Characterization of Narrowband Hairpin Bandpass Filter Composed of Fractal Koch Geometry

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Abstract— In this paper, a narrowband hairpin bandpass filter (BPF) composed of fractal Koch geometry is characterized numerically and experimentally. The implementation of fractal Koch geometry aims to minimize the dimension of filter which affects to reduce the need of material. The filter which utilizes the 1st iteration of fractal Koch geometry, later referred as fractal hairpin BPF is established using 7 elements deployed on a Rogers RO4350 dielectric substrate with the thickness of 1.52 mm. Prior to hardware realization, the proposed filter is numerically characterized to deal with the required specification. The filter which is intended for radar application is designed to have center frequency of 3 GHz with the 3 dB minimum working bandwidth of 200 MHz. It is shown that the realized fractal hairpin BPF which has the dimension of 16 mm $\times$ 47 mm and is approximately 20% smaller than the dimension of conventional one demonstrates the 3 dB working bandwidth of 260 MHz with the center frequency of 3.01 GHz.

1. INTRODUCTION

In 5 decades ago, the development of filters including bandpass filter (BPF) was usually carried out by employing the concept of electric field and magnetic field interaction. From the concept, the filters were then implemented through lumped elements such as capacitors and inductors [1, 2]. However, along with the growth of technology for communication devices especially in high frequency and microwave regions, some designs of filter have been approached based on distributed elements instead of lumped elements and realized by using dielectric resonator, stripline, and microstrip line [3–5]. Furthermore, BPF with high performance and compact size is primarily required to improve the performance of system, as well as to reduce the cost of fabrication, in microwave communication systems.

During last decade, microstrip-based filter with its advantages such as planarity in structure, insensitivity to fabrication tolerances, and reproducibility has been widely implemented in the RF front end of wireless communication systems [6, 7]. Even so, due to the element of microstrip filter which almost requires $\lambda/2$ resonator, the dimension is essentially considered in which the size is an important issue for the systems. Some solutions have been proposed using hairpin-line filter by applying a structure of folded $\lambda/2$ resonator [8–10]. Although it was some advantage in producing compact structure of filter by adopting the hairpin-line technology, however there was some disadvantage in unavoidable coupling between the elements affecting to the limitation in bandwidth response.

In connection to the size reduction, in this paper, a fractal Koch geometry is applied to design elements of narrowband hairpin bandpass filter (BPF) for the characterization. The fractal Koch geometry which is usually implemented for minimizing the dimension of antenna [11, 12], basically is the repetition of some similar geometry shape. By applying the fractal Koch geometry, the structure of fractal hairpin BPF can be more compact compared to the conventional one so that its dimension can be minimized reducing the need of material. The proposed fractal hairpin BPF which utilizes the 1st iteration of fractal Koch geometry is constructed using 7 elements deployed on a dielectric substrate of Rogers RO4350. The proposed filter is intended for radar application with the center frequency of 3 GHz and 3 dB minimum working bandwidth of 200 MHz. Some basic characteristics of filter such as return loss, insertion loss, and bandwidth are used as the performance indicators. Prior to the characterization, overview of fractal Koch geometry and design of fractal hairpin BPF will be briefly described. Then, the characterization result and its analysis as well as the conclusion will be presented consecutively.

2. OVERVIEW OF FRACTAL KOCH GEOMETRY AND DESIGN OF HAIRPIN BPF

The fractal geometry structure, namely fractal Koch geometry, is implemented by dividing an Euclidian element with 1 unit length, called as the 0th iteration, to be 4 parts in which each of part has $\frac{1}{4}$ unit length. Then, the second part of divided element is rotated 60 degrees to horizontal following by the third part of divided element which is rotated to the opposite angle to horizontal, i.e., -60 degrees. While the remaining parts are kept parallel to horizontal. Therefore, the total length will be the same as the total length of the Euclidian element, but the length from the starting-point to the end-point of the element will be $\frac{3}{4}$ of the Euclidian element. By using this method, the shorter length from the starting-point to the end-point of the element can be obtained by keeping the same total length of the element, and is called as the 1st iteration. To obtain the 2nd and higher order iteration, it can be carried out by repeating the similar process implemented in the 1st iteration to others. Figure 1 illustrates the fractal Koch geometry for the 0th, 1st, 2nd, and 3rd iteration where one of them, i.e., the 1st iteration, will be implemented in the design of narrowband hairpin BPF.

Figure 2 shows a design of conventional hairpin BPF which is constructed using 7 elements. The construction is deployed on top side of a 1.52 mm thick Rogers RO4350 dielectric substrate with the relative permittivity of 3.48 and the dimension of 56.9 mm × 15.9 mm, while the bottom side is for groundplane. The geometry of filter indicated in Figure 2 is the optimum design for conventional hairpin BPF to work at the center frequency of 3 GHz with 3 dB minimum working bandwidth of 200 MHz where this is obtained by performing intensively parametrical studies for each element filter using a commercial software. The input/output signals for conventional hairpin BPF are obtained from 50 Ω microstrip line ports with the width of each port is the same as of all filter elements, i.e., 1.3 mm. These ports are connected to the SMA connector types for experimental characterization. The thicknesses of lines both for filter elements and input/output ports on the top side of dielectric substrate as well as the ground plane on the bottom side are set to be 0.035 mm. To obtain the accurate design, the dielectric substrate loss and metal copper conductive losses of lines and groundplane are taken into account.

