Design and analysis of planar spiral resonator bandstop filter for microwave frequency

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Abstract. In microwave frequency, a spiral resonator can act as either frequency reject or acceptor circuits. A planar logarithmic spiral resonator bandstop filter has been developed based on this property. This project focuses on the rejection property of the spiral resonator. The performance analysis of the exhibited filter circuit has been performed by using scattering parameters (S-parameters) technique in the ultra-wideband microwave frequency. The proposed filter is built, simulated and S-parameters analysis have been accomplished by using electromagnetic simulation software CST microwave studio. The commercial microwave substrate Taconic TLX-8 has been used to build this filter. Experimental results showed that the -10 dB rejection bandwidth of the filter is 2.32 GHz and central frequency is 5.72 GHz which is suitable for ultra-wideband applications. The proposed design has been full of good compliance with the simulated and experimental results here.

1. Introduction
An electrical or mechanical resonator is a physical structure that displays resonance behavior. Usually, it has a natural oscillation frequency, which can either be an electromagnetic or mechanical oscillation in nature. At this frequency greater amplitude of oscillation is provided than the other frequencies. The resonators are insensitively used to make waves at a specific frequency or to select a band of a specific frequency from a signal. This characteristic enables electronic devices to produce oscillations of the appropriate frequency. Dielectric resonators are effectively used at microwave frequencies. The electrical behavior of one or more multi ports, the electrical network can be performed over a narrow range of frequencies by using S-parameters analysis. A planar transmission line is commonly used as a resonator to make a microwave filter [1][2]. It is possible to construct the filter precisely by using microwave printed board materials or substrate and photolithography and etching processes.

The microstrip planar components are widely used in the microwave frequency band [3][4]. A cross sectional view of a microstrip line is shown in Figure 1. Generally, these comprise of a low loss dielectric substrate having one or two layers of the metal sheet. The signal and ground currents are flowing on the separate conducting metal surface. The microstrip planar resonator can any structure which is able to resonate at least one oscillating electromagnetic field. Basically, a microstrip is a printed geometric structure of metal strip over a ground plane or conducting metal sheet. This structure has a tendency to radiate electromagnetic waves and it increases with increasing the space between the ground plane and the strip. However, it is possible to diminish the radiation without making the strip...
width too narrow by using a substrate of very low thickness compared to the wavelength of the operating frequency. The microstrip transmission lines are extensively used in the RF and microwave circuits, due to its planar nature, easy integration of active and passive components, good mechanical support, excellent heat sinking and easy to construct using photolithography and etching processes.

![Cross sectional view of basic structure of a microstrip line](image)

Figure 1. Cross sectional view of basic structure of a microstrip line

A large signal S-parameter analysis has been used for analyzing the proposed filter performance study. When an n-port network is interconnected into a microwave transmission line the propagating waves that are scattered or reflected can be analyzed by S-parameter. From the S-parameter analysis, it is possible to predict the circuit behavior to the designed level of precision. In addition, it can also provide a means of illustrating the quantitative and qualitative measures and behavior of the circuit elements as well. To obtain an accurate design and calculation, only computer based test system could reasonably handle the type of measurement and mathematics involved. The system consists of N5230A PNA-L Vector Network Analyzer with S-Parameter test set that is able to measure the frequency range of interest. Besides, a software program that is capable of performing vector error correction, computes an equivalent circuit parameter, setting up measurements and calibrating the measurement system is also implemented.

2. Methodology

The design was modeled according to a specific dimension by calculating the required parameters using the formula. The simulation and design process was conducted using the CST Microwaves Software. Then, the design was fabricated and the values were analyzed using N5230A PNA-L Network Analyzer. This validity test was conducted to confirm that the simulation through software would give approximately the same result as the fabrication built. The design parameters were, gap between turns, $s = 0.3$ mm, width of turns, $w = 0.80$ mm, distance between line and resonator, $d = 0.20$ mm, width of transmission line, $W_L = 2.26$ mm, width of the resonator, $W_T = 5.20$ mm and length of the resonator, $L_T = 8.00$ mm. The PCB was fabricated using Taconic TLX-8 as the substrate with its thickness of 0.50 mm. The dielectric constant was 2.55 and the material used was copper with a thickness of 0.035 mm. Table 1 shows the summary of the dimensions of the filter elements.

Table 1: Dimensions of the Filter Elements

| Filter parameter | Value(mm) | Filter parameter | Value(mm) |
|------------------|-----------|------------------|-----------|
| $S$              | 0.3       | $L_T$            | 8.0       |
| $W$              | 0.8       | $W_T$            | 2.26      |
| $d$              | 0.2       | $L_T$            | 17.75     |
| $W_R$            | 5.2       |                  | - -       |

Design with less than 0.2 mm width might cause a problem during the fabrication process. Therefore, some of these parameters were chosen for the practical purpose during fabrication while other
parameters were obtained using formula Equation 1, Equation 3 and Equation 3. The design, layout and the photograph of the prototype filter are shown in Figure 2.

![Prototype Filter Design](image)

Figure 2. Proposed filter, (a) layout and (b) developed filter with SMA connectors

Using the same design parameters, a real spiral resonator bandstop filter prototype was fabricated on the Taconic TLX-8 substrate. For microwave circuit, PCB enables the transmission line to be laid out in a planar form. Briefly, the design was printed out onto a glossy paper and was transferred onto the PCB via heat compressor. After that, the unwanted materials were removed using a specific combination of solutions. The finished product was then soldered with Sub Miniature version A (SMA) connector on both sides of the ports. Specifically, there were using two female PCB type for the PCB. The finished prototype was analyzed by Vector Network Analyzer model N5230A PNA-L as shown in Figure 3.

