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Miniaturization of Resonator based on Moore Fractal

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Abstract

This paper presents the simulation and fabrication of miniaturized half wavelength resonator design using Moore fractal iteration technique. These resonators have been prepared for wireless application at a centre frequency of 2.45GHz using a substrate with dielectric constant of 2.2. The size and performance are compared with the conventional half wavelength open line resonator. It can be shown that the Moore fractal iteration technique able to reduce 46% of the size of conventional half wavelength resonator through first iteration, and 30% through second iteration while maintaining the resonance performance. The resonators have been fabricated using conventional printed circuit board facilities not specialized in microwave devices. However, the unloaded Q-value of the Moore structure generally much lower compared the open line type.

Keywords: *microstrip resonator, Moore fractal curve, resonator miniaturization, unloaded Q-value*

1. Introduction

Miniaturization becomes an interesting trend nowadays in developing cost effective radio frequency (RF) devices. Miniaturization can be done in many different techniques and by using combination of materials. Planar resonators are not an exceptional, and they are particularly attractive since they form the basic components to many communication devices such as filters [1] and oscillators. A conventional half-wavelength open line resonator is always too large [2]. To reduce the size, hairpin resonator can be formed by folding the two ends toward one another [3]. Another popular technique for miniaturization is using fractal iteration [4]. Fractal construction comes with many curvature shapes and names depending on its mathematical equations [5, 6]. To this end, fractal have been used for several applications, such as in the electromagnetic propagation [4], antenna miniaturizations [7], as well as filters and resonators development [8]. Among the popular fractal shapes is known as the Moore iterations. This paper presents the possible application of Moore iteration towards the development of compact resonator and compare the results with conventional planar resonator design.

2. Research Method

2.1. Moore Microstrip Resonator

Moore fractal is achieved by curving a single line while obeying to a special recursive procedure to maintain the original length of the line when filling the space [9]. This special characteristic is called space filling curve (SFC). SFC makes miniaturization of RF devices possible. At a glance, Moore fractal looks very similar with another type of fractal shape called the Hilbert [10]. Their shapes are outlined in Figure 1 to show the different between both. The main different is at the endpoints of the fractal. Moore has its endpoint coincides with each other and creates a spacing gap, while Hilbert's endpoint is facing outwards. From microstrip technology's perspective, a gap between microstrip lines creates capacitance effect which influences the coupling characteristic. This effect holds for both Moore and Hilbert.

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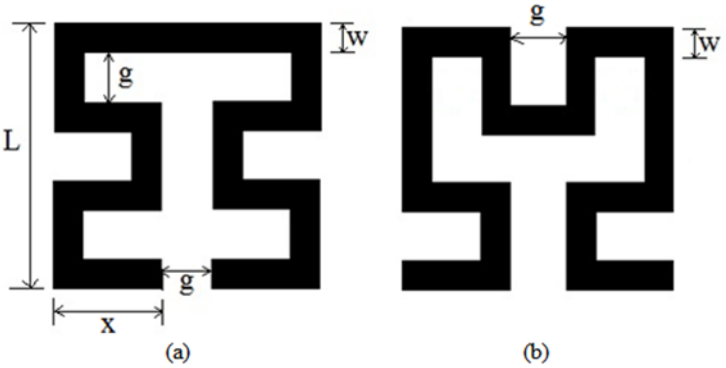

Figure 1. (a) Moore curves and (b) Hilbert curves with 2nd iteration level (n=2)

The total perimeter length, *S* of Moore fractal is determined using its iteration level, *n* [9].

$$S_n = \left(2^n + 1 + \frac{1}{2^n - 1} \right) L \tag{1}$$

L, is the external side length of overall structure (see Figure 2), and is referred to determine the area occupied by the Moore fractal curve. To develop a resonator using Moore fractal, a single half wavelength open line resonator is folded to some iteration level. Theoretically, the effective resonator's length should be maintained to provide the same resonance frequency. Ideally, it is much preferred to fit the original resonator shape to a small area as much as possible through iteration technique. Hence, the structure's width, *w*, and the gap space, *g*, needed to be carefully defined to shape the curvature effectively according to Moore. The higher the number of iterations would decrease the resonator's width and spacing between lines. The relations between these dimensions are formulated by (2).

