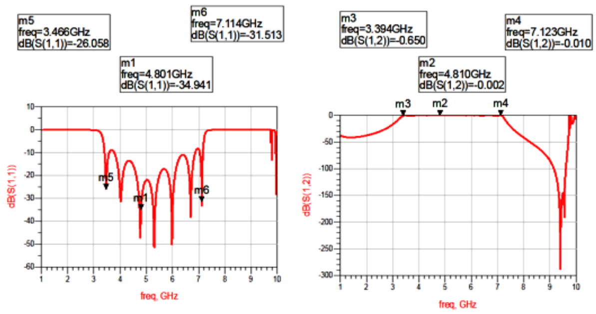

Fig.9. Simulated performance of combline filter in RT/Duroid 6010

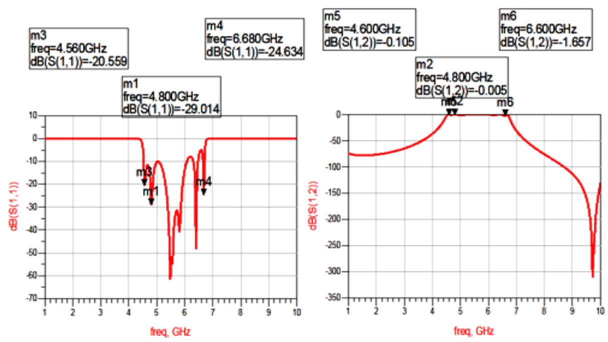

Fig.10. Simulated performance of combline filter in RO3010

TABLE IV PERFORMANCE COMPARISON OF FILTERS

Substrate Materials	Hairpin filter		Combline filter	
	Insertion loss (dB)	*Return loss (dB)*	*Insertion loss (dB)*	*Return loss (dB)*
FR4	0.055	18.112	0.005	29.014
RT/ Duroid 6010	0.010	26.863	0.002	34.941
RO3010	0.003	30.677	0.003	40.043

VI. CONCLUSION AND FUTURE WORKS

Both the filters have been successfully designed and simulated for the same center frequency of 4.8 GHz. Their return loss and insertion loss values are given in Table IV for different substrates. It shows that combline filter performs better than hairpin filter slightly over some points by having higher return loss and lower insertion loss. Also, filters designed on RO3010 substrate shows better performance than RT/Duroid 6010 and FR4 substrates. The main advantage of using ADS is that it decreases EM simulation time and shows the exact results.

Further, both hairpin and combline filters have to be fabricated on the above three substrates and their performance can be verified using network analyser by measuring S_{11} and S_{21} parameters. Further optimization can be done to get exact dimension values and with tapping at the end ports, greater coupling can be obtained between resonators and its end ports.

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