# Analysis of The Effects of Microstrip Configurations on RF MEMS Tunable Transformation Filters

**Aswathy R P, Resmi R**

***Abstract***— ***In this paper an RF microelectromechanical (MEMS) tunable bandpass to bandstop transformation filter designed for 3-4.2 GHz with low insertion and return loss and the effect of substrate thickness was analyzed. The bandpass to bandstop transformation is achieved by adjusting the coupling parameters of microstrip resonator. The microstrip resonator is designed by coupling more than one microstrip lines resulting in the independent tuning of centre frequency and the bandwidth. The simulative analysis of the effect of different microstrip configurations in microstrip bandpass to bandstop tunable filter is performed using COMSOL Multiphysics software.***

***Index Terms—Micro Electro Mechanical Systems (MEMS), Bandpass to Bandstop Tunable Filter, Microstrip Resonator,S parameter.***

## I. INTRODUCTION

RF Micro Electro Mechanical Systems (MEMS) tunable filters gain greater attention nowadays due to their role in wireless communication systems [1]. The rapid growth of wireless communication systems demand a huge amount of communication devices such as filters and antennas. Filters are the basic building blocks that contributes to the overall performance of a communication system. Filters are build up by coupling the resonators, the key component to design the filters. Resonators can be implemented by including one or more coupled microstrip lines [2]. Basically a resonator can exhibit three types of behaviour i.e bandpass, bandstop and all pass behaviour [3].The main objective of this paper is to use the microstrip line to design a bandpass to bandstop transformation tunable filter with a tuning range of 3.0 to 4.2 GHz and to analyze the resonance behaviour for different microstrip configurations by evaluating the S-parameter.

## II. THEORETICAL EXPLANATION

### *A. MEMS and TUNABLE FILTERS*

MEMS is a technology that integrates mechanical elements, sensors, actuators and electronics on a common silicon substrate through micro fabrication technology. The high precision fabrication technology (bulk micromachining and surface micromachining) of MEMS offers micro-level fine features, system integration capacities, and provides the unique performance in insertion loss, bandwidth for the micro components such as RF switches, tunable capacitors and inductors. The most intrinsic characteristics are miniaturization, microelectronics integration and precise mass production. MEMS technology fabricate electromechanical and microelectronics component in the range of 1µm~1mm. Modern high frequency systems employ multifunction receiver subsystems that have a broad bandwidth to support multiple frequency bands. This trend has led to the increased demand for filter topologies with adaptable preselection frequency behavior. Tunable filters are the integral components in a variety of RADAR and multiband communication systems. The conventional tunable filters typically utilize YIG resonators, active resonators or varactors as tuning elements but suffers from low Q values. Tunable filters have the potential to reduce the complexity and linearity requirements [6]. Of the many filter topologies available, only a few are amenable to the construction of a tunable filter. There are two different frequency-tuning methods in MEMS technology: analog and digital. Analog tunable filter can provide continuous frequency variation, but its tuning range is limited to 5-15% but in the case of digital one capacitors are switched in and out of the circuit, so the centre frequency can be changed discretely and the wide tuning range (20%-60%) can be achieved. Bandpass to Bandstop filters are widely used now a days for the applications in wideband radio systems receiving desired signals in a spectrum with a dynamic interference environment [6]-[10]. Eventhough Bandpass mode is used for low interference environment, the Bandstop mode is best suitable for eliminating the high power interference [1].

### *B. Bandpass to Bandstop Tunable filters*

Bandpass filter is a passive component which is able to select signals under a certain frequency known as pass band and reject all other signals known as stop band. The bandpass filter plays an important role in communication systems because they exhibit low insertion loss and have compact size [2]. Microstrip transmission lines are one of the most popular type of planar transmission lines used in microwave devices. It has small size, low cost, no critical machining, ease of integration etc [5]. These microstrip transmission lines is coupled to form the microstrip resonators in such a way that the internal impedance of the filter is to be 50Ω. The coupling parameters of the proposed filter are controlled in order to obtain the bandpass to bandstop transformation.

## III. 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 five transmission lines placed parallel to each other and in close proximity [2]. In this design there is a continuous coupling of electromagnetic fields between the lines and coupling coefficients i.e, the gap give rise to bandpass and bandstop mode respectively.

