Fractal-Shape 40 GHz Microstrip Bandpass Filter on High-Resistivity Si for Suppression of the 2nd Harmonic

Il Kwon Kim[1], Nickolas Kingsley[2], Matt Morton[2], John Papapolymerou[2], Manos M. Tentzeris[2], and Jong-Gwan Yook[1]

[1]Yonsei University, Department of Electrical and Electronic Eng., 134 Shinchon-Dong, Seodaemun-Gu, 120-749 Seoul, Korea, +82-2-2123-3565
[2] Georgia Institute of Technology, School of Electrical and Computer Engineering, 85 Fifth Street, GA 30308 Atlanta, U.S.A., +1-404-385-6402

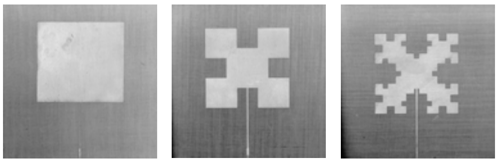
***Abstract* — In this paper, the Koch fractal shape is applied for the first time to microstrip bandpass filters integrated on a high-resistivity Si substrate. By using this method, the second harmonics of the filter can be suppressed to about -40 dB. Conventional microstrip coupled line filters are popular in RF front ends, because they can be easily fabricated and integrated with other RF components. However, they typically have large second harmonics that can cause unwanted interference. Without any additional filters, the proposed Koch shape filters have suppressed the 2nd harmonics by about -40 dB, so they can be used in systems with stringent harmonic suppression requirements.**

I. INTRODUCTION

Microstrip coupled line filters have been used to develop narrow fractional bandwidth band pass filters due to their relatively weak coupling [1]. These filters have various advantages, such as low-cost fabrication and easy integration. Despite of these advantages, this type of filter has the inherent problem that large 2nd harmonics are generated by the even and odd mode phase differences of the microstrip coupled line geometry due to the inhomogeneous characteristics of the microstrip structure, especially when the substrate dielectric constant is high. To overcome this disadvantage of microstrip band pass filters, there have been several 2nd harmonic suppression techniques, such as equalizing the phase velocity of the even and the odd modes by adding compensating lines or reactive components (like photonic band gap (PBG) and defected ground structure (DGS) on coupled lines [2]) or modifying the shape of the coupled lines as asymmetric to control even mode phase velocity (such as grooved [3] and wiggly lines [4]).

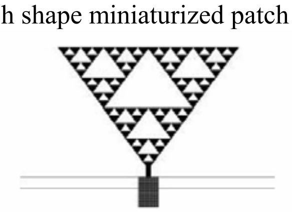
As the frequency of RF applications increase, radio-frequency integrated circuit (RFIC) designs on silicon substrates become a key factor for low-cost, highly integrated circuits. However, the substrate loss in CMOS-grade silicon (resistivities between 1 and 30 Ω-cm) emerges as a troublesome issue for microwave integrated circuits particularly for passive components. To reduce the silicon substrate loss, high resistivity silicon (HRS) can be used.

Several fractal geometries, such as Koch curve, Sierpinski gasket, Cantor dirt, and Hilvert curves, have been widely studied to develop microwave devices, such as antennas, frequency selective surfaces (FSS), and PBGs. Fractal shapes have unique two properties, such as space filling property and self similarity property. A fractal shape can be filled in a limited area as the order increases and occupies the same area regardless of the order. This is due to th space filling property. By self similarity, a portion of the fractal geometry always looks the same as that of entire structure. The research on fractal antenna element is concentrated on miniaturized antenna and multi-band antenna. The space filling property is useful to miniaturize physical dimensions and the self-similar property is advantages to designing multiband/broad band antennas. However, most research on this has been focused on antenna elements and arrays [5]. Some fractal shape antennas are shown in Figure 1. In this paper, Koch fractal geometry is applied for the first time to suppress the 2nd harmonic of a microstrip coupled line on a high-permittivity substrate. Conventionally, the fractal geometry has two properties: the space filling property and the self-similarity. These properties can also be adopted to microwave applications. By numerical and experimental methods, it is found that this type of filter can be used in a system required to suppress 2nd harmonic interference.



