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Finite Element Modeling of Coupled Microstrip Resonator in Different Configurations

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Abstract: Finite Element Method has been used in this paper for design and analysis of coupled microstrip line resonator. Distinct characteristics of microstrip resonator are investigated by varying different design parameter as coupling gap between microstrip lines, substrate thickness and substrate material. The modeling is performed on FEM based COMSOL Multiphysics simulation software. The results show that the proposed microstrip resonator exhibits bandpass and bandstop behavior in different configurations which can be utilized for designing filters for X-band applications.

Keywords: Microstrip line, Finite Element Method, Microstrip Resonator, S-parameter

I. INTRODUCTION

The rapid growth of microwave wireless communication systems demands a huge amount of communication devices, such as microwave filters and antennas. Microwave filters used in many microwave applications are the fundamental component that contributes to the overall performance of a communication system. Filters are build by coupling multiple resonators together i.e. resonator is the key component to design filters. Resonator is also used in controlling or stabilizing the frequency of oscillator, wave meter, antennas and measurement equipment [1]. Resonators can be designed by including two or more coupled microstrip lines arranged in different configurations [2]. Basically resonator is a device that exhibits resonance or resonant behavior i.e. it naturally oscillates at some frequencies called its resonant frequencies with greater amplitude than at other frequency. Resonator has three types of behavior, bandpass behavior, bandstop behavior and all pass behavior. The frequency selectivity property of resonant circuits are used in building oscillators, filter circuits. The main objective of this paper is to use coupled microsptrip lines to design microwave resonator to operate in X-band ranging from 8-12 GHz. The basic design is further modified to operate in different configurations exhibiting multiband operation, bandpass and bandstop behavior. The X-band frequencies are used in satellite communication, radar application and terrestrial communication.

The resonance behavior of microstrip resonator can be determined by evalating S-parameters. In case of microstrip resonator the S_{21} transmission coefficient displays resonance when strip length is a multiple of $\lambda_g/2$ [3]. Wavelength λ_g can be calculated in the microstrip line at the resonating frequency, f_r by

$$\lambda_g = {\lambda_0}/{\sqrt{\epsilon_r}}$$

where, ϵ_r is the dielectric constant and λ_0 is the wavelength of the wave with resonating frequency f_r in free space

$$\lambda_0 = {c}/{f_r}$$

The Quality factor, Q of resonator can be measured as

$$Q = \frac{f_r}{(\Delta f)_{3dB}}$$

Where f_r is resonance frequency and Δf is 3-dB bandwidth. High Q-factor is needed for an efficient resonator [4].

II. Microstrip Resonator Design

Fig. 1 shows the cross sectional view of the coupled microstrip line resonator.

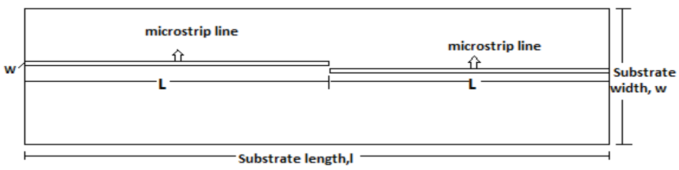


Fig.1 Cross sectional view of microstrip line resonator

The geometry of microstrip resonator designed in COMSOL software shown in Fig. 2 consists of two coupled microstrip lines on substrate having the following dimensions:
L= microstrip line length= 30mm
W= microstrip line width= 1mm
l = substrate length= 60 mm
w= substrate width= 15 mm
substrate thickness= 20 mil
coupling gap between strips= 0.05mm
It is assumed that the thickness of the strip is negligible and that all the media and conductors are lossless.
The substrate material used for microstrip resonator is Roger material (RO4000B). The properties of substrate are
Relative permittivity ($\in_r$) = 3.48
Relative permibility (μ_r) = 1
Conductivity (σ) = 0 S/m
An air box is used to enclosed the model with perfect electric conductor boundaries having following dimensions:
Length of Air box= 63mm
Width of Air box= 15mm
Height of Air box= 6mm