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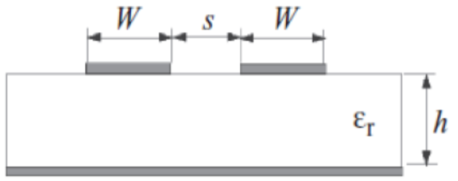


**Fig.1. Coupled Microstrip line**

Fig.1 shows a simple microstrip filter geometry which consist of two microstrip lines having width W and are separate by a distance S. They are attached to a dielectric medium of thickness h having a dielectric constant ϵr. The microstrip lines are capactively coupled and support two quasi-TEM modes.

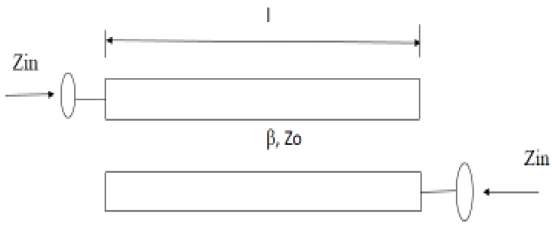


**Fig.2. Bandpass filter element**

For the bandpass filter section, the geometric arrangement with input and output ports and the corresponding transmission line representation are shown in Fig.2.

## IV. MICRORESONATOR FILTER DESIGN

The filter design uses λ/2 coupling between microstrip lines with narrow gap hence resulting in reduced size. FEM based COMSOL Multiphysics software which is a powerful interactive environment for modelling and simulation has been used for the design and simulation of coupled resonator bandpass filer.

Five microstrip lines are coupled to form two parallel resonators with a common microstrip line. The microstrip filter is designed on a Rogers substrate material having relative permittivity 3.38. It is assumed that the thickness of the strip is negligible because 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= microstrip line length= 25 mm
Substrate thickness=20 mil
Coupling gap = 0.7 mm

The substrate material used for microstrip resonator is Roger material. The properties of substrate are

Relative permittivity ($\epsilon_r$) = 3.38
Relative permibility ($\mu r$) = 1
Conductivity ($\sigma$) = 0 S/m

An air box is used to enclose 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

The filter is designed to operate in the frequency range from 3.0 GHz to 4.2 GHz. Appropriate boundary conditions are assigned, then meshing is performed on the model to obtain final refined mesh. In meshing, a finer mesh (more elements) will give a more precise solution. Fig.3 shows the meshing structure.

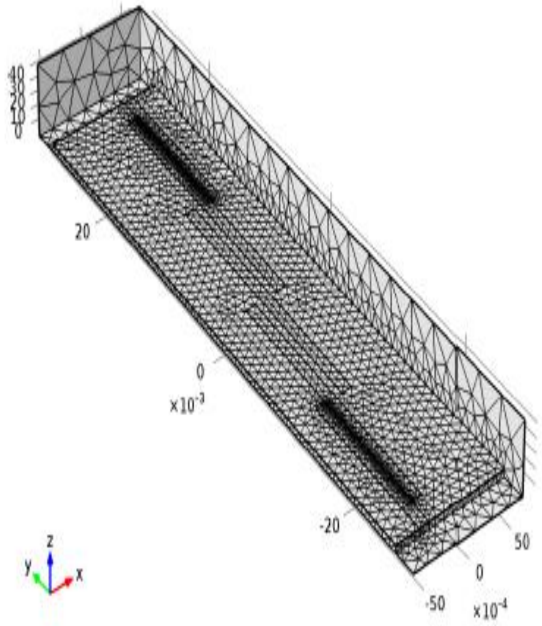


**Fig.3. Meshing Structure**

## V . SIMULATION RESULTS

Fig.4 shows the surface plot of electric field distribution. The maximum value of electric field that can be obtained is $1.6635*10^4$ V/m but in the proposed filter the electric field obtained is around 1V/m.

