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Design of a Symmetrical Microstrip Bandpass Filter for S-Band Frequency Range

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Abstract: A new type of microstrip bandpass filter is presented with a center frequency operation at 2.5GHz which lies in the S-band frequency range. The filter is designed to be much smaller compared to the same type of parallel-coupled bandpass filter. The simulation results are excellent and the filter is suitable for integration within various microwave subsystems.

Keywords: Band pass filter, microwave, S-band frequency

INTRODUCTION

Bandpass filters are filters containing one or more combination of capacitance and inductance which are designed mathematically to respond to design frequencies while rejecting all other out of band frequencies. Usually the filter's standards or characteristics are described by the value of their 3dB or 1dB bandwidth which corresponds to the allowable frequency band of the filters. The spurious resonance and the insertion loss of the filter should also be taken into account [1]

The main goal of the design is printed filter size reduction compared to conventional printed parallel-coupled bandpass filters. The most efficient way in order to obtain a filter with maximum size reduction is by using the microstrip technique in which each filter's lumped component is realized as microstrip transmission line [1]. Further optimization and tuning of the microstrip circuit would produce an equivalent microstrip circuit with certain percentage of size reduction relatively compared to the parallel-coupled filters. The center frequency is designed to be at 2.5GHz, which describes the operation of the filter with a maximum gain.

Concept: The design of the basic circuit for the project is done as a capacitively coupled combination of four resonators [2]. The basic resonator without coupling used in the design is shown as a combination of capacitors and inductors in Fig. 1.

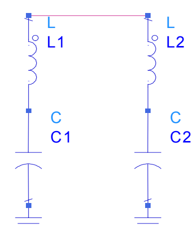

Fig. 1: Basic schematic of resonator for the design

Basically each resonator has 2 variable inductances and capacitances and 4 identical resonators are coupled with each other to form using capacitances in order to create a bandpass filter model which is square-shaped as shown in Fig. 2.

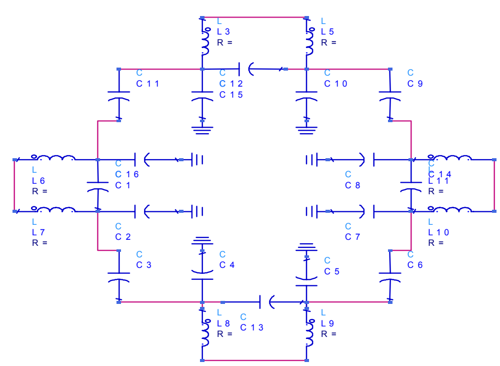

Fig. 2: Basic configuration of four identical resonators with capacitive coupling

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Table 1: Values of corresponding lumped components in Fig. 2

Description	Component	Value
Pair of capacitances in each resonator	C16,C2,C4,C5,C7,C8,C10,C15	1.15pF
First inductance in each resonator	L1,L7,L6,L4	2.15nH
Second inductance in each resonator	L2,L8,L5,L3	4.25nH
Coupling capacitance	C11,C3,C6,C9	0.075pF
Capacitance within the resonator	C1,C13,C14,C12	0.024pF

The overall filter is square-shaped in order to minimize the space required during fabrication on the desired substrate. One of the main goals of the project is the overall filter size reduction to make them more suitable for integration with other microwave circuits[3]. The filter has 0 dB resonant frequency and bandwidth in S-band frequency range. In most filters, the resonators are coupled by various combinations of both inductive(magnetic) and capacitive(electrical) coupling[4]. The design and realization of this filter would propose a new type of filter with resonators coupled only by capacitive coupling, which can be realized on a significantly smaller area compared to inductive coupling[5] .

Within each resonator, there is an extra added capacitance within the resonator (C1, C13, C14 and C12) which connects the pair of inductances and capacitances that form the resonator. This extra capacitance at first emerges as an unwanted component which is formed between two capacitive patches belonging to the same resonator. The main goal of this inclusion is for the minimization of the filter's overall size[6] . The extra included capacitance does not affect the desired output much is mainly used for filter size reduction since the circuit would be more compactly integrated. Its value could be significantly reduced by resonator's reshaping but however, in this case each resonator would take up or occupy more space, which is undesired as opposed to the main goal or objective of the project which is filter size reduction[7] .
However, through proper analysis and simulation works, it could be noticed that the capacitance do play a slight role in determining the output characteristics of the filter, in which increment of the capacitance value would lead to decrease of the center frequency of the filter to some extent. Thus, it is possible to include this capacitance in order to obtain smaller printed filters having required f_o or center frequency.

