Analysis of Spiral Resonator Filters

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Abstract:

The performance of two alternative designs of spiral resonators have been analyzed using COMSOL Multiphysics: a compact spiral microstrip line filter and a fractal spiral resonator filter. A compact microstrip based spiral resonator filter with a resonant frequency of 7.2 GHz shows low insertion losses with a high level of performance and sharp cut off over the specified frequency range. Analysis of a fractal spiral resonator consisting of two unit cells of magnetic meta-materials operating at a resonant frequency of ~1.3 GHz also shows a high level of selectivity at 100 dB/GHz. The results of these analyses are in good agreement with experimental data.

Keywords: Electromagnetics, Frequency domain, Spiral resonator

1. Introduction

Increasing demand for more advanced wireless systems requires the development of novel designs that are capable of simultaneously fulfilling multiple operating and performance criteria. The implementation of high data rate transmission systems requires the development of innovative designs for microwave filters that must fit within a reduced volume that allows the integration of multiple filters into more compact wireless systems. In addition, the filter's specific passband frequencies and quality factors must be achieved within the system's geometrical and topological constraints. Spiral resonator filters offer one option for significantly reduced size compared to conventional ring resonators.

2. Model definition

2.1 Spiral Resonator

A schematic representation of the geometry of the compact microstrip filter using spiral resonators is shown in Figure 1, the resonator cell has dimensions of 3mm x 1mm.

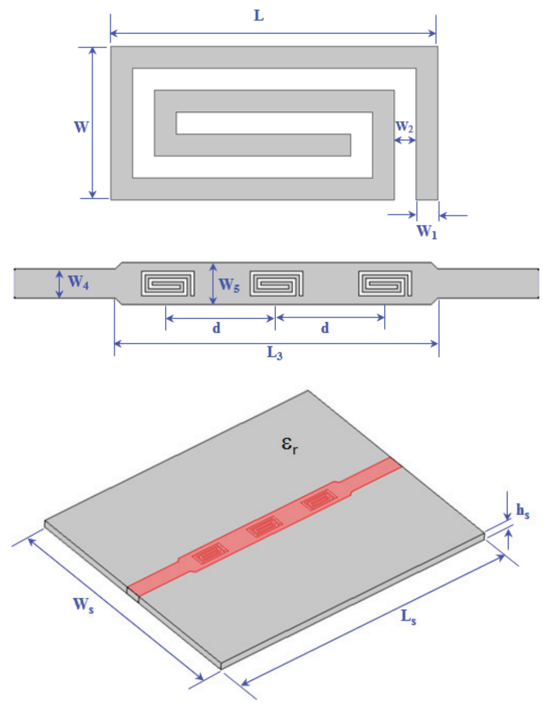


Figure 1: Geometry of compact microstrip filter using spiral resonators

The dimensions are chosen to provide a target resonance frequency of 7.2 GHz (1). A microstrip line is placed on a substrate made from Taconic RF-35 that has a relative permittivity, ε_r , of 3.5, the bottom surface of the substrate is connected to ground.

The corresponding COMSOL Multiphysics model of the spiral resonator is shown in Fig. 2.

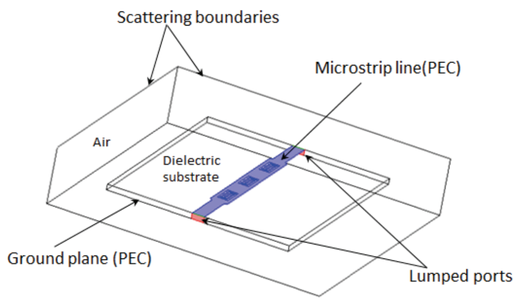


Figure 2: Schematic of spiral resonator model in COMSOL Multiphysics

The microstrip line is modeled as perfect electric conductor (PEC) surface, another PEC surface on the bottom of the dielectric substrate acts as the ground plane. The two lumped ports are modeled as small rectangular faces that bridge the gap between the PEC face that represents the ground plane and the PEC faces that represent the microstrip line at each port. A small air domain bounded by scattering boundary (SBC) surface around the filter is added to avoid back reflection of radiated fields and reduce the size of the modeling domain. The model includes the dielectric substrate defined as a volume with the relative permittivity of the dielectric

2.2 Fractal resonator

The computational model of the fractal spiral resonator is based on a geometry developed by Palandöken & Henke (2), Figure 3.

