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Narrow Gap Coupled L-Shaped Microstrip Filter Design For WIMAX Applications

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Abstract

In modern microwave communication systems high performance bandpass filters having low insertion loss and high selectivity together with linear phase in the passband are required. L-shaped coupled microstrip lines with controlled gap coupling are utilized in this paper to obtain narrowband filter characteristics. The bandpass filter is designed on Rogers substrate material with permittivity of 3.38 and achieves bandwidth of 163.02 MHz (4.52% fractional bandwidth) at center frequency of 3.65 GHz while maintaining narrow gap between coupled resonators. The simulative analysis of microstrip bandpass filter is performed using FEM based COMSOL Multiphysics software.

Keywords

Finite Element Method, Insertion Loss, Microstrip Line, Microstrip Filter, Return Loss, WIMAX

1. Introduction

Bandpass filter is a passive component which is able to select signals inside a specific bandwidth at a certain center frequency known as pass band and reject signals in another frequency region, especially in frequency regions, known as stop band. At microwave frequency, the bandpass filter with low insertion loss and compact size plays an important role in the microwave communication systems especially in the transmitting and receiving systems to identify and transmit the desired signals [1]. Filters with planar nature are particularly attractive because of their easy fabrication, simple synthesis procedure, good repetition, compact size, and low cost [2]. Besides their evident application of providing frequency selectivity, filters are necessary for matching networks which form an integral part of multiplexers and amplifiers.

Microstrip transmission lines are one of the most popular types of planar transmission lines, used in microwave integrated circuits (MIC) and monolithic microwave integrated circuits (MMIC), primarily because of its relative ease of fabrication and its simple integration with other passive and active microwave devices. It has many advantages, which include small size, low cost, no critical machining, no cutoff frequency, ease of active device integration, use of photolithographic method for circuit production, good reproducibility, repeatability and ease of mass production [3]. There are four different types of bandpass filters at microwave frequency: the combined filters, interdigital filters, parallel coupled filters and the hair-pin line filters. In modern RF/microwave communication systems, the size of the planar microwave filters is one of the major concerns, especially when these filters are applied in the monolithic microwave integrated circuits (MMIC) [4]. Larger gaps between coupled resonators is desirable to achieve narrow bandwidth and high selectivity demanding large quality factor, Q, which however will lead to increased filter size. The present day applications in wireless communication near 3 GHz demand for small size and low cost designs while achieving narrow FBW and high value of Q.

2. Design Methodology

The filter design is based on the coupling of microstrip lines through a common ground plane. A coupled microstrip line configuration consists of two transmission lines placed parallel to each other and in close proximity. In this configuration there is a continuous coupling of the electromagnetic fields between the two lines and cascading the stripline elements gives rise to bandpass and bandstop filter structures that are most easily designed with the aid of RF circuit simulation packages. A simple modelling approach of coupled microstrip line interaction is established considering the geometry depicted in Figure1.

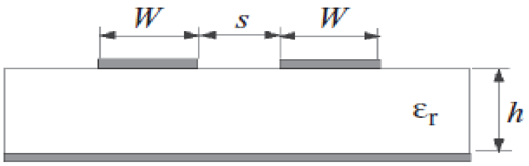
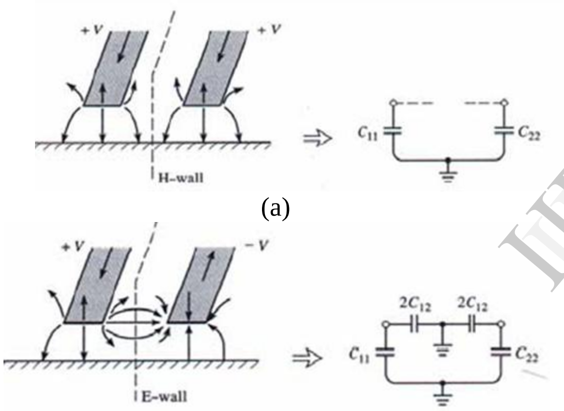


Figure 1. Coupled microstrip line

Two microstrip lines having W width and negligible thickness are separated over a distance S and attached to a dielectric medium of thickness h and dielectric constant ϵ_r. The microstrip lines are capacitively coupled and support two quasi-TEM modes, i.e. the even and the odd mode. For an even-mode excitation, there is a magnetic wall at the symmetry plane between microstrip lines because they have the same voltage potentials, and for an odd mode excitation, there is an electric wall at the symmetry plane between microstrip lines because they have the opposite voltage potentials, as indicated in Figure 2.