$$L = 2^n (w + g) - g \tag{2}$$

L can be controlled by defining the width of resonator, *w* and spacing between lines, *g*. However, the curve length, *x* will also be varied in order to maintain the resonant frequency of the structure especially when the number of iteration increases e.g to n = 2 (second iteration). The dimension of curve length for the second iteration, x_2 can be calculated by:

$$x_2 = \left(\frac{S_2 - 2w_2 - 7g_2}{8} \right) \tag{3}$$

One can control the resonance frequency by changing only the *x* value while maintaining the width of resonator, *w* and spacing between lines, *g*. So, the optimization would be easier to be implemented. Smaller width would increase the dissipation losses, thus the quality factor, *Q* would as well diminished. So, the designer should consider this parameter carefully if the application emphasizes on higher quality factor, *Q*. The trade-off between miniaturization and dissipation losses should be defined well according to priority.

2.2. Moore Resonators: Design and Modeling

In this study, three types of resonators namely the half-wavelength open line (reference), the first Moore iteration and the second Moore iteration have been designed and modeled using CST Microwave Studio to resonate at 2.45 GHz. The input and output (I/O) is based on the coupled feed technique. The dimension of the feed line is fixed at 5mm x 5mm, and the coupling gap is at 0.5mm. This condition ensures that all resonators have the same characteristics in term of I/O coupling. The substrate used on all cases is RT Duroid 5880 with effective permittivity of 2.2, and thickness of 1.57mm.

The half-wavelength open line microstrip resonator is designed by using general microstrip transmission line technique to determine its width and length respectively. Based on our calculation, the resonator's width is determined as w = 5.0mm and length as l = 42.5mm.

Then the first iteration of Moore is designed. The resulting shape is quite similar to a hairpin line resonator. It is designed by taking consideration of the value of half-wavelength resonator's length. The original design of the half wavelength open line resonator is folded to 'U' shape. After optimization, the width of the resonator is found as w = 2.0mm and the length is divided into 3 segments with $L_2 = L_3$ = 14.5mm, L_1 = 17.0mm, as outline in Figure 2.

The second iteration of Moore resonator is also designed based on the half-wavelength open line resonator. This ensures consistent length is used and that the resonance frequency is maintained. The width of the microstrip line is first determined as w = 2.5mm and spacing coupling between segments, g = 0.5mm. Then, the external length, L and x are calculated based on equation (2) and (3). The geometry of all three resonators are as shown in Figure 2 and the dimensions are as tabulated in Table 1.

Table 1. Comparison of resonators geometry

Resonator	Occupied area (mm^2)	Width of resonator (mm)	Miniaturization rate (%)
Open half wavelength	1337	5.0	-
First iteration Moore	624	2.0	46
Second iteration Moore	436	2.5	30

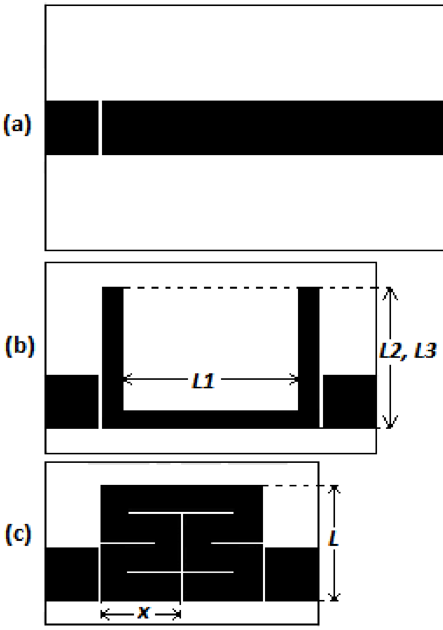

Figure 2. Evolution of Moore curves, (a) Open half wavelength resonator, (b) First iteration Moore, (c) Second iteration Moore