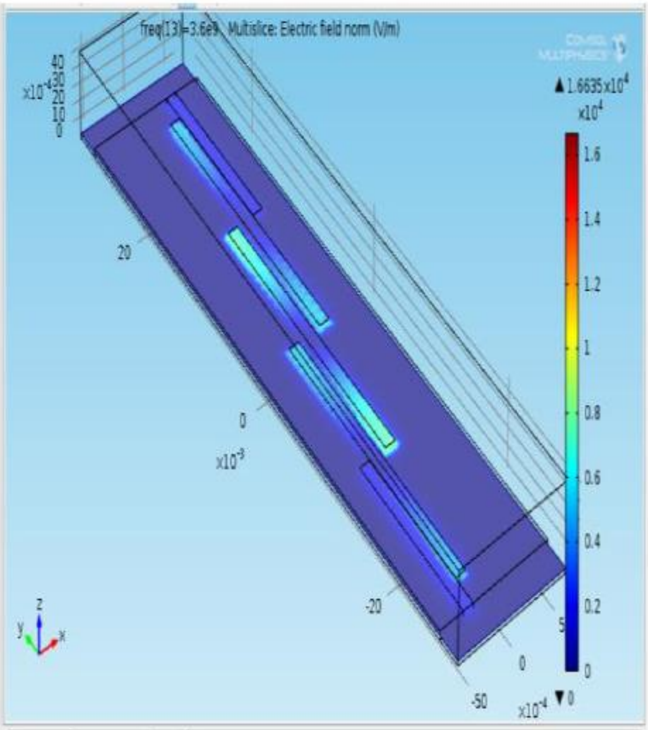


**Fig.4. Electric Field Distribution**


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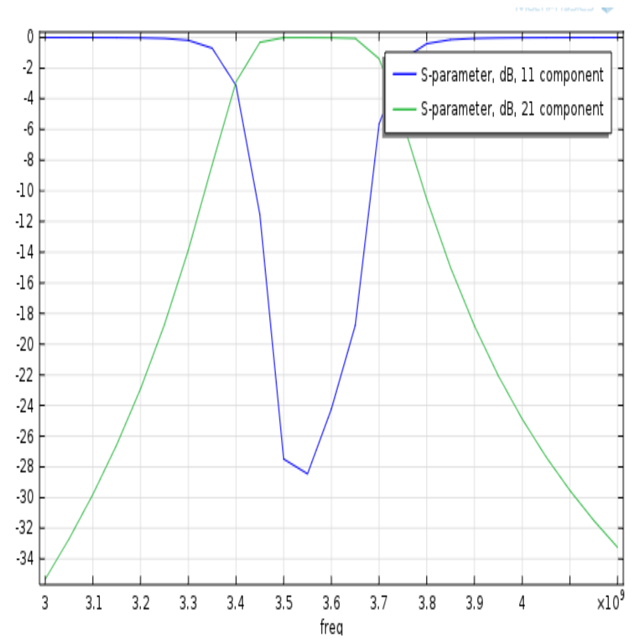
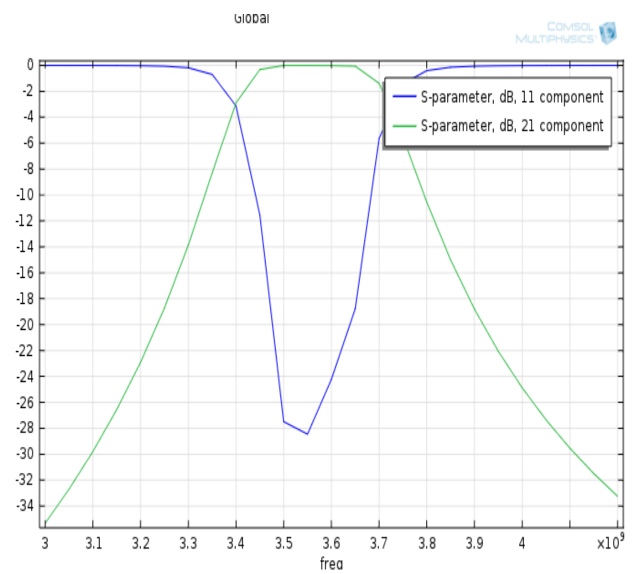



**Fig.5. S-parameter plot**

S parameter performances are plotted in Fig.5 which shows the characteristics of the microstrip resonator. The filter is tuned at a centre frequency of 3.56GHz. The S11 parameter corresponds to input port voltage reflection coefficient and S21 parameter corresponds to forward voltage gain. The value of S11 determines the return loss and here the return loss value is -28.1dB. The value of S21 determines the insertion loss and here the insertion loss value is -0.2dB.