(a)

(b)

Figure 2. (a) Even (b) Odd-mode excitations and equivalent circuit for coupled microstrip lines

The resulting even mode capacitance of either line to ground is:

$$C_e = C_{11} = C_{22}$$

And odd mode capacitance,

$$C_o = C_{11} + 2C_{12} = C_{22} + 2C_{12}$$

The relationship between even and odd mode capacitances and impedances are given by

$$Z_{0e} = \frac{1}{v_{pe}} = \frac{\omega}{\beta_e C_e}$$

$$Z_{0o} = \frac{1}{v_{po}} = \frac{\omega}{\beta_o C_o}$$

where Z_{oe}, v_{pe}, β_e denotes the characteristic impedance, phase velocity and phase constant, respectively, of the even mode of the coupled lines; and Z_{oo}, v_{po}, β_o denote the same quantities for the odd mode.

For the bandpass filter section, the geometric arrangement with input and output ports and open-circuit conditions and the corresponding transmission line representation are shown in Figure 3.

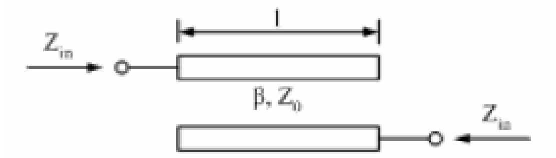


Figure 3. Bandpass filter element

The input impedance, Z_{in} is a function of the electric length in the range, $0 \leq (\beta l) \leq 2\pi$.

$$Z_{in} = \frac{1}{2\,sin(\beta l)}\sqrt{(Z_{0e} - Z_{0o})^2 - (Z_{0e} - Z_{0o})^2 cos^2(\beta l)}$$

3. Multi-Resonator Filter Design

The filter design presented uses simple L-shaped coupling between λ/2 and λ/4 microstrip lines with narrow gap hence resulting in reduced size. FEM based COMSOL Multiphysics software has been used for the design and simulation of coupled resonator bandpass filter, which is a powerful interactive environment for modeling and solving all kinds of scientific and engineering problems based on partial differential equations (PDEs). For more realistic implementation, 3D model of microstrip filter has been created in frequency domain of RF module. The cross-sectional view of the structure generated for designing filter model is shown in Figure 4.

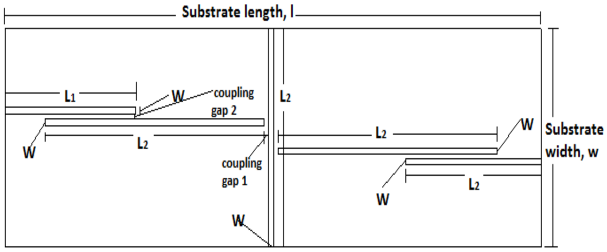


Figure 4. Cross sectional view of proposed microstrip filter design

Five microstrip lines are initially coupled to form two L-shaped resonators with common central microstrip line. The microstrip filter is designed on a Rogers substrate material having relative permittivity 3.38 and thickness 2.79 mm. It is assumed that the thickness of the strip is negligible because with small thickness of transmission line the signals can be easily transmitted at high frequencies with low distortion and also assume that all the media and conductor are lossless.

The geometrical parameters of microstrip filter are as follows
W = microstrip line width= 1.13mm
L_1= microstrip line length= 15 mm= $\lambda/2$
L_2= microstrip line length= 25 mm= $\lambda/4$
l = substrate length= 57.5 mm
w = substrate width= 25 mm
coupling gap1 =92.89 µm
coupling gap 2= 49 µm

The model created is enclosed in an air box with PEC boundaries as shown in Figure 5. The dimensions of air box is given as
Width of air box = 25mm
Length of air box = 60mm
Height of air box = 5mm