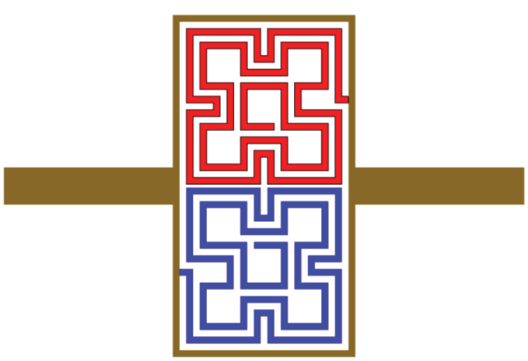


Figure 3: Geometry of metamaterial fractal spiral resonator: two fractal resonators are connected anti-symmetrically along the feeding line.

The filter is composed of two unit cells of electrically small artificial magnetic metamaterials formed with the direct connection of two concentric Hilbert fractal curves. The unit cell size was 6mm with a substrate thickness of 0.5mm. The substrate has a relative permittivity, ε_r , of 3.5 and dielectric losses, tanδ of 0.0037. Operation is based on the excitation of two electrically coupled fractal spiral resonators through direct connection with the feeding line.

3. Results

The results of experimental measurements made by Lim et al. and COMSOL Multiphysics simulation for S_{11} and S_{21} over a range of frequencies of interest are shown in Figure 3; S_{11} specifies the ratio of signal reflected from port 1 for an input on port 1, while S_{21} specifies the signal transmission coefficient from port 1 to port 2.

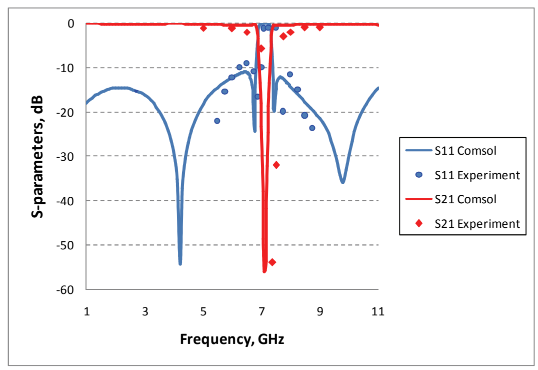
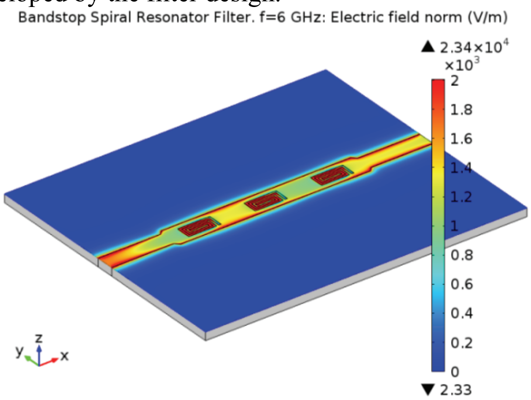


Figure 4: Frequency response of the bandstop spiral resonator filter comparing experimental measurements with COMSOL Multiphysics simulations.

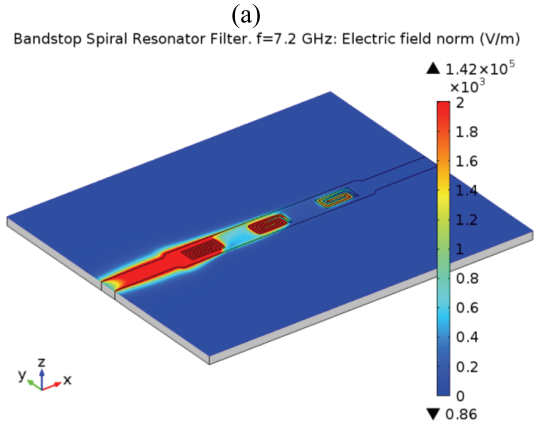
The simulation results agree well with experimental data for the transmitted and reflected signals, and demonstrate rejection of frequencies outside the required frequency cut off. The resonant frequency is 7.2 GHz and the bandwidth of the stopband is 0.5 GHz(7.1-7.6 GHz) with the reference level of $|S_{21}| = -10$ dB. A deep rejection band ($S_{21} > -50$ dB) is obtained at the resonant frequency with a steep cutoff; a flat passband ($S_{21} < 1.2$ dB) is observed, suggesting the proposed spiral filter design has low insertion losses thus limiting its effect on transmitted signal when integrated into a circuit.