Koch 0 (square patch) **Koch 1 (1/4 factor)** **Koch 2 (1/4 factor)**

(a) Koch shape miniaturized patch antenna



(b) Seripinski monopole

Fig.1. several fractal shape antennas

II. KOCH SHAPE COUPLED LINE FILTERS

The permittivity of HRS considered here is 11.7 and the substrate thickness is 100 um. The resisitivity of silicon is approximately 8000 ohm-cm. The operating frequency of the designed filter is around 40 GHz and the 2nd harmonic (around 80 GHz) is also investigated. The Koch fractal geometry is a well-known structure to use for antenna miniaturization, by realizing effectively longer electrical lengths [6]. This has been applied to wire and planar type antennas to reduce antenna size. Figure 1 shows the configuration of the proposed Koch structure. This type of Koch structure can be defined by two factors: the fractal factor and the iteration order. The fractal factor represents the construction law of the fractal geometry generation and the iteration order depicts how many iteration processes are carried out. We used traditional filter theory to design conventional filters first, then applied the 1st and 2nd iteration number shapes, whose fractal factor is ¼, into the coupled section of conventional microstrip coupled line.

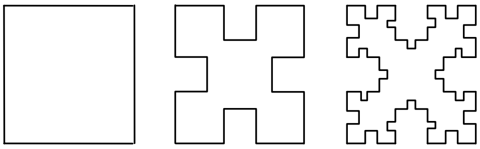

(a) zero (b) first (c) second

Fig.2 Koch fractal island geometry

The configurations and dimensions of the proposed fractal shape filters are shown in Figure 2. As shown in this figure, coupled sections of microstrip filter have Koch fractal shape geometry. The properties of these filters are investigated by using a commercial method of moments (MOM) based simulator, IE3D. Also, to verify the simulation results, the designed filters were fabricated on a high resistivity silicon substrate. A photo of the fabricated filters is shown in Figure 3. Copper was electroplated to 2 µm thicknesses on a 100 µm thick wafer. The total size of filter is 1.228 mm × 0.264 mm, 1.837 mm × 0.405 mm, and 2.448 mm × 0.49 mm for 1-pole, 2-pole, and 3-pole, respectively. The simulated and measured S-parameters are shown in Figure 4 verifying that the resonance frequency of the fractal shape filter is almost the same as the conventional filter (Koch zero case),as well as that first or second iteration geometries are sufficient for a 2nd harmonic suppression around or below 30 dB's even for 1-pole designs. Without an additional matching circuit, the insertion loss at the center frequency is slightly larger than the conventional one. However, the 2nd harmonic insertion loss is approximately 40 dB larger than the conventional one even for higher permittivity substrates, as is the case of silicon. This result clearly demonstrates that the fractal shape filter can be used to suppress the 2nd harmonic. As the fractal iteration order increases, the suppression becomes larger than that of the previous iterations. This is due to the space filling property of fractal geometry. The electrical length at higher frequencies is more effected by this property. As the iteration order increases, the length around the perimeter increases, the physical perimeter length remains constant but the effective electrical length increases. This causes the transmission zero point to shift lower as the iteration order increases.


(a) zero(K0) (b) First(K1) (c) 2nd iteration(K2)