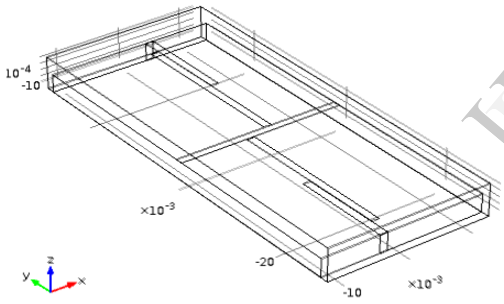


Figure 5. Geometry of narrow gap coupled L-shaped microstrip filter

The filter is designed to operate in the frequency range from 3 GHz to 4.2 GHz. Appropriate boundary conditions are assigned, then meshing is performed on the model to obtain final refined mesh. In meshing, it is generally understood that a finer mesh (more elements) will give a more precise solution. However, a finer mesh will also need more time for the computer to solve the study. Therefore, it is essential to determine the appropriate balance between computation time and an acceptable level of accuracy. Figure 6 shows the final refined mesh of the model. The complete mesh consisted of 36716 elements and the number of degree of freedom is 241458. The governing equations are then defined for discretized model and solved inside each of these sub-domains.

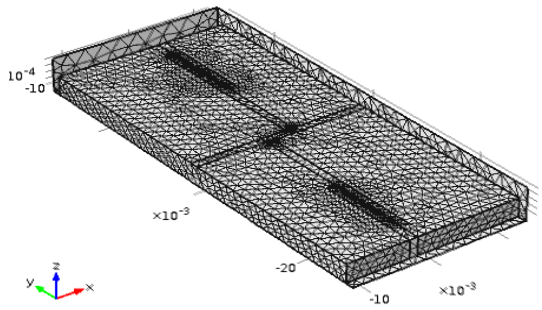


Figure 6. Meshing of narrow gap coupled L-shaped microstrip filter

The parametric solver is used together with a stationary solver to handle settings for parameter stepping. The stationary solver (including parametric sweeps) uses a linear solver algorithm for solution determination. The execution has been performed using Intel(R) Core(TM) i7-3770 @3.40 GHz 3.90GHz CPU with simulation time of 780sec.

4. Simulation Results

Figure 7 shows the surface plot of electric field distribution. S_{21} and S_{11} parameters are plotted as a function of frequency to characterize the transmission coefficient and return loss respectively as depicted in Figure 8. It can be observed that microstrip filter achieves bandwidth of 163.02 MHz (4.46% fractional bandwidth) at center frequency of 3.65 GHz. The value of return loss S_{11} shoots down to a peak of -18.655 dB and minimum insertion loss S_{21} of 0.169 dB at passband is obtained with 22.38 Q-factor. The coupled resonator microstrip bandpass filter achieves the narrowband characteristics using simpler design with narrow gap couplings for compact size. The commercially available and cost effective Rogers material is used as substrate.

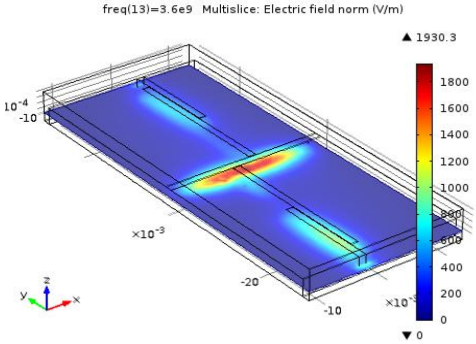


Figure 7. Electric field distribution of narrow gap coupled L-shaped microstrip filter

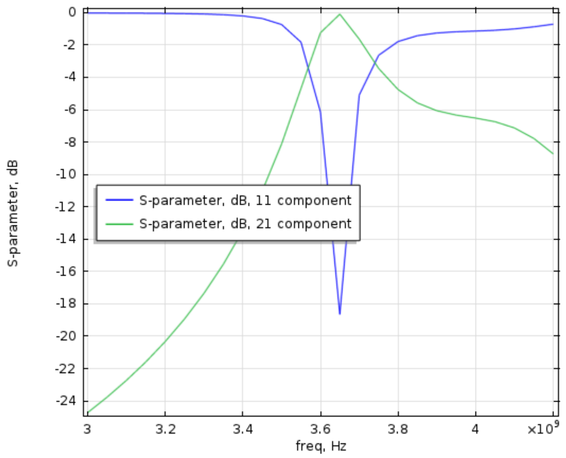


Figure 8. S-parameter plot for narrow gap coupled microstrip filter

Analysis of proposed filter design for different substrate thickness

The thickness of substrate has significant impact on microstrip filter design. The decreased substrate thickness renders compact circuits, ease of integration, less tendency to launch higher-order modes or radiation. The effect of varying substrate thickness on proposed microstrip filter performance has been presented in this section. In this analysis, using the same design parameters, microstrip filter is designed on substrates with thickness of 2 mm and 1 mm. After simulation, S_{21} and S_{11} parameters are plotted as a function of frequency as shown in Figure 9. It can be clearly seen from the graphs that microstrip filter with substrate thickness of 2 mm and 1 mm have 3-dB insertion loss bandwidth of 230.1 MHz (6.39% FBW) and 286.38 MHz (8.18% FBW) respectively.