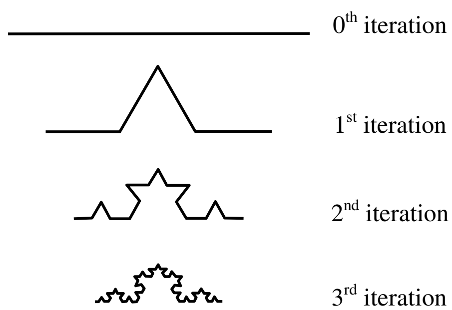

Figure 1: Fractal Koch geometry for the 0th, 1st, 2nd, and 3rd iterations.

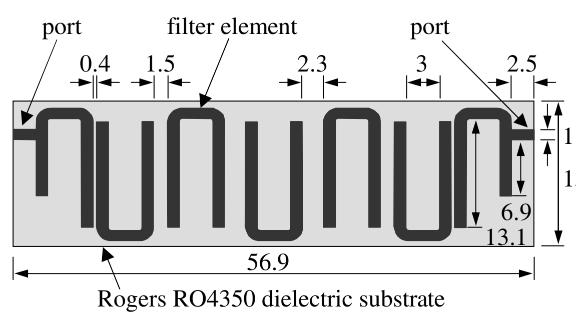

Figure 2: Top view of conventional hairpin bandpass filter (unit in mm).

In order to minimize the dimension of filter, the 1st iteration of fractal Koch geometry illustrated in Figure 1 is applied for conventional hairpin BPF. The hairpin BPF which implements fractal Koch geometry for its elements, namely fractal hairpin BPF, is also deployed on a Rogers RO4350 dielectric substrate with the thickness of 1.52 mm. After performing some parametrical studies for each element filter, the optimum geometry design of proposed fractal hairpin BPF with 7 elements is shown in Figure 3 with the dimension of 42.6 mm × 16.7 mm. The parametrical studies which is carried out by use of a commercial software is conducted not only for acquiring the geometry design but also for obtaining the optimum performance of filter to satisfy the required specifications. Here, parameters used to analyze the performance include center frequency, working bandwidth, return loss and insertion loss.

The performance of both hairpin BPFs as numerical characterization result is plotted in Figure 4. It seems that the characterization result for fractal hairpin BPF has agreed very well with the conventional one for frequency range lower than 3.3 GHz. However, there is some slight difference for frequency range higher than 3.3 GHz where the fractal hairpin BPF has a poor skirt of insertion loss which is possibly affected by unavoidable coupling between elements of filter. From the results, it shows that the maximum insertion loss at passband area is similar each other, that is 2.49 dB at frequency of 2.98 GHz. While the 3 dB working bandwidth for fractal hairpin BPF with center frequency of 3.005 GHz is 230 MHz ranges from 2.89 GHz to 3.12 GHz where this is 10 MHz wider than the conventional one which has 3 dB working bandwidth of 220 MHz ranges from 2.89 GHz to 3.11 GHz with the center frequency of 3 GHz. In addition, it can be inferred that by keeping the

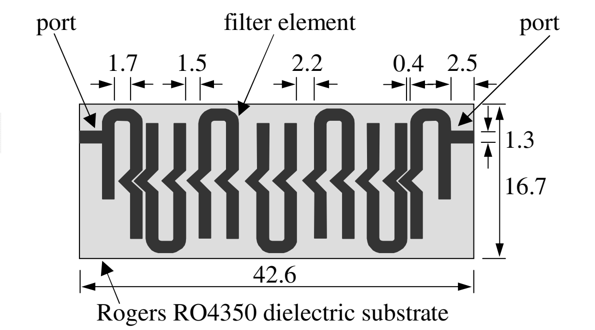

Figure 3: Top view of proposed fractal hairpin bandpass filter (unit in mm).

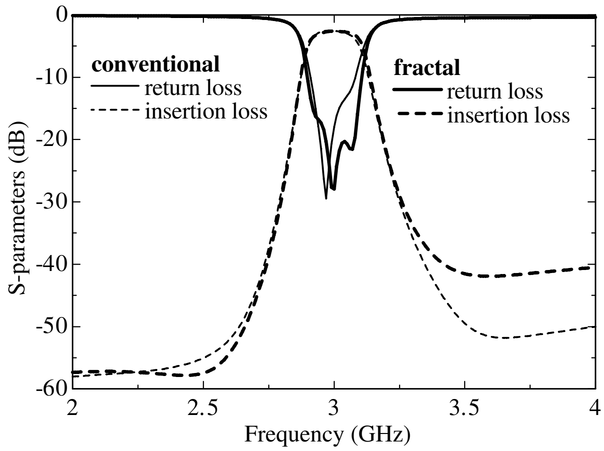

Figure 4: Simulation results for both hairpin bandpass filters.

similarity of performances with some efforts the utilization of fractal Koch geometry for hairpin BPF with 7 elements has reduced the physical dimension up to 20% from the conventional one.