![Prototype Analysis](image)

Figure 3. Photograph to measure the data of S11 and S21 by using Vector Network Analyzer
Dimensions of the filter are calculated by using the proposed formulas [5][6]. The approximate of the effective dielectric constant of a microstrip line can be calculated by using Equation 1.

$$\varepsilon_e = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \frac{1}{\sqrt{1 + 12d/W}}$$  \hspace{1cm} (1)$$

The characteristic impedance can be calculated by Equation 2.

$$Z_0 = \begin{cases} \sqrt{\varepsilon_e} \ln \left( \frac{8d}{W} + \frac{W}{4d} \right) & \text{for } \frac{W}{d} \leq 1 \\ \frac{120\pi}{\sqrt{\varepsilon_e \left[ \frac{W}{d} + 1.393 + 0.667 \ln \left( \frac{W}{d} + 1.444 \right) \right]} } & \text{for } \frac{W}{d} \geq 1 \\ \end{cases}$$  \hspace{1cm} (2)$$

The W/d ratio can be calculated by characteristic impedance $Z_0$ and dielectric constant $\varepsilon_r$.

$$\frac{W}{d} = \begin{cases} \frac{8 e^A}{e^{2A} - 2} & \text{for } \frac{W}{d} \leq 2 \\ \frac{2}{\pi} \left[ B - 1 - \ln(2B - 1) + \frac{\varepsilon_r - 1}{2 \varepsilon_r} \left( \ln(B - 1) + 0.39 - \frac{0.61}{\varepsilon_r} \right) \right] & \text{for } \frac{W}{d} \geq 2 \\ \end{cases}$$  \hspace{1cm} (3)$$

The constant parameters $A$ and $B$ can be calculated by Equation 4(a) and Equation 4(b) respectively.

$$A = \frac{Z_0}{60} \left[ \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{\varepsilon_r + 1} \left( 0.23 + \frac{11}{\varepsilon_r} \right) \right]$$  \hspace{1cm} (4.a)$$

$$B = \frac{377\pi}{2 Z_0 \sqrt{\varepsilon_r}}$$  \hspace{1cm} (4.b)$$

3. Result and Discussion

The simulation and experimental graphical results are described from Figures 4 to 8.

![Simulated S-parameters of S11 and S21](image)

Figure 4. Simulated S-parameters of S11 and S21

To study the S-parameter characteristic of the circuit can help to find out the resonant frequency of the spiral resonator. Based on the result, it is observed that the resonant frequency is 5.7039 GHz.
Figure 5 shows both the S11 and S21 properties of the filter circuit. The graphical results show that it is a bandstop filter characteristic and there is a high attenuation of the signal at the resonant frequency. At resonant, S11 exhibit its reflective signal characteristics where the signal passes as high as possible while S21 exhibit its transmitted signal characteristics, the signal goes as low as possible.

The CST software simulation of surface current is shown in Figure 5. From the figure, it shows that there are almost no current flows through the transmission line at frequency 5.7039 GHz. Since at that frequency, all the current absorbed by the spiral resonator.

![Surface current of the spiral resonator at frequency 5.7039 GHz.](image)

**Figure 5.** The surface current of the spiral resonator at frequency 5.7039 GHz.

The result from VNA (Vector Network Analyzer) is shown in Figure 6. The measured value shows that the resonant frequency is at 5.726 GHz. Nevertheless, the experimental result shown is close to the simulation result with a difference of 0.023 GHz (5.726 GHz – 5.7039 GHz = 0.023 GHz). It is believed that this disagreement exists due to conductor loss which was not accounted in the simulation. Moreover, there might be an error in the fabrication process and some losses occur in the connection during measurement. From the article reviewed, MMIC technology can overcome these types of problems, if the resonator was designed and fabricated using this technology.

![S-Parameter of S21 port from VNA.](image)

**Figure 6.** S-Parameter of S21 port from VNA.
To compare the simulation with the experimental results, graphs are combined in Figure 7. From Figure 6 it is found that the -10 dB bandwidth of the filter is 2.32 GHz. The simulation and experimental results of S21 are well agreed as shown in Figure 7.

![Figure 7. S-parameters of S21 port from VNA is the black line and CST simulation is green line](image)

**4. Conclusion**

Although the size of this spiral resonator is small, the experimental result proves that this resonator has a -10 dB bandwidth of 2.32 GHz. It also shows spiral resonator can be used to construct a small bandstop filter. The spiral resonator also corresponds closely to the simulated results thus validating the theory from simulated data. It is a simple design procedure can also reduce the cost of fabrication. This project shows that each parameter is interconnected when designing a spiral resonator. Thus, understanding the theories and formula related to it is essential for filter designer. The S-parameter provides great insight into the design problem and it can work at high frequencies. This shows that S-parameter is important knowledge in microwave design. Moreover, when deciding on the dimension, it is important to consider practicality when fabricating as an error in fabrication can affect the experimental result. The simulation and experimental result should not disagree with each other as disagreement shows the problem in the design. However, a small disparity can be tolerated as there is no perfect PCB that can be fabricated.

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