Multilayer Coupled Ring Resonator Filter for Digital Broadcasting Applications

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Abstract - a design of a multilayer microstrip bandpass filter based on coupled ring resonator is presented for digital satellite broadcasting applications. Centered at around 2.6 GHz with bandwidth of 4.2 % from 2.54 GHz to 2.65 GHz the filter is designed on a 0.75-mm-thick Rogers RO3003 substrate ($\varepsilon_r = 3$, $\tan\delta = 0.0013$). The Computer Simulation Technology (CST) simulator is used to design and simulate the response of the microstrip coupled ring resonator. Results from electromagnetic simulation of the filter involving return loss, S_{11} and insertion loss, S_{21} are presented through this paper.

Keywords— Multilayer bandpass filter, microstrip ring resonator, digital broadcasting frequencies

I. INTRODUCTION

THE microstrip filters have found wide applications in many RF/microwave circuits and systems. This is particularly driven by rapidly growing wireless communications, emerging high-temperature superconducting (HTS), and micromachining technologies [5]. In general, microstrip band-pass filters may be designed using single- or dual-mode resonators. In the past, microwave bandpass filter appeared as one of the most critical point since they required hardened constraints in term of selectivity, out-of-band rejection ratio, insertion loss, and size reduction [4]. Therefore, the research on ring resonator had been observed and found that micostrip ring resonator offers very special characteristics such as compactness, dual resonance capability, and transmission zeros in the frequency response. It exhibit two transmission zeros on either side of the pass band, the filter selectivity can be increased while limiting the filter order and therefore its insertion loss [1, 4].

Recently multilayer structure approach has been proposed to reduce the size of the planar microstrip filters. Multilayer bandpass filters provide another dimension in the flexible design and integration of other microwave components. The design procedure of single-layer filter using symmetric couple microstrip lines is well documented in literature [10]. However, tight coupling lines between the resonators in this configuration are difficult for the fabrication to be realized. Multilayer filter overcome this kind of restriction and based on [12, 13], the technical methods normally used to realize miniaturized filters is by fabricate filters on high dielectric constant substrates and implementing multilayer structure.

The main attractive features of the ring resonator are not only limited to its compact size, low cost, and easy fabrication but also present narrow passband bandwidth and low radiation loss. Many applications, such as bandpass filters, oscillators, mixers, and antennas using ring resonators have been reported.

However, a conventional end-to-side coupling resonator suffers from high insertion loss, which is due to the circuit conductor, dielectric, radiation losses, and an inadequate coupling between feeders and the ring resonator. The size of the coupling gap between ring resonator and feed lines affect the strength of coupling and the resonant frequency [10]. Besides that, by introducing small change along the ring such as short stubs on the ring or by using asymmetrical feed lines, the dual modes of the resonator will be obtained. Thus, the ring resonator design involves the adjustment of the small change along the ring and/or the adjustment of the coupling gaps.

In a recent report concerning the ring resonator, quarter wavelength side coupled lines have been used. A complete synthesis was developed which help designers in fixing the whole filter characteristics (central frequency, transmission zeros frequencies, in-band ripple and bandwidth) [1].

A general conventional single-layer ring resonator consists of a pair of feed lines, coupling gaps, and a ring whose length is equal to the guided wavelength, as shown in Figure 1 [4].

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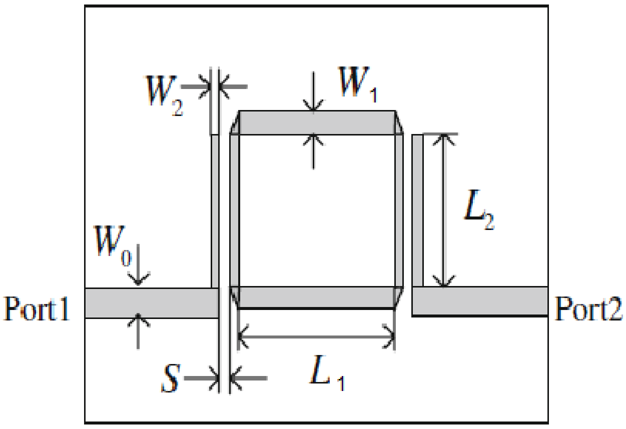