### *A. Analysis of the Effect of Coupling gap and substrate thickness on the proposed filter design*

The coupling gaps and the substrate thickness affect the shape of resonance, insertion loss and return loss. The base model has been designed using the coupling gap of 0.7mm and substrate thickness of 20mil. The gap is changed to 0 mm for substrate thickness of 4mil and 0.7 mm for substrate thickness of 20mil respectively to perform the analysis. Fig.6 plots the S21 and S11 parameters to observe the effect of coupling gap on the performance of microstrip resonator.

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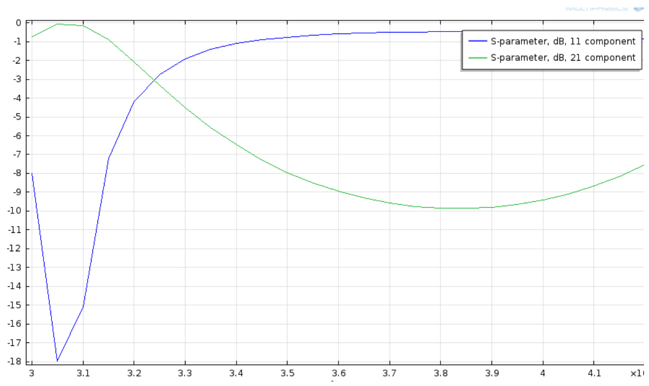


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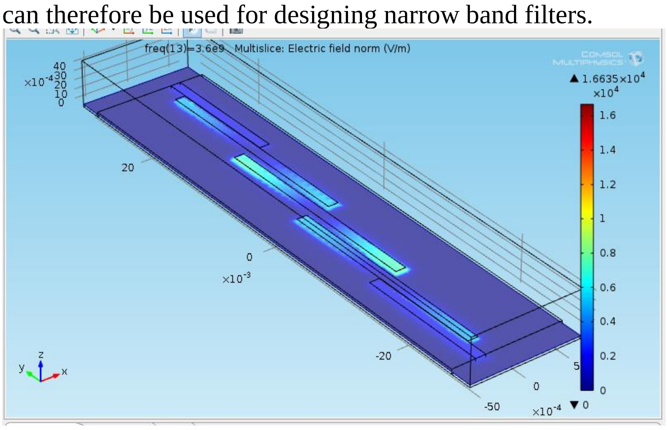
**Fig.6. (a) Coupling gap of 0.7mm and substrate thickness of 20mil & (b) Coupling gap of 0mm and substrate thickness of 4mil**

The bandwidth varies as inversely proportional to the coupling gap between strips. Above two configuration of microstrip resonator exhibits bandpass and bandstop behavior respectively. The proposed resonator configurations can therefore be used for designing narrow band filters.

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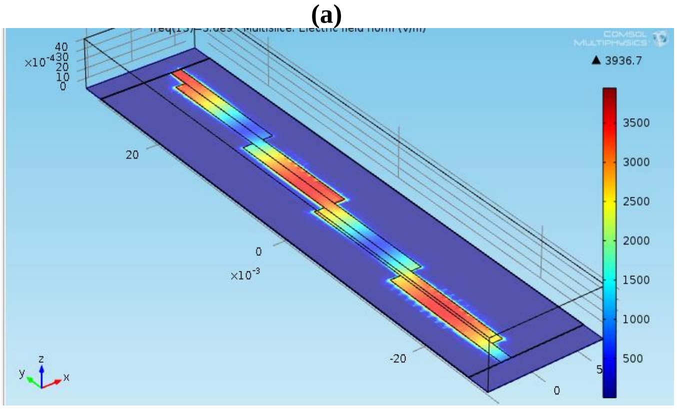


**(b)**

**Fig.7. (a) Electric Field Distribution of Bandpass Filter & (b) Electric Field Distribution of Bandstop Filter**

Fig.7 (a) and Fig.7 (b) shows the surface plot of electric field distribution of Bandpass and Bandstop filter respectively. For a Bandpass filter, the maximum value of electric field that can be obtained is 1.6635*10$^4$V/m but in the proposed filter the electric field obtained is around 1*10$^4$V/m whereas in the case of a Bandstop filter, the maximum value of electric field that can be obtained is 3936.7V/m but in the proposed filter the electric field obtained is around 1700V/m