The data can also be visualized by the electric field distribution below and at the resonant frequency, Figure 5. Below the resonant frequency a high level of signal is transmitted through the device; at the resonant frequency of

7.2 GHz a high level of signal is attenuated thus demonstrating the degree of signal selectivity developed by the filter design.



(a)



(b)

Figure 5: Electric field below (a) and at (b) resonant frequency of the compact microstrip filter using spiral resonators.

Similarly, simulation results for transmission (S_{21}) and reflection (S_{11}) losses for the fractal spiral resonator composed of two unit cells of electrically small artificial magnetic metamaterials are shown in Figure 6; the selectivity of the filter is 100 dB/GHz with a 3 dB reference insertion loss.

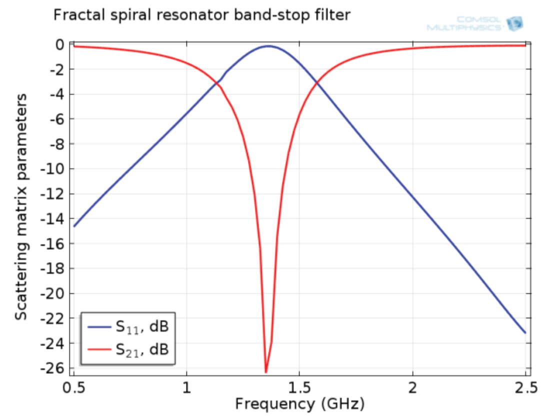
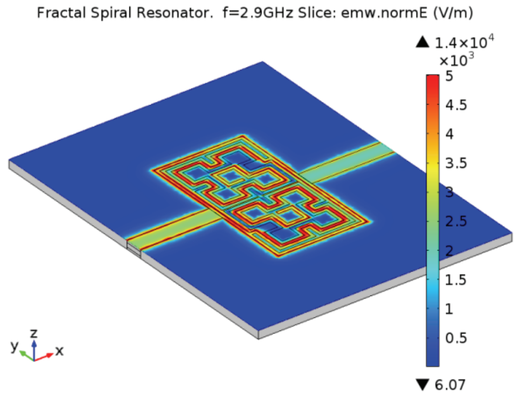
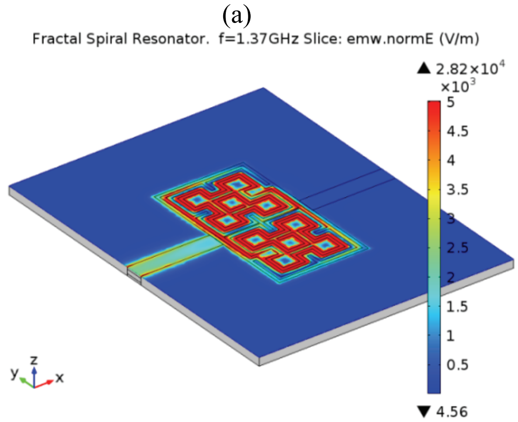


Figure 6: Reflection and transmission parameters of the fractal spiral resonator.

The electric field distribution developed by the fractal spiral resonator is shown in Figure 7; below the resonant frequency signal passes through the filter, at resonance the signal is highly attenuated with an extremely low level of signal transmitted.



(a)



(b)

Figure 7: Electric field at a frequency below the resonant frequency (a) and at the resonant frequency (b).

4. Summary

The performance of a spiral resonator filter has been analyzed using COMSOL Multiphysics and shown to demonstrate agreement with experimental data. A compact microstrip based spiral resonator filter with a resonant frequency of 7.2 GHz shows low insertion losses with a high level of performance and sharp cut off over the specified frequency range. Analysis of a fractal spiral resonator consisting of two unit cells of magnetic meta-materials operating at a resonant frequency of ~1.3 GHz also shows a high level of selectivity at 100 dB/GHz. Analyses of this type can be extended to assess the performance of other filter designs prior to fabrication and integration into operating circuits.

5. References

1. Ho Lim, Jong-Hyuk Lee, Sang-Ho Lim, Dong-Hoon Shin, and Noh-HoonMyung, Proceedings of Asia-Pacific Microwave Conference 2007, p 2221-2224.

2. M. Palandöken, H. Henke, Applied Electromagnetics Conference 2009, p. 1–4, 2009.