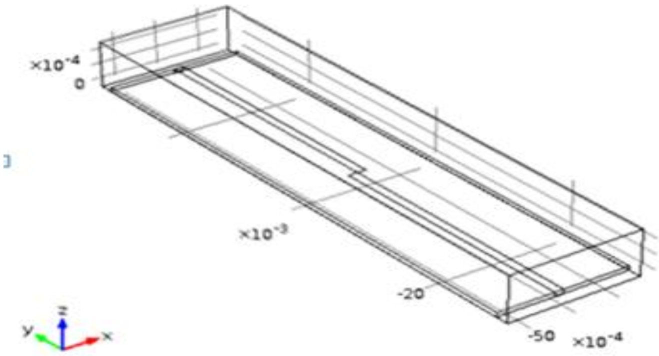


Fig.2 Basic geometry of microstrip line resonator

Operating frequency range in which this compact microstrip resonator works is 8-12 GHz. The model is assigned suitable boundary settings, the microstrip lines act as perfect electric conductor and two lumped ports are defined, wave excitation being activated at one of the ports. After applying the boundary conditions, meshing is performed on the model with mesh statics shown in Table1. Meshing can be contemplated as the splitting of domains into smaller sub-domains made up of geometric primitives like hexahedra and tetrahedral in case of 3D and quadrilaterals and triangles in case of 2D. Fig. 3 shows the meshing of microstrip resonator model. The final refined mesh consists of 19962 elements with 134868 no of degree of freedom.

TABLE 1
MESHING STATISTICS OF MICROSTRIP RESONATOR MODEL

Property	**Value**
Minimum element quality	0.06428
Average element quality	0.6708
Tetrahedral elements	19962
Triangular elements	5648
Edge elements	518
Vertex elements	28

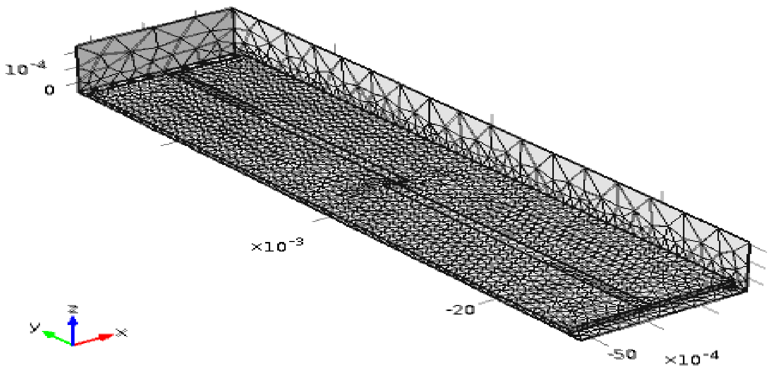


Fig. 3 Meshing of microstrip resonator

The model generated is then solved using stationary solver and produce the field values. Stationary solver is used to find the solution to stationary problems (also called static or steady-state problems). The parametric solver is an attribute feature that is used together with a stationary solver to handles settings for parameter stepping. The stationary solver (including parametric sweeps) uses a linear solver algorithm.

III. Simulation Results

After finding the solution of model, to analyze results, COMSOL Multiphysics provides numerous postprocessing and visualization tools including advanced graphics, data display and export functions. The execution has been performed using Intel(R) Core(TM) i7-3770 @3.40 GHz 3.90GHz CPU with simulation time of 833 sec. Fig. 4 shows the surface plot of electric field distribution.

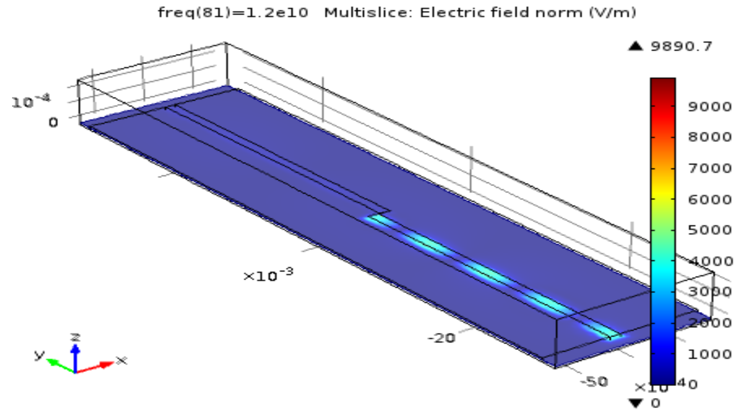


Fig.4 Electromagnetic analysis of basic microstrip resonator

The S-parameters S_{21} and S_{11} are plotted in Fig. 5. The resonator behavior of structure of coupled lines can be observed from the distribution. The value of return loss S_{11} shoots down to a peak of -23.01 dB at 9.95 GHz frequency. Further the insertion loss S_{21} is -0.028 dB at the same frequency. At the resonance frequency of 9.95 GHz with 3-dB insertion loss bandwidth of 17 MHz is achieved after simulation. The value of Q-factor obtained is 585.29. This model of microstrip resonator demonstrates bandpass behavior and good for design of narrow band filter.