Figure 1: ring resonator topology

With the above topology, the electric characteristics such as the bandwidth and locations of the transmission zeros of the resonator can be easily controlled by varying the line impedance of the ring and the odd and even-mode coupled lines impedances and also because the existence of dual-resonance. The parallel coupled lines can be used for development of a synthesis of resonator where the impedance levels of all the elements of the resonator can be obtained for given central and transmission zero frequencies.

TABLE 1
Design Specification

Filter Specification	Values
Center frequency	2.585 GHz
Lower cut-off frequency	2.52 GHz
Upper cut-off frequency	2.65 GHz
Insertion loss, S_{21}	> -2 dB
Return loss, S_{11}	< -20 dB
Bandwidth	130 MHz (5%)

In this paper, the multilayer bandpass filter using coupled lines parallel with square-ring resonator is presented. The RO3003 substrate with 0.75 mm thickness and dielectric constant of 3 is being used to implement the proposed filter. Meanwhile, the operating frequency is designed at 2.6 GHz with 4.2 % bandwidth.

II. METHODOLOGY

By using Computer Simulation Technology (CST) software, the multilayer bandpass filter is designed and simulated. The dimensions are then being adjusted for a number of times in order to improve the response of the filter. Figure 2 and Figure 3 the show structures of the parallel lines with feedings and the rectangular ring respectively by its layer with all the dimensions. Meanwhile Figure 4 shows all the layers involved in the design. As illustrated in the figure, the coupled line feedings are found at the first layer while the ring is being traced in the third layer, with the substrate RO3003 located between them. The fourth layer is to be epoxy ($\varepsilon_r = 4$) and the ground is at the bottom layer. The overall dimension of the filter is 40.56 x 36.56 x 1.155 mm.

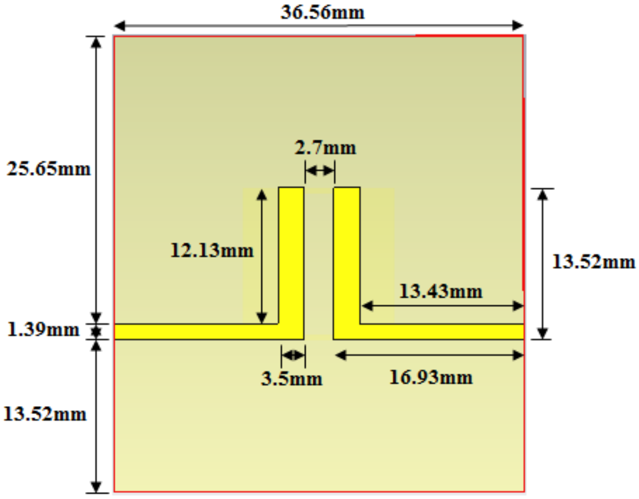

Figure 2: The proposed microstrip coupled ring filter (upper layer)

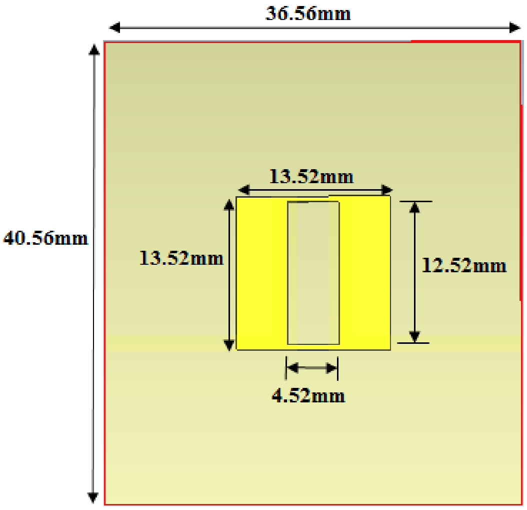

Figure 3: The proposed microstrip coupled ring filter (inner layer)