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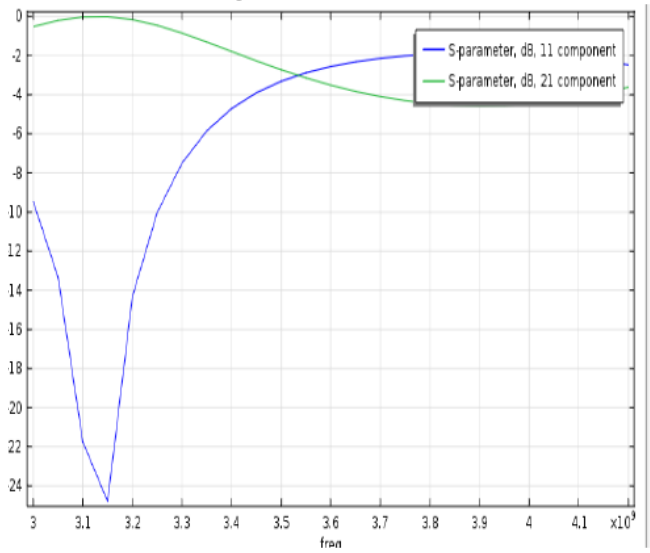
**Table 1. Effect of Coupling gap and Substrate Thickness in Filter Performance**

| Coupling Gap | Substrate Thickness | Insertion Loss(dB) | Return Loss(dB) | Centre Frequency (GHz) |
|---|---|---|---|---|
| 0.7mm | 20mil | -0.2 | -28.1 | 3.56 |
| 0.0mm | 4mil | -0.02 | -18 | 3.05 |

Table 1 shows that as the value of coupling parameters such as coupling gap and substrate thickness decreases, the value of insertion loss and return loss were improved.

***B. Analysis of the Effect of different Substrate thickness on the proposed filter design***

The reduced substrate thickness is desirable in microstrip design due to benefits of compact circuits and ease of integration but will contribute 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 10 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.8.

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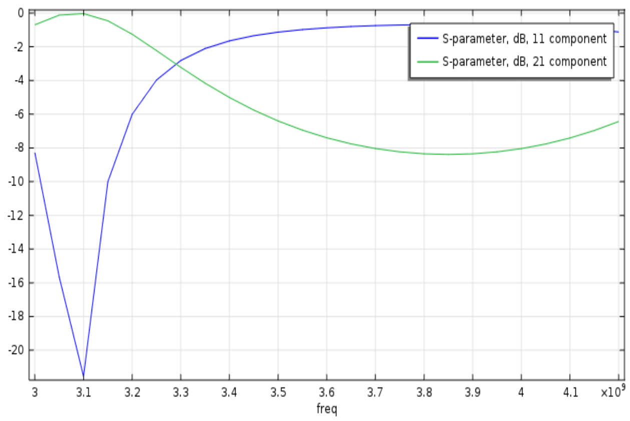


**(b)**

**Fig.8. (a) Substrate thickness of 10mil & (b) Substrate thickness of 5mil**

**Table 2. Effect of Substrate Thickness in Filter Performance without Coupling Gap**

| Substrate Thickness | Resonant Frequency (GHz) | Insertion Loss(dB) | Return Loss(dB) | Quality Factor | BW (GHz) |
|---|---|---|---|---|---|
| 20mil | 3.2 | -0.1 | -30 | 2.2 | 1.4 |
| 15mil | 3.17 | -0.4 | -26.4 | 4.8 | 0.66 |
| 10mil | 3.15 | -0.01 | -24.5 | 6.17 | 0.51 |
| 5mil | 3.1 | -0.02 | -22 | 6.32 | 0.49 |