Fig.3 The layout of proposed fractal filters: 1-pole configuration

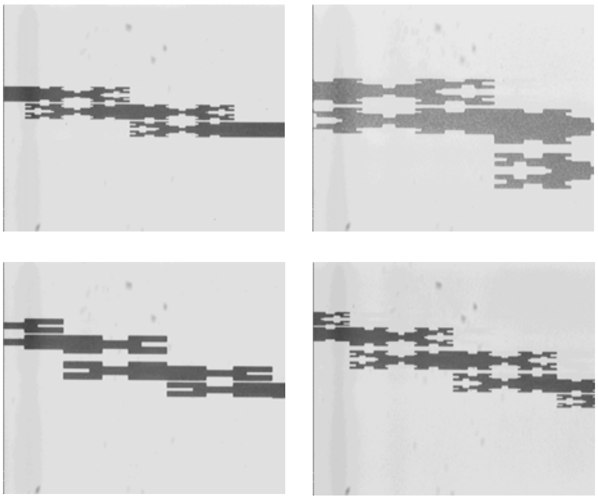
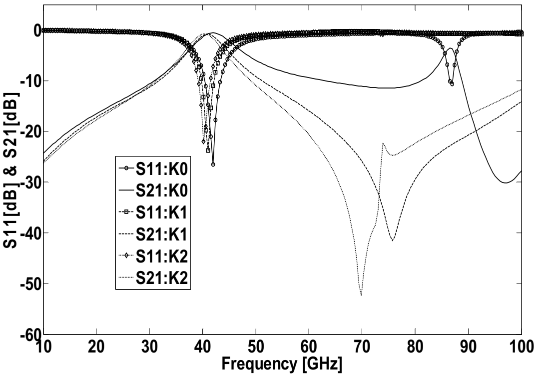
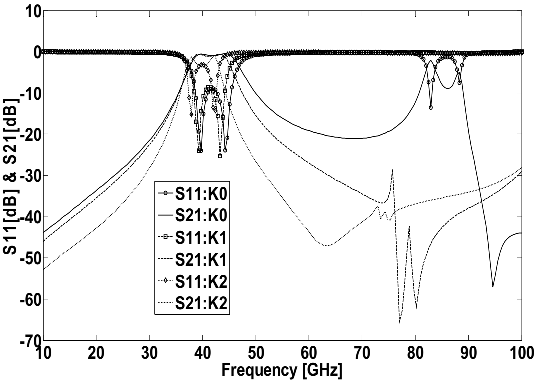


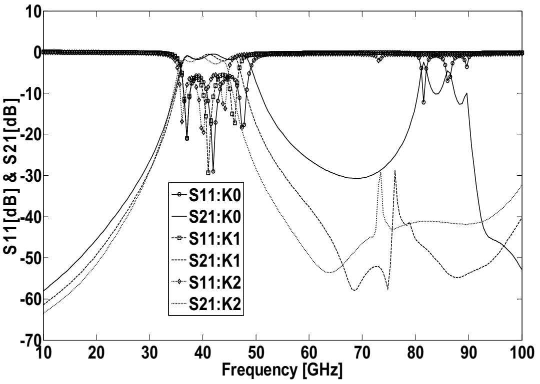
Fig.4 Fabricated fractal shape silicon filters



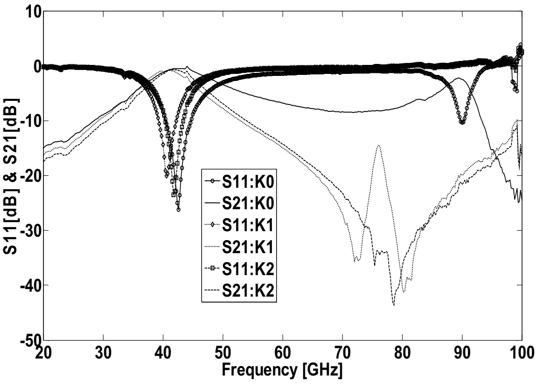
(a) 1 pole configuration



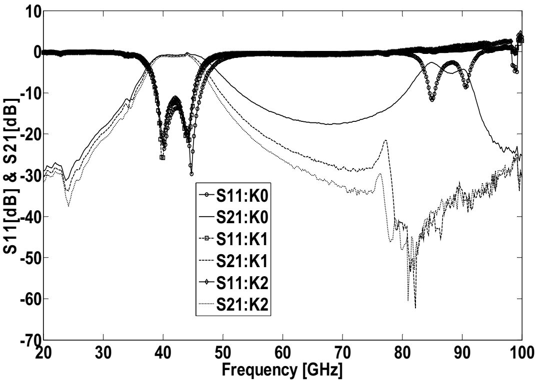
(b) 2 pole configuration



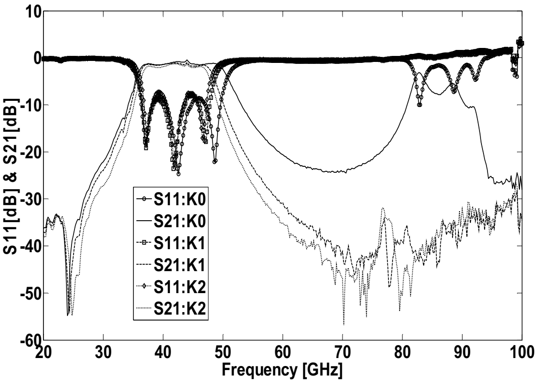
(c) 3 pole configuration
Fig.5 Simulation results



(a) 1 pole configuration



(b) 2 pole configuration



(c) 3 pole configuration
Fig.6 Measurement results

All results are summarized in Table.1, where it is clearly demonstrated that fractal shape filters can be used to suppress the 2nd harmonics in microstrip coupled line filter implementations on high dielectric constant substrate.