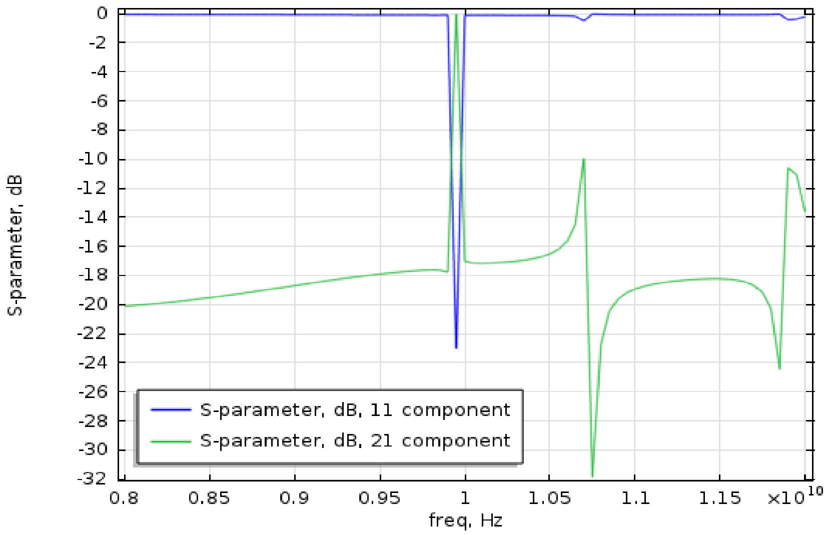


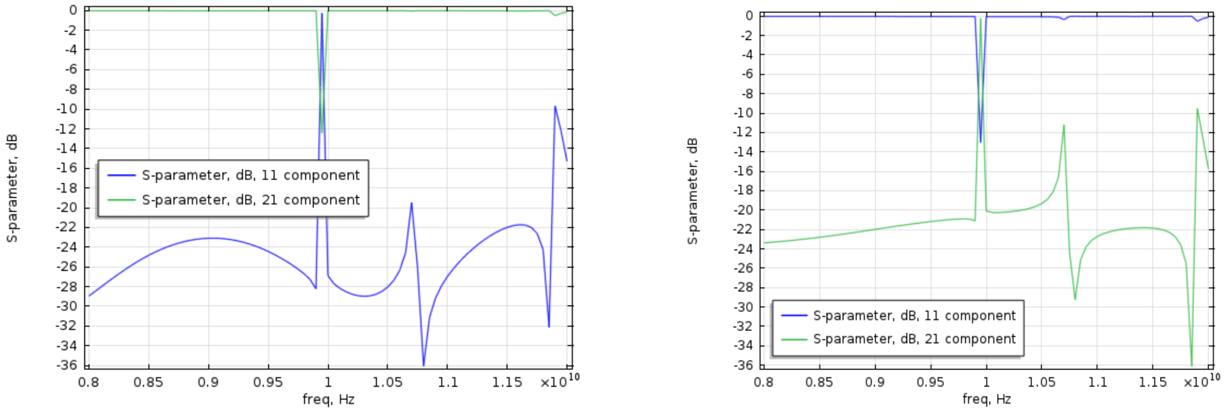
Fig.5 S-parameter plot of basic microstrip resonator

IV. Microstrip Resonator Configurations

The basic model of microstrip resonator presented in the above section resonates at 9.95 GHz. Various design parameters such as coupling gap, substrate thickness and substrate material in the basic model of microstrip resonator have been changed to generate the models for different configurations of the microstrip resonator.

A.Effect of Coupling Gap

Attempt has been made to study the effects of coupling gap between coupled microstrip line in microstrip resonator. The coupling gaps are expected to affect the shape of resonance, insertion loss and return loss. The base model has been designed using the coupling gap of 0.05mm. The gap is changed to 0 mm and 0.1 mm respectively to perform the analysis. Fig. 6. plots the S_{21} and S_{11} parameters to observe the effect of coupling gap on the performance of microstrip resonator.