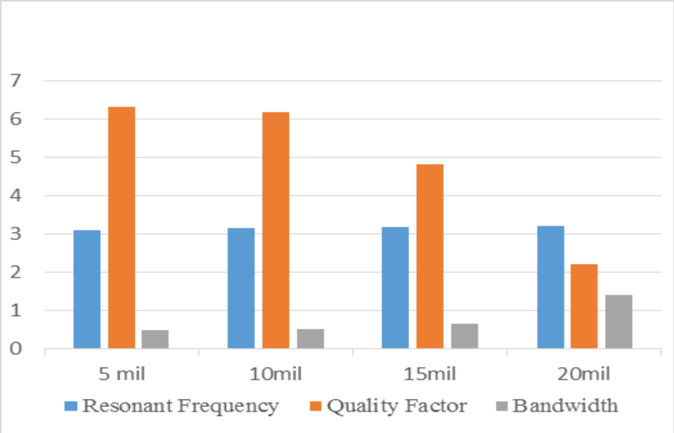


**Fig.9. Effect of substrate thickness without coupling gap**

Fig.9 shows that the microstrip resonator without coupling gap ie,coupling gap=0mm.As the substrate thickness increases the resonant frequency and the bandwidth also increases whereas the quality factor decreases.

**Table 3. Effect of Substrate Thickness in Filter Performance with Coupling Gap**

| Substrate Thickness | Resonant Frequency (GHz) | IL (dB) | RL (dB) | Q value | BW (GHz) |
|---|---|---|---|---|---|
| 20mil | 3.56 | -0.01 | -28.5 | 11.125 | 0.32 |
| 15mil | 3.5 | -3.8 | -19 | 8.75 | 0.45 |
| 10mil | 3.46 | -4.1 | -13 | 7.67 | 0.4 |
| 5mil | 3.45 | -13.1 | -4.9 | 6.9 | 0.5 |

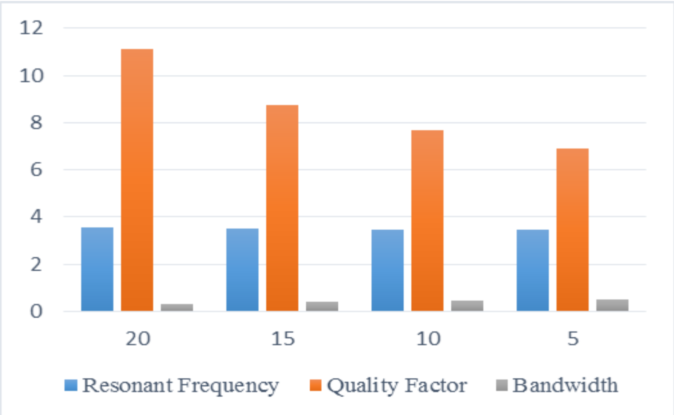


**Fig.10.Effect of substrate thickness with coupling gap**


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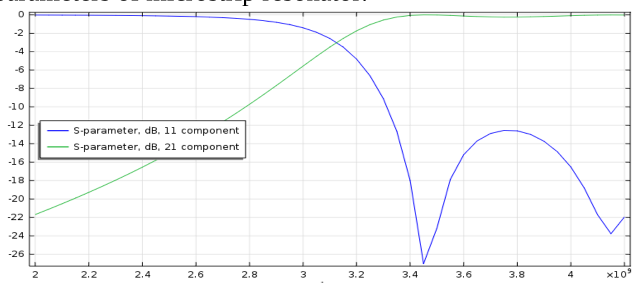
Fig.10 shows the effect of substrate thickness with coupling gap ie,the coupling gap = 0.1mm.In the above figure,as the substrate thickness increases resonant frequency and quality factor also increases whereas the bandwidth decreases gradually.

### *C. Analysis of the Effect of different Substrate Material on the proposed filter design*

Five different substrate material PTFE ($\epsilon_r$=2), Duroid ($\epsilon_r$=2.35), Silica ($\epsilon_r$=3), Roger material ($\epsilon_r$= 3.38) and Quartz ($\epsilon_r$=3.8) are taken with substrate thickness 20 mil and with coupling gap of 0.1mm between strips. Fig. 11 shows the effects of different substrate material on $S_{21}$ and $S_{11}$ parameters of microstrip resonator.

