Microstrip Low-Pass Filter using Hexagonal Patch with Wide Stopband

Kumud Ranjan Jha
School of Electronics and Communication Engineering
Shri Mata Vaishno Devi University
Katra, Jammu and Kashmir, India,182301
email: jhakr@rediffmail.com

G. Singh
Department of Electronics and Communication
Jaypee University of Information Technology
Solan, India, 173215
email: drghanshyam.singh@yahoo.com

Abstract— **In this present paper, a microstrip low-pass filter using hexagonal capacitive patch with the upper cut-off frequency equal to 2 GHz is analyzed and designed. The proposed filter shows significant reduction in the effective area on the substrate along with an improved pass-band performance and a wide stop-band. To verify the analysis, the structure has been simulated using two popular software packages: a) IE3D and b) Sonnet Lite both based on the method of moments technique and the performance of the filter is in the good agreement.**

Keywords- Microstrip Low Pass Filter, Impedance, Hexagonal, Microstrip Filter.

I. INTRODUCTION

In the modern communication system, miniaturization of the circuit has become a key factor in any active and passive component design. In addition to this, the circuit must perform optimally. Microstrip low-pass filter designed using high-low impedance technique is available in the literature [1-2]. The performance of this low-pass filter does not meet today's requirement as it is bulkier and stop-band performance is also not up to the mark. Apart from this, a filter has been designed using hairpin resonator [3] whose return loss in the pass-band is not better than -13 dB. Moreover, the filter design is based on the analysis of ABCD matrix which makes the solution a tedious work. The defected ground structures (DGS) and photonic bandgap (PBG) filters have also been reported but they do not give a way to reduce the effective size on the substrate [4-7]. Manufacturing cost of this kind of filter also increases as the etching on the ground plane is required. Low-pass filter using inter-digital capacitance [8] and a simple structure [9] have been designed whose response in stop-band is appreciable but pass-band return loss is still needs an improvement. A microstrip low-pass filter using open-loop resonators with the sharp cut-off frequency has been proposed in [10] but the size reduction is not possible. Further, its stop band characteristic also diminishes due to inherited resonating property of open loop resonator. Apart from this, the microstrip low-pass filter using different techniques has also been analyzed in [11-15] but they have their own advantages and disadvantages. In the recent past, a filter using simple structure and parallel coupling of microstrip transmission lines was proposed [16] which may be well suited for modern filter design requirement. However, a further reduction in size with improved performance is still possible.

In the present paper, a new microstrip low-pass filter using hexagonal capacitive patch is proposed. This filter is characterized by small size, good pass-band and stop-band performance. This paper is organized as follows. The Section II of the manuscript deals with the theory of the proposed filter design. The design example is presented in the Section III. Finally, the work is concluded in the Section IV.

II. THEORY

The proposed structure and its equivalent circuit model are shown in Fig. 1(a) and Fig. 1(b), respectively. The proposed structure contains two inductive lines and one capacitive patch whose equivalent circuit models are shown in the Fig. 2.

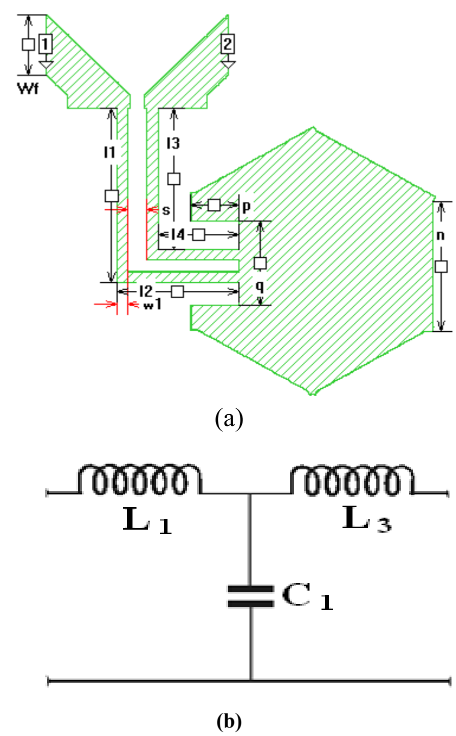

Figure 1. Proposed (a) Hexagonal structure and (b) its equivalent circuit model.