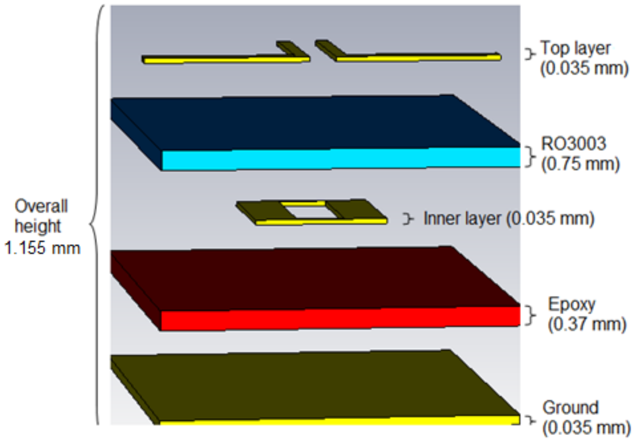

Figure 4: The proposed microstrip coupled ring filter by layers

The multilayer is primarily consists of core material that has copper laminated to both layer side construct the ring resonator. Copper foil acts as a ground layer and epoxy resin acts as a glue to combine the layer together. The multilayer arrangement is depicted in Figure 4. The proposed filter design method is simply derived from microstrip resonator design. By overlapping adjacent resonator on different layer, strong couplings between resonators can be achieved.

The filter was constructed and simulated in CST MWS with familiar configuration consisting of microstrip circuit RF components such as microstrip lines, TEE- sections and coupled lines. The dimensions are then adjusted a number of times in order to improve the response of the filter to achieve the target specifications as shown in Table 1.

.This multilayer model is In this design, copper with a thickness of 0.035 mm is being used. The line width for microstrip feedings at the upper layer is chosen at w = 1.39 mm, which give characteristic impedance Zo = 50 ohm on the substrate.

There are two parameters that must be considered in designing mirostrip filter and the parameters are S_{11} and S_{21}. S_{11} parameter is refer to return loss or a measure of power reflected which occur in the circuit during the communication links while S_{21} parameter is about the insertion loss which is the loss of signal power resulting from the insertion of a device in a transmission line or a measure of attenuation.

The important fundamental in designing microstrip coupled ring filter are the length and width value of variable parameters and the length for gap which exist between coupled lines to the dual-mode ring resonator. This values can be determine during simulation process by tuning each parameters which involves.

III. RESULT AND DISCUSSIONS

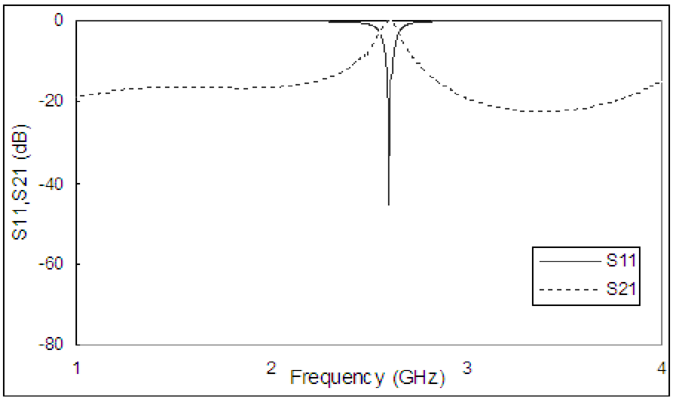

Figure 5: Frequency response simulation result for microstrip coupled ring

TABLE 2
Results on the Simulation Response using CST MWS

Properties	**Parameters**
Lower cut-off frequency (f_C), GHz	2.54
Upper cut-off frequency (f_L), GHz	2.65
Insertion loss (S_{21}), dB	-0.0724
Return loss (S_{11}), dB	-44.289
Bandwidth, MHz	110
Size (mm)	40.56 × 36.56 × 1.155

Figure 5 shows the simulation result of frequency response for the microstrip coupled ring filter. It shows that at the center of 2.6 GHz, the insertion loss value is -0.0724 dB and not 0 dB. The insertion loss at low frequency is about 0 dB, meaning that the entire signal is getting through. Refer to the central frequency of this filter is quite high (2.6 GHz), that is why the insertion loss is not at 0 dB.