(a) (b)

Fig. 6 S-parameter plot of microstrip resonator (a) without coupling gap (b) with coupling gap 0.1mm

Table 2 shows the comparison of resonant performance characteristics of the microstrip resonator with different coupling gaps.

TABLE 2
EFFECT OF COUPLING GAP ON MICROSTRIP RESONATOR PERFORMANCE

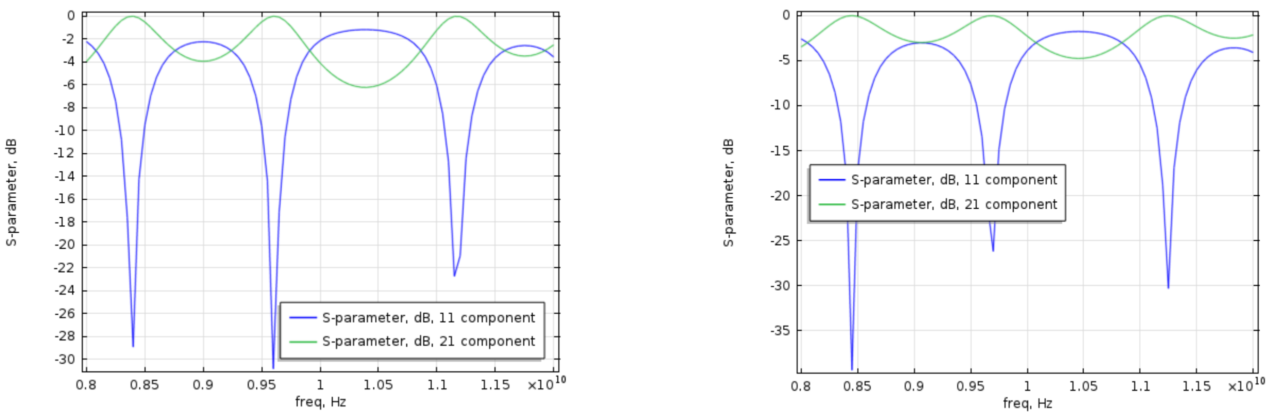
Coupling Gap	**f_r**	**IL**	**RL**	**Q**	**3-dB BW**
0.0mm	9.95 GHz	-12.43 dB	-0.26 dB	130.92	76 MHz
0.1mm	9.95GHz	-0.022 dB	-13.03dB	2733.5	3.64 MHz

It is evident that microstrip resonator operates at the same resonating frequency of 9.95 GHz irrespective of varying coupling gap. It has been observed however that the bandwidth varies as inversely proportional to the coupling gap between strips. The Q-factor is improved as coupling gap between strips is increased. Above two configuration of microstrip resonator exhibits bandstop and bandpass behavior respectively. The proposed resonator configurations can therefore be used for designing narrow band filters.

B. Effect of Substrate Thickness

The reduced substrate thickness is desirable in microstrip design due to benefits of compact circuits, ease of integration, less tendency to launch higher-order modes or radiation, and via holes drilled through the dielectric substrate will contribute smaller parasitic inductances to the overall performance. The present analysis studies the effect of decreasing substrate thickness on microstrip resonator performance. The substrate thickness is reduced from 20 mil in base model to values of 4 mil and 5 mil with no coupling gap between strips. The effect of varying substrate thickness on S_{21} and S_{11} parameters has been shown in Fig. 7.

It is observed that microstrip resonator having substrate of thickness 4 mil resonates at three frequencies that are 8.5 GHz, 9.75 GHz and 11.35 GHz Microstrip resonator having substrate of thickness 5 mil also resonate at three frequencies that are 8.45 GHz, 9.7 GHz and 11.25 GHz.



(a) (b)

Fig. 7 S-parameter plot of microstrip resonator having substrate thickness (a) 4 mil (b) 5 mil

The comparison of resonant performance characteristics of the microstrip resonator with different substrate thickness are tabulated in Table 3.