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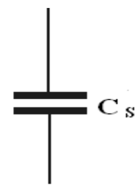
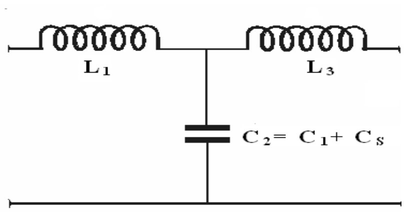


(a)



(b)

Figure 2. Equivalent circuit model of (a) Hexagonal patch and (b) Hexagonal low-pass filter.

The value of the lumped inductive and capacitive elements in the equivalent circuit model of the hexagonal low-pass filter as shown in Fig. 1 are obtained by using the following formulas:

$$C_1 = Y_I \sin(\theta_l)/\omega \tag{1}$$

$$L_1 = L_3 = Z_I \tan(\theta_l/2) \tag{2}$$

where θ_l and Y_I are the electric length of right angled inductive line and the image impedance of line, respectively. The image impedance is given by the following formula.

$$Z_I = 1/Y_I = \sqrt{Z_{oe}Z_{oo}} \tag{3}$$

$$\cos(\theta_i) = \left[\left(Z_{eo}/Z_{oo}\right) - \tan^2\theta_c\right] \Big/ \left[\left(Z_{eo}/Z_{oo}\right) + \tan^2\theta_c\right] \tag{4}$$

$$C_S = (Y_S + \tan(\theta_S))/\omega \tag{5}$$

In the Equation (4) and (5), Y_S and θ_S are characteristics admittance and electrical length of the equivalent rectangular capacitive patch, respectively. If the fringing field is ignored, C_S α Area of the rectangular capacitive patches. Further, area of the rectangular patch can be made equal to the area of any irregular/regular patch with the caution that the behavior of the patch remains capacitive only. On this way, each side of hexagonal patch is calculated with the help of the following formula.

Area of Hexagonal patch = Area of rectangular patch

$$= \left(side^2 \times N\right)/\left(4\tan(\pi/N)\right) \tag{6}$$

where N= 6 is number of sides of regular polygon. A small fraction of capacitance is associated with parallel coupled microstrip lines, which is in the parallel to the capacitance associated with the hexagonal capacitive patch. For a negligible fringing field, the total capacitance in the circuit is equal to the $C_2 = C_1 + C_S$, whose value can be obtained from the table of low-pass filter available in the literature.

III. DESIGN EXAMPLE

A 3rd order Chebyshev filter with -3 dB cut off frequency at 2.0 GHz and -0.1 dB maximum attenuation in pass-band with 50Ω port impedance is designed. The proposed hexagonal filter is designed on the substrate with the relative dielectric constant 3.2and thickness 0.762 mm, respectively. To realize the high and low impedance lines, their characteristic impedances equal to 120 Ω and 20 Ω, respectively have been selected. Prototype value of low-pass filter for the said specifications is obtained from the available table [1].

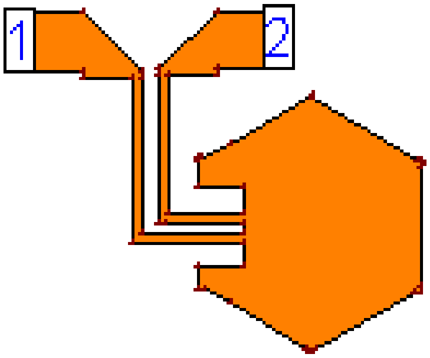
TABLE I. DIMENSIONS OF DIMENSIONS OF EQUIVALENT STUBS

Element	Length (mm)	Width (mm)
L1	6.79	0.322
C2	5.76	6.94
L3	6.79	0.322
s	--	0.55