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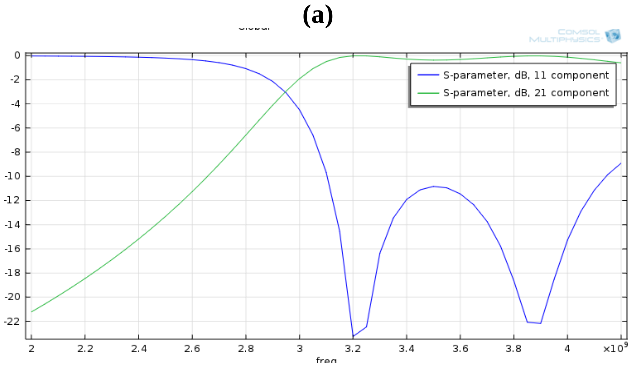


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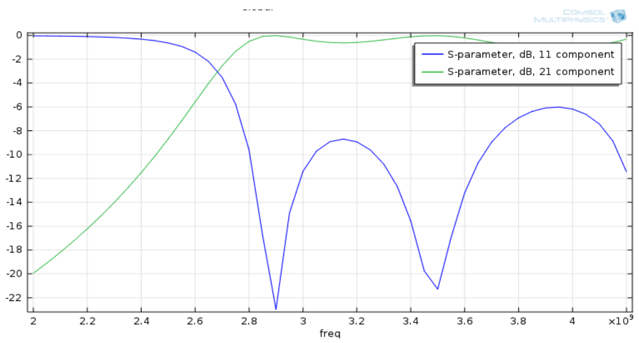


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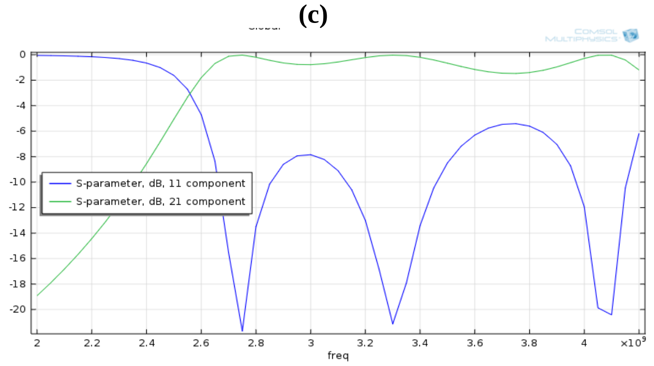


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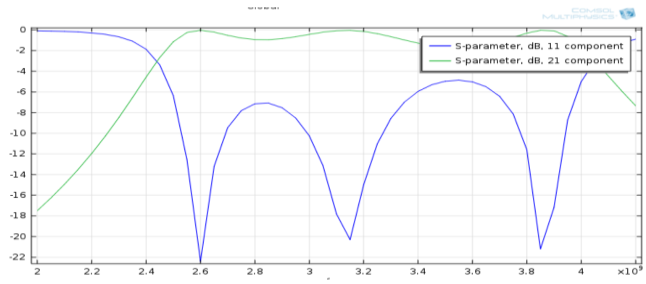


**(e)**

**Fig.11. (a) PTFE, (b) Duroid, (c) Silica, (d) Rogers material, (e) Quartz**

**Table 4. Effect of Substrate Material in Filter Performance**

| Substrate Material | Relative Permittivity (Ɛr) | Resonant Frequency (GHz) |
|---|---|---|
| PTFE | 2 | 3.45 |
| | | 4.17 |
| Duroid | 2.35 | 3.2 |
| | | 3.9 |
| Silica | 3 | 2.9 |
| | | 3.45 |
| Roger | 3.38 | 2.78 |
| | | 3.3 |
| | | 4.1 |
| Quartz | 3.8 | 2.6 |
| | | 3.18 |
| | | 3.84 |

Table 4 shows the behaviour of microstrip resonantor by varying the substrate material. It can be concluded that by changing the substrate material circuits with multiple resonating frequencies can be obtained.

## VI. CONCLUSION

In this paper a tunable bandpass to bandstop transformation filter is obtained with a frequency range of 3-4.2 GHz. The S parameter performance is analyzed by varying the different microstrip resonator parameters. As the substrate thickness of the microstrip resonator vary the performance of the filter also varies. As the coupling gap between the microstrip line increases the bandwidth decreases. Resonators with multiple frequency is designed by changing the substrate material.

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