3. HARDWARE REALIZATION AND CHARACTERIZATION

To verify the numerical characterization, the hardware realization is carried out by fabricating both designed hairpin BPFs on Rogers RO4350 dielectric substrates with the thickness of 1.52 mm. Pictures of both realized hairpin BPFs are shown in Figure 5. For experimental characterization purpose, 2 SMA connector types are soldered at the input/output ports of each filter. Figure 6 depicts the measured result of experimental characterization for realized fractal hairpin BPF with the measured result for conventional one plotted together as comparison.

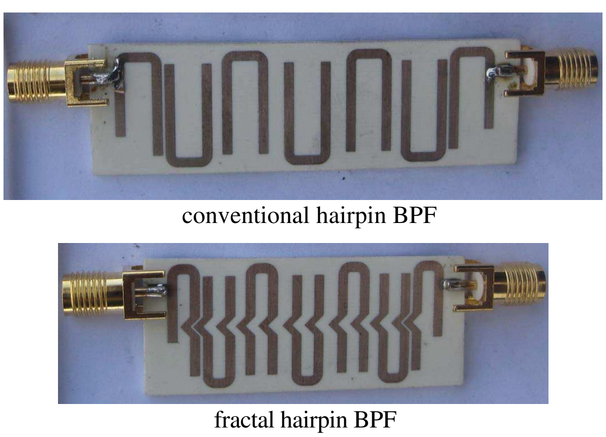

Figure 5: Pictures of both realized hairpin bandpass filters.

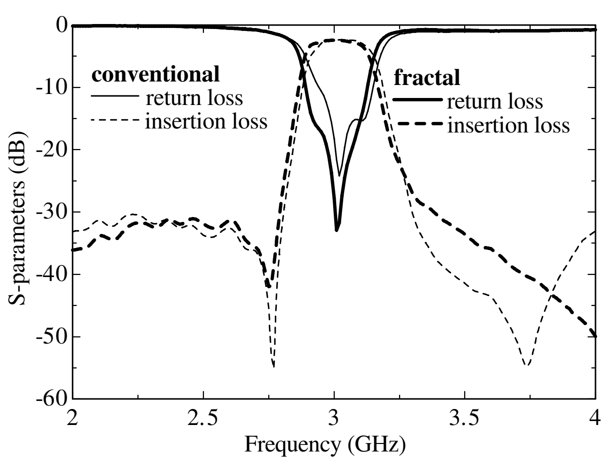

Figure 6: Measurement results for both hairpin bandpass filters.

In general, the characteristic responses for both realized filters as well as their passband characteristics are coincided qualitatively each other. Both results seem to have poor skirt of insertion losses at frequency range lower than 2.75 GHz. This is probably evoked by inappropriateness of RF cables used for the measurement. From the results, although the center frequencies of both realized filters are slightly different, however their 3 dB working bandwidth are similar each other, i.e., 260 MHz, range from 2.88 GHz to 3.14 GHz for fractal hairpin BPF and from 2.9 GHz to 3.16 GHz for convectional one. The center frequency of realized fractal hairpin BPF is at 3.01 GHz which is 5 MHz higher than the simulated result, i.e., 3.005 GHz. Whilst for realized conventional hairpin BPF, the center frequency is at 3.03 GHz which is 30 MHz higher than the simulated one, i.e., 3 GHz. It is noticeable that the insertion loss of measured result in passband area for fractal hairpin BPF shows similar tendency with the conventional one. The maximum insertion loss in passband area is 2.46 dB and 2.33 dB for realized fractal hairpin at frequency of 2.99 GHz and conventional one at frequency of 3.03 GHz, respectively. It shows that the realized fractal hairpin BPF is worse than the conventional one which is probably caused by inaccurateness of fabrication process. Nevertheless, from the results it can be concluded that the proposed fractal hairpin BPF which has been realized based on microstrip technology has adequate bandwidth response complying with the required bandwidth coverage.

4. CONCLUSION

The characterization of narrowband hairpin BPF composed of fractal Koch geometry has been demonstrated numerically and experimentally. The fractal hairpin BPF which has utilized the 1st iteration of fractal Koch geometry has been implemented using 7 elements deployed on a Rogers RO4350 dielectric substrate. As comparison, a conventional hairpin fractal has also been designed on the same dielectric substrate. From the characterization result, it has been shown that the fractal Koch geometry utilization has reduced the dimension of fractal hairpin BPF up to 20% from the conventional one. It has been demonstrated that the realized fractal hairpin BPF has had narrowband bandwidth response with center frequency of 3.01 GHz and 3 dB working bandwidth of 260 MHz. Whereas the realized conventional hairpin BPF, it has had the center frequency of 3.03 GHz with the similar working bandwidth. It has been confirmand that both realized filters have satisfied and complied with the requirement for desired radar application.

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