At the center frequency also, the return loss is defined at 44.289 dB which is a good result for a filter. The return loss is a measure of the ratio of the reflected voltage amplitude of each sine wave to the amplitude that is incident to the front of the interconnected. A small amount of reflected amplitude, an indication of a good impedance match, would be a large, negative number in dB. The more signals can be transmitted from the input to the output port with less or without power which reflected back, the larger value (-ve) for return loss, the more efficient the filter will be. In real world, entire filters will have return loss. None of them give an ideal result such without any losses.

In this case, substrate RO3003 is being used because of its specialty of having very low dielectric loss which is 0.0013. Hence, this characteristic make the insertion loss to have a low value rather than by using other substrate such as FR4 even it is cheaper than RO3003.

For the analysis of the simulation result, few parameters' sweeps have been done to show variation of responses gained. From Figure 6, the return loss is found to be maximum at gap=1.5mm and by increasing the gap length between coupled lines, the response experienced a little shifting to the left. While Figure 7 shows the S_{21} responses due to the variations of the gap lengths. The bandwidth becomes wider by increasing the gap length. It is known that the gap between resonators has large influence on the coupling property. Weak coupling lead to the increment of insertion loss, and over coupling will bring the ripple effect.

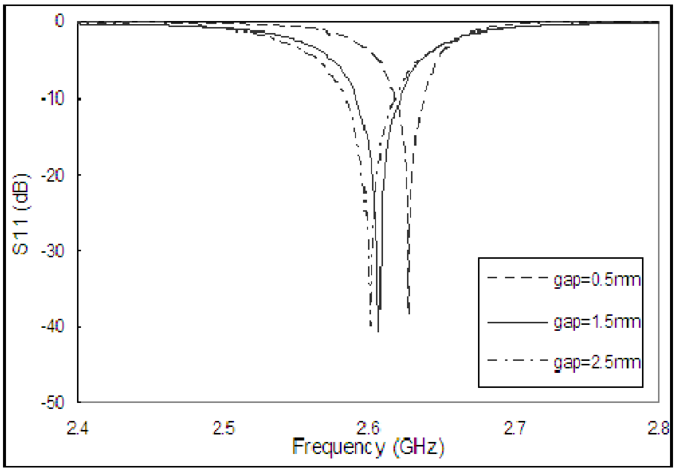

Figure 6: S_{11} frequency response for different gap lengths between the coupled lines

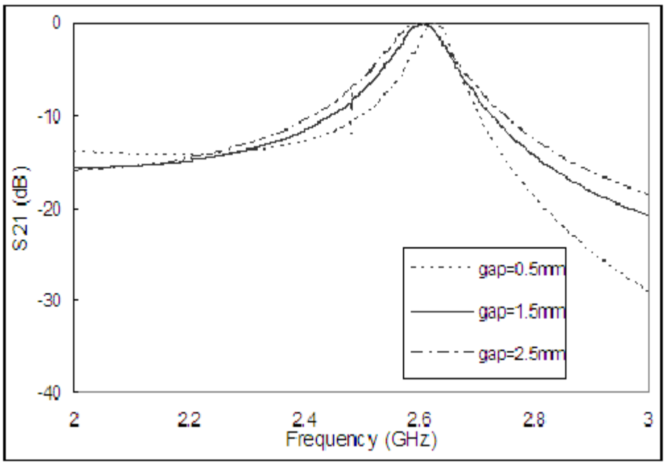

Figure 7: S_{21} frequency response for different gap lengths between the coupled lines

The effects of parameter sweeps involving different values of coupled length are shown in Figure 8 and Figure 9. The responses have shifted to the right and wider bandwidth is observed when the coupled length is increased. This parallel coupled arrangement gives relatively large coupling for the design spacing between resonators, and thus, this filter structure is particularly convenient for constructing filter having a wider bandwidth as compared to structure for end-coupled microstrip filter.