2.3. Extraction of Unloaded Quality Factor of Moore Resonators

We apply the method that introduced by P. Jarry *et al*. [8] to extract the unloaded quality factor. The input coupling characteristic depends on spacing gap between the first resonator and input feedline while the output coupling depends on the spacing between last resonator and output feedline. From reflection coefficient transmission characteristic, S_{11}, we could calculate the input coupling by measuring its resonant frequency, f_c and bandwidth corresponding to 180^o phase shift from resonant frequency. Then, the input coupling is represented by external quality, Q_e factor given by:

$$Q_e = \frac{f_0}{\Delta f} \tag{4}$$

Since the performance of filter is referred to unloaded quality factor, Q_u, spacing gap between input and output feedlines can be manipulated. To eliminate the effect of input and output coupling, the spacing between feedlines and resonators is shifted away (see Figure 3) until attenuation of S_{21} transmission characteristic at least 20dB from its maximum value at resonant frequency. The -3dB bandwidth is measured to calculate unloaded quality factor, Q_u by extrapolating external quality factor, Q_e given by:

$$Q_u = \frac{Q_e}{1 - S_{21}(f_o)} \tag{5}$$

Higher quality factor suggests more power is delivered between resonator lines due to strong coupling between resonators.

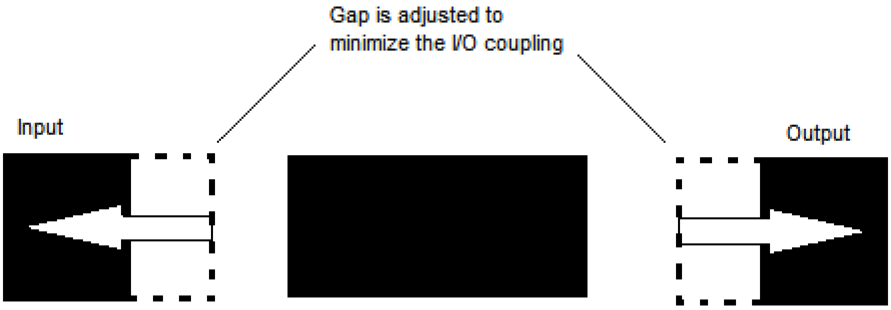

Figure 3. Method used to determine the unloaded quality factor

3. Results and Analysis

3.1. Simulation Result

Based on simulation, all resonators approximately resonate at the same resonant frequency of 2.45GHz as depicted in Table 2. The first spurious response occurs at twice the resonant frequency for half-wavelength line and the second iteration Moore resonators. Interestingly, the first spurious response for the first iteration Moore occurs at nearly its third resonant frequency. This is due to a transmission zero profile occurs at 5.92GHz causes the spurious response to be shifted. On the other hands, transmission zeros does as well occurs at the second iteration Moore resonator but further at 6.72GHz. Transmission zeros is not visibly observed for the half-wavelength line resonator. The corresponding simulated response is shown in Figure 4.

The unloaded quality factor, Q_u relates to the dissipation loss of a resonator structure. The loss was due to copper and dielectric material. The metallic losses for copper are characterized as σ = 5.96 x 10^7 S/m for thickness of 35μm while the dielectric losses are characterized by substrate's loss tangent (tan σ = 9 x10^{-4}) having a dielectric constant of 2.2 and a thickness of 1.57mm. Table 2 shows the comparison of the unloaded quality factor, Q_u for all resonators in this study.

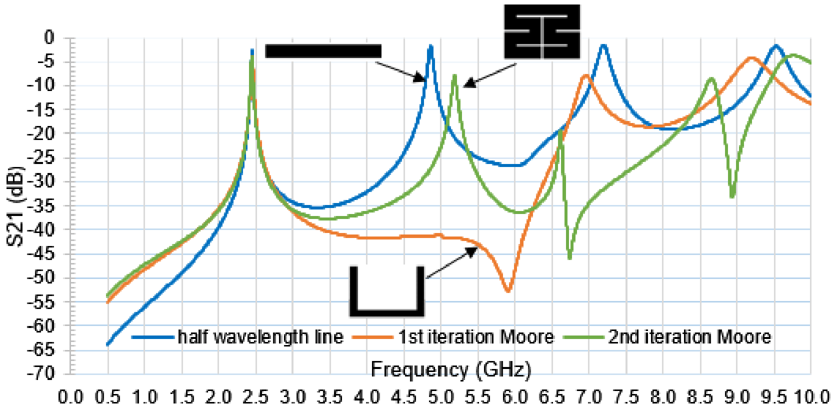

Figure 4. Transmission characteristics (S_{21} parameter) of modeled resonators

Table 2. Transmission characteristics of modeled resonators

Resonator	Resonant frequency (GHz)	Transmission zero (GHz)	Unloaded quality factor, Q_u
Open half wavelength	2.45	none	480
First iteration Moore	2.45	5.92	283
Second iteration Moore	2.45	6.72	303