Table 1. Summary of results

P	**Iter**	**Simulation Results**			
		CF	**IL(1)**	**2H**	**IL(2)**
1	**K0**	41.6	-0.62	83.2	-6.737
	K1	40.6	-1.08	81.2	-30.57
	K2	39.8	-1.04	79.6	-26.64
2	**K0**	42.0	-1.21	84.0	-4.71
	K1	41.0	-1.45	82.0	-49.97
	K2	40.0	-3.70	80.0	-36.93
3	**K0**	41.8	-0.56	83.6	-9.11
	K1	41.2	-0.70	82.4	-43.63
	K2	39.8	-1.66	79.6	-42.47

P	**Iter**	**Measurement Results**			
		CF	**IL(1)**	**2H**	**IL(2)**
1	**K0**	42.8	-0.48	85.6	-5.15
	K1	41.8	-0.71	83.6	-28.97
	K2	41.0	-0.81	82.0	-34.02
2	**K0**	43.0	-0.80	86.0	-3.45
	K1	42.2	-1.08	84.4	-44.57
	K2	42.0	-1.32	84.0	-41.46
3	**K0**	44.0	-0.49	88.0	-5.76
	K1	42.4	-1.13	84.8	-43.25
	K2	41.8	-1.27	83.6	-41.78

P: Pole number, Iter: Iteration order, K0: Koch zero order, K1: Koch first order, K2: Koch 2nd order, CF: Center frequency [GHz], IL(1): Insertion Loss [dB] at first harmonic, 2H: 2nd harmonic frequency [GHz], IL(2): Insertion Loss [dB] at 2nd harmonic

VI. CONCLUSION

In this paper, the Koch fractal shape is applied for the first time to mm-wave microstrip band pass filters integrated on a high-resistivity Si substrate. From simulation and experimental results, it was found that the 2nd harmonic of fractal shape filters can be suppressed as the fractal factor increases reaching a level of 40 dB, while maintaining the physical size. These fractal shape filters can be easily integrated with RF systems which require a highly reduced 2nd harmonic component.

ACKNOWLEDGEMENT

This work was supported by the International Research Internship Program of the Korea Science and Engineering Foundation (KOSEF) and the Georgia Electronic Design Center (GEDC).

REFERENCES

[1] David M. Pozar, *Microwave Engineering*, 2nd Ed, pp. 474-485, 1998.

[2] Jun-Seok Park, Jun-sik Yun, and Dal Ahn, “ A Design of the Novel Coupled-Line Bandpass Filter using Defected Ground Structure With Wide Stopband Performance,” *IEEE Trans on Microwave Theory and Techniques*, Vol.50, No.9, pp. 2037-2043, September 2002.

[3] Bong S. Kim, Jae W. Lee, and Myung S.Song, “An Implementation of Harmonic-Suppression Microstrip Filters with Periodic Grooves,” *IEEE Microwave and Wireless Components Letters*, Vol.14, No.9, pp. 413-415, September 2004.

[4] Texa Lopetegi, Miguel A. G. Laso, Francisco Falcone, Ferran Martin, Jordi Bonache, Joan Gracia, Lteticia Perez-Cuevas, Mario Sorolla, and Marco Guglielmi, “Microstrip “Wiggly-Line” Bandpass Filters With Multispurious Rejection,” *IEEE Trans on Microwave Theory and Techniques*, Vol.49, No.9, pp. 1593-1598, September 2001.

[5] Douglas H. Werner and Suman Ganguly, “An Overwiew of Fractal Antenna Engineering Research,” *IEEE Antennas and Propagation Magazine,* Vol.45, No.1, pp.38-57, February 2003.

[6] Il Kwon Kim, Jong-Gwan Yook and Han-Kyu Park, “Fractal-Shape Small Size Microstrip Patch Antenna,” *Microwave and Optical Technology Letters*, Vol.34, No.1, pp.15-17, July 2002.