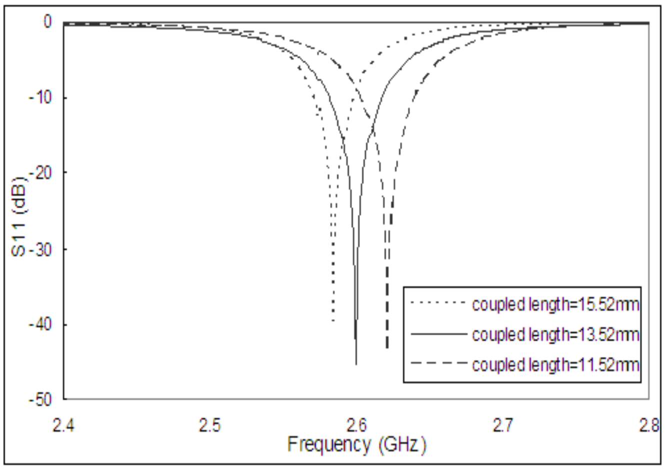

Figure 8: S_{11} response for three different sets of the coupled length values.

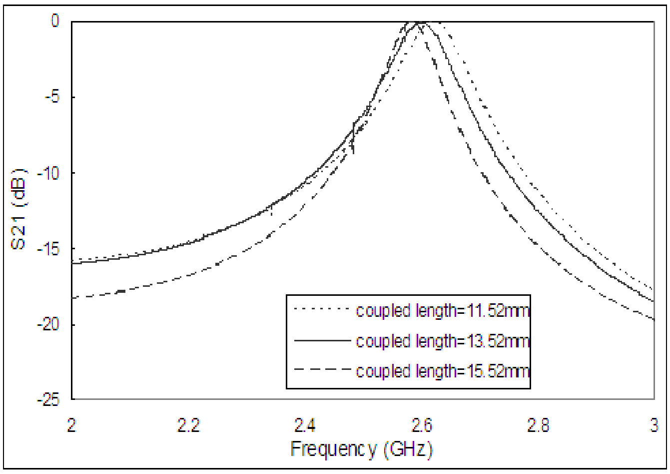

Figure 9: S_{21} response for three different sets of the coupled length values.

Next analysis is involving the length of the rectangular ring. As in Figure 10 and Figure 11, it is shown that the length of 13.52 mm applied to the ring experienced maximum return loss at the center frequency (fo = 2.6 GHz). The responses are observed to shift to the left (to lower frequency) by increasing the length of the ring. The relationship between frequency and wavelength that is known to be inversely proportional to each other from equation f=c/ λ is proved in this analysis.

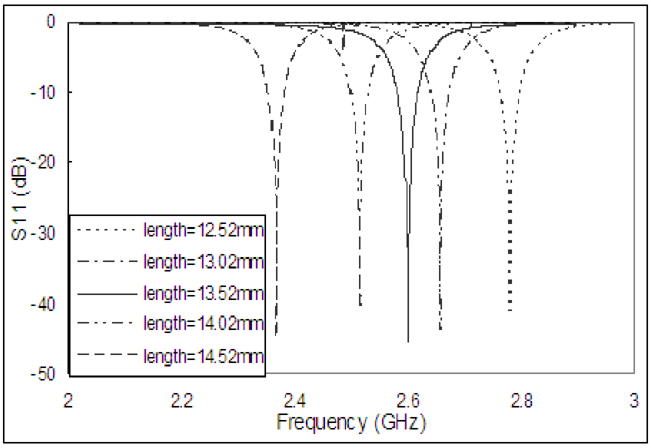

Figure 10: S_{11} response for parameter sweeps involving different ring length values.