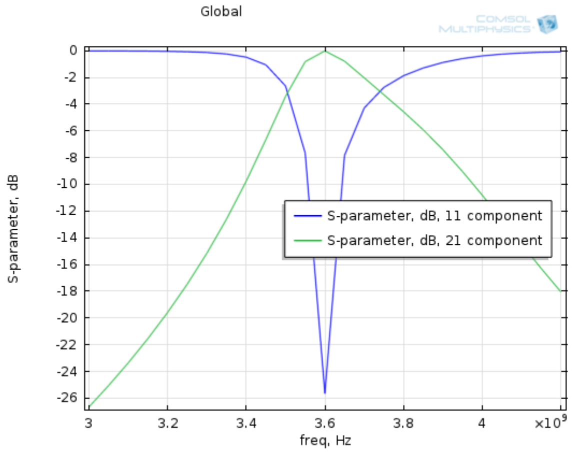


Figure 9(a). S-parameter plot for microstrip filter with substrate thickness 2 mm

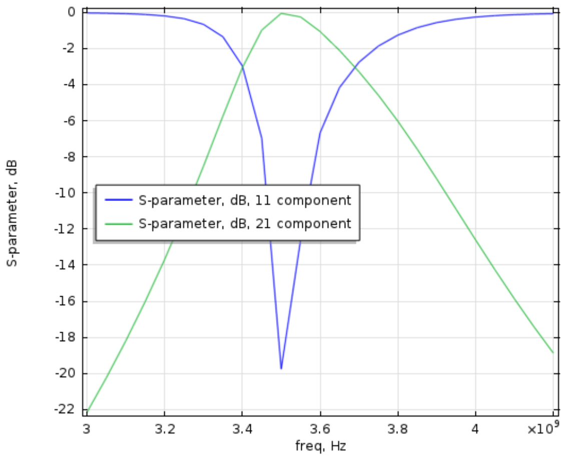


Figure 9(b). S-parameter plot for microstrip filter with substrate thickness 1 mm

It has been observed that with decrease in the substrate thickness, the bandwidth increases notably and the Q-factor however decreases. Further it is illustrated that center frequency shift towards lower side with decrease in the substrate thickness. The comparative analysis in terms of FBW, Q-factor, IL & RL is presented for different value of substrate thickness in Table 1. The minimum fractional bandwidth of 4.46% (163.02 MHz) is achieved with filter designed on 2.79 mm thick substrate material. The compromise on the overall size is compensated by using λ/2 and λ/4 strip length sections to optimize the performance of the filter with high Q-factor of 22.38.

Tabel 1. Comparative analysis of microstrip filter with different substrate thickness

Substrate Thickness	**FBW (%)**	**RL (dB)**	**IL (dB)**	**Q**	**Center Freq (GHz)**
2.79mm	4.46	-18.6	-0.1	22.38	3.65
2 mm	6.39	-25.6	-0.01	15.64	3.6
1 mm	8.18	-19.7	-0.05	12.22	3.5

5. Conclusions

This paper presents a very simple design of narrowband bandpass microstrip filter modeled by using L-shaped coupled resonators. The simulative analysis is performed with the help of FEM based COMSOL Multiphysics software. Less than 3-dB insertion loss and better than 10-dB return loss at center frequency 3.65 GHz with 3 dB bandwidth of 163.02 MHz is achieved. The effect of varying substrate thickness on the filter performance is analyzed and it has been shown that improved Q-factor and reduced fractional bandwidth of less than

5% at resonant frequency of 3.65 GHz is obtained by increasing the substrate thickness. Very narrow gap coupling between microstrip resonators designed by using microstrip lines of lengths λ/2 and λ/4 is therefore utilized to reduce the overall size of the filter achieving optimized performance. The proposed microstrip filter is hence feasible for WiMAX applications.

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