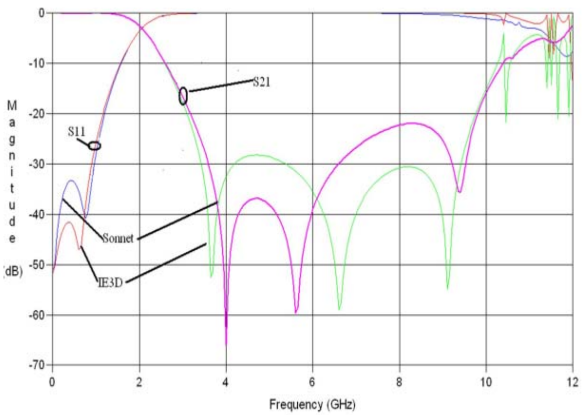
TABLE 2 FINAL DIMENSIONS OF HEXAGONAL LOW-PASS

Element	Dimension (mm)
l1	5.17
l2	3.38
l3	4.17
l4	2.28
p	1.36
q	2.50
Wf	1.8
n	3.85
s	0.55

The dimensions of equivalent rectangular stubs are calculated using formulas (1)–(5) which are presented in Table 1. Calculated area of capacitive patch after making a room to connect inductive lines is equal to 39.97 mm^2. However, this capacitance contains parasitic value which is reduced by iteration and optimization and final value of capacitive patch is equal to 36.6 mm^2. With the help of formula (6), the dimension of hexagonal patch is calculated. To tune the filter response to specified frequency of 2.0 GHz, Patch and line dimensions of the filter as shown in Fig. 1 have been adjusted and it is presented in Table 2. Simulated structure using IE3D and its response obtained by using two different simulators are shown in Fig. 3 (a) and (b), respectively. The filter also exhibits an excellent group delay, whose maximum value is 0.27 ns in the pass band. The group delay of the filter obtained using Sonnet Lite software is shown in Fig. 4.



(a)



(b)

Figure 3. Proposed (a) low-pass filter and (b) its response

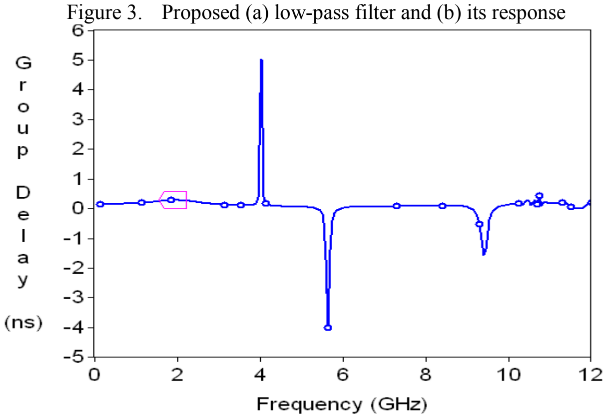


Figure 4. Group delay of hexagonal microstrip low-pass filter.

IV. CONCLUSION

In the present paper, a new microstrip low pass filter has been designed and the responses have been verified. The filter shows and excellent skirt type response due to coupling of high impedance lines. Due to folding of the lines and application of hexagonal capacitive patch the miniaturization of the filter is achieved. Total effective area on the substrate is equal to 8.517X 9.04 mm^2, which is quit less than the conventional low pass filter and there is a significant reeducation of 0.0013 $\lambda_g^{\ 2}$ mm^2 area in comparison to the skirt type filter reported in [16]. Insertion loss in pass band is better than -0.1 dB and wide stop band better than -20 dB extends from 3.2 to 9.8 GHz. The group delay of this filter is less than 0.27 ns. The presented design will further stimulate the microstrip low-pass filter design using abruptly chosen capacitive patch for wireless communication system.

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