The lumped component values of capacitances and inductances can be varied accordingly in order to obtain filters with different center frequencies and passbands desired. The value of the parameters which favors a small filter size is chosen among other possible values of parameters. The filter in the project is designed to operate at center frequency 2.5GHz which lies in the measured S_{21} parameter of 0dB.

To realize a printed bandpass filter, the scheme shown in Fig. 2 is represented in its equivalent cross-section microstrip transmission line circuit as shown in Fig. 3.

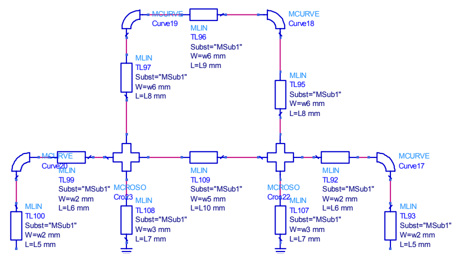

Fig. 3: Cross section (top) of the whole microstrip equivalent circuit of Fig. 2

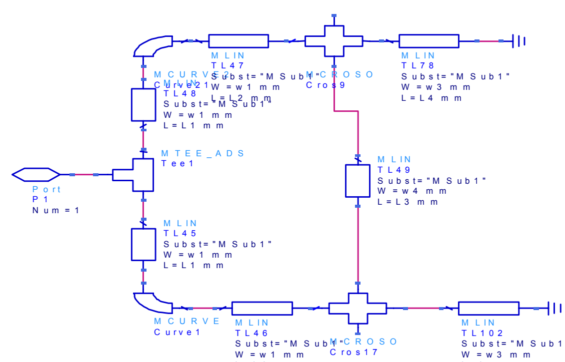

Fig. 4: Cross section (side) of the whole microstrip equivalent circuit of Fig. 2

There are a total of 6 widths (w1 until w6) and 9 lengths (L1 until L9) to be calculated and optimized in order to create a symmetrical filter. The width for the curved microstrip line is w1. The lengths and widths of each microstrip transmission line are tuned and optimized in order to obtain center frequency at 2.5GHz and lower and upper 3dB cut-off frequencies at approximately 2.4GHz and 2.6GHz accordingly. Both capacitances and inductances are realized as microstrip transmission lines with impedance Z_O =50ohm. The substrate used for simulation purposes and further implementation purposes is Rogers RO3010 (ε = 10.2 , h = 0.635mm). By using a higher ε and thinner substrate, a smaller filter size could be achieved. Since the main goal or objective of the design is achieving a small filter size, the substrate RO3010 is suitable for optimum performance.

SIMULATION RESULTS

The scattering parameter plots of the filter scheme of Fig. 2 are shown in Fig. 4,5 and 6.

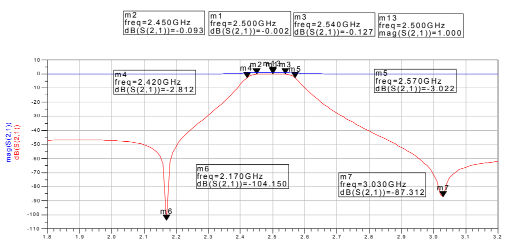

Fig. 5: S_{21} dB and magnitude plot of the filter

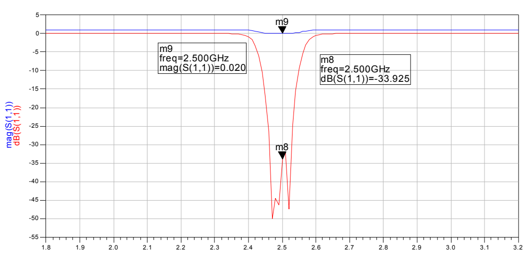

Fig. 6: S_{11} dB and magnitude plot of the filter

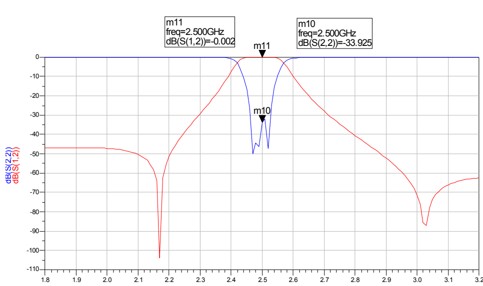

Fig. 7: S_{12} and S_{22} plot of the filter

From Fig. 5, the center frequency f_o, 2.5GHz is obtained at the S_{21} value of -0.002dB which is approximately 0dB. The magnitude plot on the same graph shows that at 2.5GHz, the magnitude is unity which means voltage transfer ratio from the input to the output port is unity.