TABLE 3
EFFECT OF SUBSTRATE THICKNESS ON MICROSTRIP RESONATOR PERFORMANCE

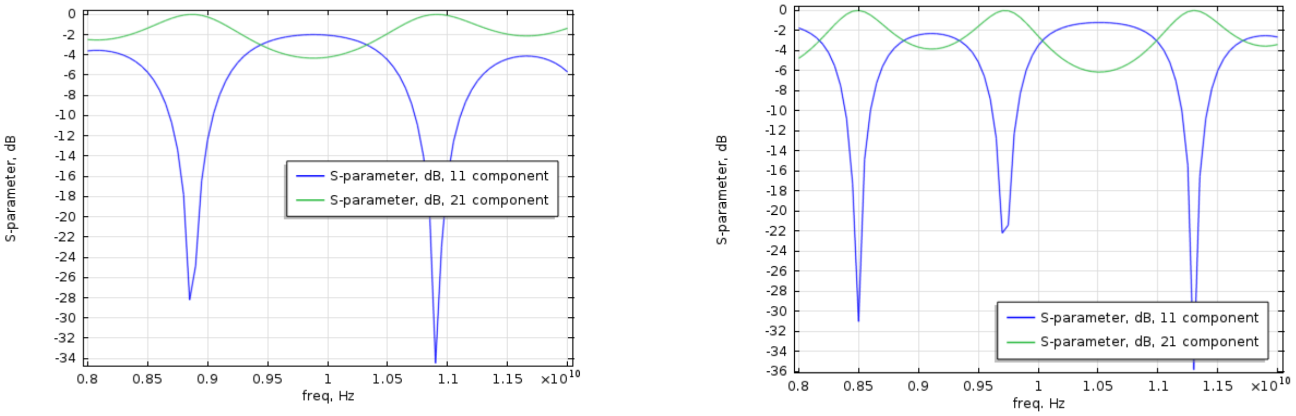
Thickness	**Resonant frequencies**	**Insertion Loss, IL**	**Return Loss, RL**
4 mil	8.5 GHz	-0.0003 dB	-32.04 dB
	9.75 GHz	-0.0035 dB	-31.77 dB
	11.35 GHz	-0.02 dB	-23.4 dB
5 mil	8.45 GHz	-0.001 dB	-39.39 dB
	9.7 GHz	-0.011 dB	-26.2 dB
	11.25 GHz	-0.005 dB	-30.31 dB

From the table it can observed that changing the substrate thickness to 4 mil and 5 mil shifts the resonating frequencies towards the lower side.

C. Effect of Substrate Material

Two different substrate material PTFE (ϵ_r= 2) and Roger material (ϵ_r= 3.38) are taken with substrate thickness 4 mil and without coupling gap between strips. Fig. 8 shows the effects of different substarte material on S_{21} and S_{11} parameters of microstrip resonator.

The S-parameter plot shows that microstrip resonator having substrate material with ϵ_r= 2 resonates at two frequencies that are 8.85 GHz and 10.9 GHz and having substrate material with ϵ_r=3.38 resonates at three frequencies that are 8.5GHz, 9.7 GHz and 11.3 GHz.



(a) (b)

Fig. 8 S-parameter plot of Microstrip Resonator having Substrate Material of (a) ϵ_r =2 (b) ϵ_r =3.38

TABEL 4
EFFECT OF SUBSTRATE MATERIAL ON MICROSTRIP RESONATOR PERFORMANCE

Substrate Dielectric Constant	**Resonance frequency**	**Insertion Loss**	**Return Loss**
ϵ_r= 2	8.85 GHz	-0.01 dB	-28.2 dB
	10.9 GHz	-0.001 dB	-34.466 dB
ϵ_r= 3.38	8.5 GHz	-0.004 dB	-31.049 dB
	9.7 GHz	-0.0026 dB	-22.216 dB
	11.3 GHz	-0.001 dB	-35.855 dB

The tabulated comparison of resonant behavior of microstrip resonator with two different substrate material PTFE (ϵ_r= 2) and Roger material (ϵ_r= 3.38) is depicted in Table 4. It is concluded that by changing the substrate material, multiple frequency resonating circuits can be obtained.

V. Conclusions

This paper presents Finite element modeling of microstrip resonator using two coupled strips. The basic model is further extended to design different configurations of microstrip resonator by varying the design parameters and their resonant performance has been analyzed. Simulation are performed with the help of FEM based COMSOL Multiphysics software. Less than 3-dB intertion loss and better than 10-dB return loss bandwidth is achieved in 8-12 GHz frequency band for different models of microstrip resonator having bandpass or bandstop behavior. As coupling gap between microstrip line increases bandwidth decreases. Multi frequency resonators can be designed by changing the substrate thickness or substrate material. The present analysis is useful to design the ultra narrow band filters for X-band applications.

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