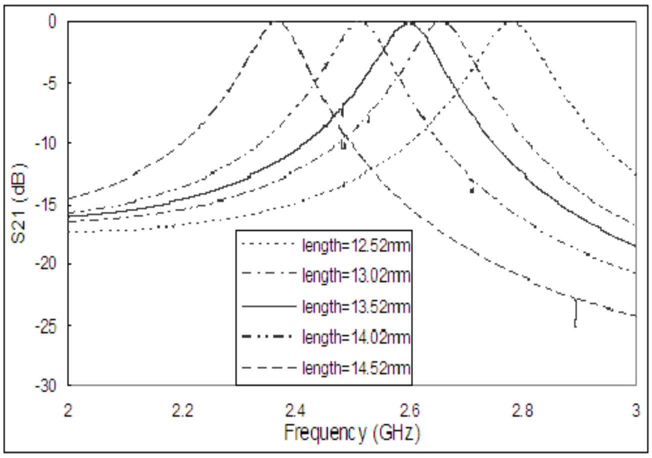

Figure 11: S_{21} response for parameter sweeps involving different ring length values.

Figure 12 shows the circuit simulation results using two different substrates: RO3003 (*tan* $\delta=0.0013$) and FR4 (*tan* $\delta=0.025$). A poor return loss of 12.721 dB was observed for substrate FR4. Besides that, the FR4's insertion loss of 2.8429 dB is quite higher, which is mainly due to the dielectric loss of the substrate. In this case, it shows that the use of substrate RO3003 with lower loss tangent will improve the filter electrical performance.

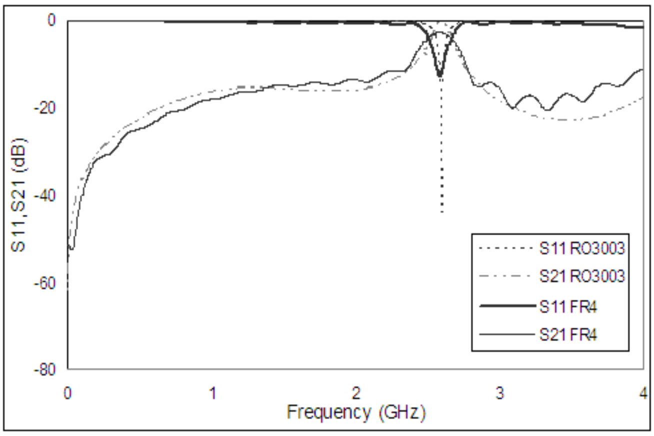

Figure 12: Frequency response simulation results for different substrates: RO3003 and FR4

TABLE 3
FR4 Substrate Properties

Properties	**FR-4**
Dielectric constant, ε_r	4.6
Substrate height, ***h*** (mm)	0.79
Loss tangent, ***tan δ***	0.025
Copper thickness (mm)	0.035

TABLE 4
Response parameters using FR-4

Properties	**Parameters**
Lower cut-off frequency (f_C), GHz	2.52
Upper cut-off frequency (f_L), GHz	2.65
Insertion loss (S_{21}), dB	-2.8429
Return loss (S_{11}), dB	-12.721
Bandwidth, MHz	130
Size (mm)	36.54 × 33.54 × 1.195

IV. CONCLUSION

In the study, a multilayer microstrip coupled ring filter using ring resonator structure with coupled lines is designed. A specific analysis was developed for ring-based resonator which eased the design of further bandpass filters. The multilayer environment favors the flexibility in coupling level realization needed in the ring filter designs. The electromagnetic simulations were performed and presented. The proposed filter used Rogers RO3003 substrate with a dielectric constant of 3 and 0.75 mm thickness. The insertion losses of the implemented filter using RO3003 are about 0.0724 dB and the return loss is 44.289 dB at 2.6 GHz. The proposed filter has the advantage of high return loss, tiny insertion loss, adequate bandwidth and almost accurate operating frequencies (right shifted).

V. FUTURE RECOMMENDATION

In the future, this design of multilayer can be modified to improve the performance of the filter. Other substrates with higher relative permittivity can be used to improve the filter and more compact filter can be realized. Lots of analysis can be done in order to optimize the performance of the filter.

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