Thus, the filter's operation is optimum at 2.5GHz since the voltage is transferred fully from input to output. The filter's optimum operation with maximum voltage or power transfer occurs at frequency 2.5GHz. The filter's lower cut-off frequency and upper cut-off frequency occurs at 2.45GHz and 2.54GHz respectively which is 10.71% of the measured frequency spectrum. The approximate 3dB bandwidth is measured to be also 10.71% of the frequency spectrum. The plot on Fig. 6 also shows that the S_{21} frequency response has 2 deep minimums of -104.15dB (at $0.868f_O$) and at -87.312dB (at $1.212f_O$).

The plot in Fig. 6 shows that at the center frequency 2.5GHz, the magnitude of S_{11} is 0.02 which is approximately 0. This shows that at optimum performance, the filter's reflection coefficient is zero, which means that the output port would receive almost all the input signal power through transmission. Thus, the filter can be considered lossless.

In Fig. 7, there are a few ripples which occur at frequencies close to the center frequency which shows that there are some low reflected signals from the output port at those frequencies. The S_{12} and S_{22} plots are exactly same as the S_{21} and S_{11} plots accordingly. This shows that the designed circuit is completely reciprocal and symmetrical. Either pair of plots can be used to determine the desired gain or cut-off frequency measurements. The Q-factor of the filter is calculated using the approximate approach of $Q = f_O / \Delta f$ which results in 27.78 , which is a reasonable constant for the design.

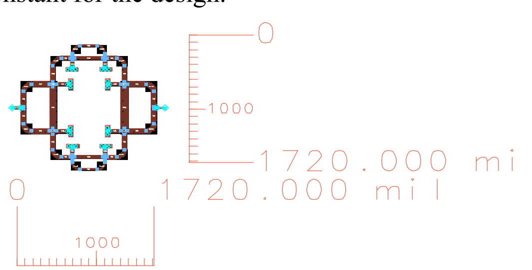

Fig. 8: Layout of the filter design

The real required space on the board is much less compared to the space shown in Fig. 8. The unoccupied space which is free at the center of the filter layout has a dimension of 24.64 mm x 20.57 mm.

Besides that, there are also unoccupied spaces on all 4 sides between the strip lines and these spaces can be removed and used for other fabrication purposes. The real surface area occupied by the filter is 1402.85 mm^2. The momentum simulation results of the layout are shown Fig. 9.

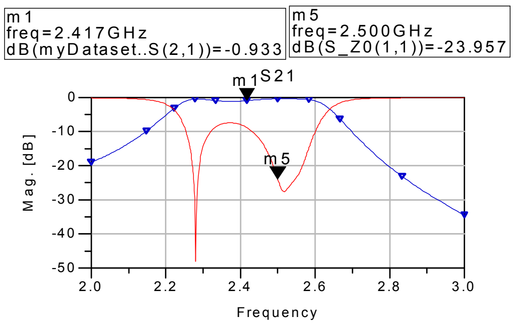

Fig. 9: S_{21} and S_{11} plot of the filter layout

The slight difference between the circuit simulator results and the layout momentum results is caused by the coupling effect between the strips. In the schematic, the coupling effect between parallel striplines is not considered during simulation because of the existence of the discontinuity components. However, this effect will be taken into account during the momentum simulation which produces results which are slightly different. The main advantage of the filter design is the overall filter size and space minimization provided the large unused space in between the strip lines on the substrate board are utilized for other purposes. The symmetrical design approach provides advantage in which the unwanted coupling effect within the lines can be minimized, providing a realized printed filter with good and appreciable response.

CONCLUSION

A new type of capacitive coupling of identical resonators to form a symmetrical microstrip bandpass filter is designed. The microstrip bandpass filter is designed to operate at 2.5GHz with 3dB lower and upper cut-off frequencies at approximately 2.3GHz and 2.7GHz accordingly. The symmetrical approach tends to produce a more compact filter with less coupling effect in its realization. Its compact nature minimizes required space for realization and is suitable for integration within RF and microwave subsystems.

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