The half-wavelength open line resonator has the highest unloaded quality factor of Q_u = 480. However, for both iterated shaped resonators, the quality factor is much lower. This degradation was due to the metallic losses. The quality factor for the first iterated shape drops to about half of the open line resonator. As more iteration is implemented to the design, the quality factor increases slightly. To enhance this quality factor, one should consider to use a better conducting material or substrate with smaller loss tangent.

3.2. Fabrication and Experiment Result

The resonators are fabricated and measured for validation. The transmission coefficient (S_{21}) performance is shown in Figure 5. We noticed that the resonant frequency of all resonators were slightly shifted towards the lower side of the target of 2.45GHz. Table 3 are detailing the measured data.

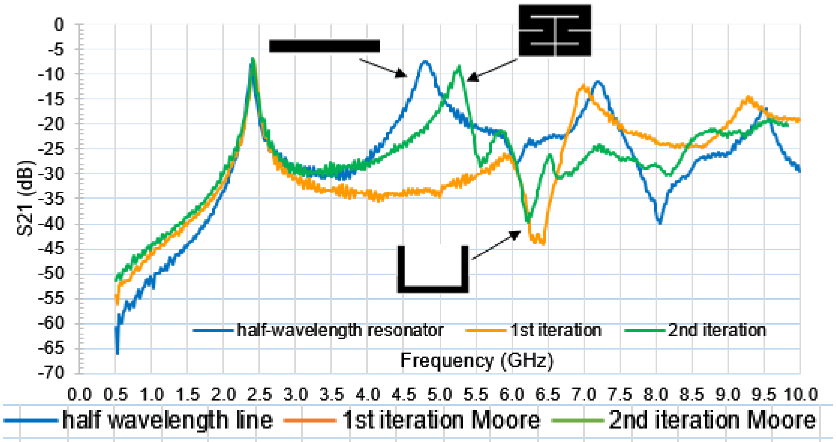

Figure 5. Transmission characteristics (S_{21} parameter) of measured resonators

Table 3. Transmission characteristics of measured resonators

Resonator	Resonant frequency (GHz)	Transmission zero (GHz)	Resonant frequency differences from simulation (MHz)
Open half wavelength	2.44	none	10
First iteration Moore	2.42	6.43	30
Second iteration Moore	2.43	6.30	20

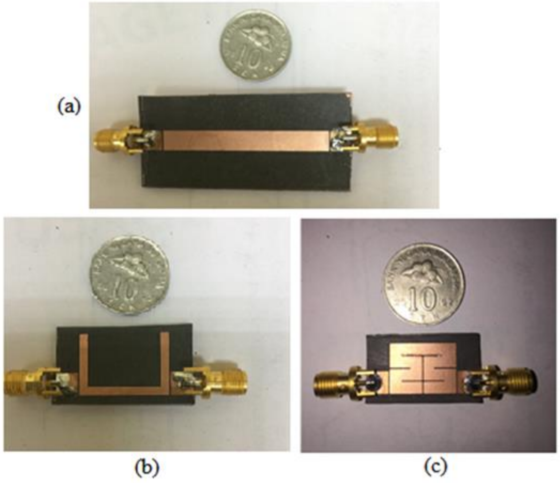

Figure 6. Realization of the resonators, (a) Open half wavelength, (b) First iteration Moore, (c) Second iteration Moore

The measured performances however are acceptable as the slight shift may due to the fabrication imperfection.

4. Conclusion

In this work, applications of Moore fractal for resonator miniaturization have been investigated. The evolution of Moore fractal curves from the half-wavelength resonator are modeled, simulated and fabricated and its electrical performances are compared. Moore fractal iteration has the potential to compact the size of a resonator and at the same time offer better stopband rejection profile. From the simulation and experimental results, it shows that Moore fractal resonator has the potential to be applied as element for a filter with high selectivity and better stopband rejection compared to conventional parallel coupled line type. However the development with higher iteration should be considered carefully by considering the limitation of a fabrication process as achieving precise geometry will become a big challenge.

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