Novel Active Reconfigurable Fractal Dipole Antenna using RF PIN diodes

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Abstract

Harmonics are harmful and undesirable in many applications. Fractal technology can be embedded into an antenna due to its high ability in reducing the physical size of the antenna, increasing its operating bandwidth and directivity. However, such introduction of fractals can cause significant undesired harmonic problems associated with higher order modes of the antenna. In this paper, the design of an active harmonic suppressed small fractal dipole antenna named TMFDB25 is presented. It has tunable capability of a reconfigurable operation within an observed range of 400 MHz to 2 GHz. The switchable small fractal dipole antenna is integrated with open circuit stubs and RF PIN diodes. The proposed structure has diode biasing circuit that influences the actual performances of the antenna. These results are the most reliable obtained. The simulation results showed that the antenna has a capability to tune single operating frequency out of four at a time, simultaneously, suppressing the higher order mode.

Keywords: Reconfigurable Antenna, Koch Curve, Harmonic Suppressed Antenna, PIN diodes

1. Introduction

Reconfigurable printed fractal dipole antenna for frequency agility and harmonic suppression has advantages such as miniaturizing the RF front-end unit and avoiding overlapping between the high band frequency with higher order mode for effective channel operating frequency used [1]. Recently, many reconfigurable antennas have been proposed which comprise of three major features; (1) “wideband to wideband reconfiguration”, (2) “wideband to narrowband reconfiguration (or vice versa)” or (3) “narrowband to narrowband reconfiguration”. A similar study is carried out for effective selection of operating frequency. Due to the significance to suppress higher order modes for improving the antenna performance, optimized and feasible design (e.g. downscale the antenna operating frequency) is especially needed to locate the RF PIN diodes on the dipole arm (e.g. causes low efficiency as well as low gain if many diodes are used). Hence, the active reconfigurable fractal antenna proposed in this paper is presented for the first time.

Recently, there are several works which integrate the PIN diode onto the antenna for frequency reconfiguration purposes [2]-[4] which have made used of folded slot antenna, PIFA antenna, and slot antenna. Four PIN diodes have been employed in a folded slot antenna (diodes are located on the slot to change the slot’s perimeter) to tune the operating frequency at 5.775 GHz to 5.25 GHz [2]. A PIN diode is used to connect the main radiator with an additional radiator in a PIFA antenna that simultaneously work with varactor diode (located on the antenna shorting line) to reconfigure the operating frequency at 2.0 GHz and 5.5 GHz [3]. In addition, two diode and varactor diode are used in an L-shape slot antenna to change the operating frequency from 2 GHz to 2.7 GHz [4].

This paper presents the design of a single band small tunable fractal dipole antenna that is incorporated with broadband quarter-wavelength triangular tapered balun using RF PIN diodes. The observed frequency range is up to 2 GHz. An extensive simulation work has been carried out using commercial simulation software using an ideal RF PIN diode. Good impedance matching performances for the desired operating bands have been achieved. Then, the results are analyzed in terms of the operating frequency and harmonic suppression level effectiveness.

2. Design of Active Antenna

In this paper, the proposed reconfigurable harmonic suppressed miniaturized fractal dipole antenna (TMFDB25) is an advanced configuration which is based on the geometry in [1]. The stubs-filter is connected on the antenna terminal (length = 10 mm, and width = 3.48 mm). Its length is controlled using three ideal switches having widths of 3 mm. The total length of the stub is covered by the top layer and the bottom layer line. In this study, the silicon PIN diode (BAR50) is selected. Its equivalent resistor, *R*, and capacitor, *C* are given in the PIN diode data sheet [5]. When the diode is in the ON state, its equivalent circuit is represented by a resistor, *R*, while during the OFF state, it is represented by a capacitor, *C*. The values of *R* and *C* are 4 Ω and 0.15 pF, respectively. In this study, six DC block capacitors are used to isolate the RF component from the DC current (from the DC line). The values of the DC blocker and RF choke are 100 pF and 54 nH, respectively. To switch the operating frequency as well as to suppress higher order modes, six RF PIN diodes are soldered on the radiating element (length on *X*-axis, *A* = 132 mm, 112 mm, 88 mm and 36 mm) while the stubs-filter's length is varied from 25 mm, 27.61 mm to 27.7 mm. The geometry of the antenna is shown in Figure 1 and its completed dimensions are tabulated in Table 1. The antenna is then extensively simulated and analyzed.

3. Results and Discussion

As shown in Figure 2 (a), the simulated operating bands can be divided into two groups. The first group covers bands which have 1st higher order modes (1st HM) while the second group without higher order mode. Operating band is referred as f_r. To remove these undesired higher order modes, an open circuit stub is used depending on the λ/4 lengths. The results obtained are shown in Figure 2 (b). It can be seen that the designed antenna can be tuned from 735 MHz ($|S_{11}| = -14.52\text{dB}$), 815.5 MHz ($|S_{11}| = \text{-}25.8\text{dB}$), 980 MHz ($|S_{11}| = \text{-}10.34\,\text{dB}$), to 1885 MHz ($|S_{11}| = \text{-}8\,\text{dB}$), at a time. Band 4 exhibits moderate return loss due to the 1st HM that is close to the operating frequency, fr-4. In this case, diodes and DC line circuitry contribute significantly to the antenna performances.

The bandwidth covering tunable ranges are obtained as 1123.5 MHz with the percentage achieved bandwidth of each band as 6.78%, 9.19%, 2.347%, and ~1%. This configuration exhibits a near omni-directional radiation pattern on the H-plane and figure-of-eight on the E-plane, as presented in Figures 3 (a)-(d). These have wide HPBWs which are close to 83.9°, 83.8°, 82.2°, and 51.8°. The graph of band 4 is different, probably due to the suppression of the 1st HM which is affecting the operating frequency, Band 4.

The TMFDB25 antenna has a good corresponding realized gain of 0.5103 dB, 1.096 dB, 1.266 dB, and 2.749 dB while the corresponding total efficiency is high, approximately 71.82 %, 79.99 %, 79.63 %, and 77.56 %, respectively. The stubs have successfully suppressed the 1st HM of bands 1, 3 and 4 approximately by 7 dB, 5 dB and 5.1 dB, respectively. The percentages of efficiencies of these 1st HMs are reduced drastically, by approximately 69.2 %, 57.02 % and 64.47 %. They are clearly presented in Figure 4.

This harmonic suppressed method does not affect the radiation pattern and do not reduce the antenna realized gain and efficiency at the operating frequencies.

4. Conclusion and Future Work

An active antenna named TMFDB25 that uses RF PIN diodes is proposed in this paper. This small size tunable antenna employs fractal technology that can eliminate higher order modes. Its efficiency depends on the number of diode, hence it has been successfully optimized. The observed four operating bands are seen as a feasible design to realize the ’frequency reconfiguration with harmonic suppressed’. In this study, RF PIN diodes, DC blocker and DC line have drastically reduced the number of the higher order modes. The 2nd HM is totally eliminated. Thus, TMFDB25 will be fabricated and tested using a real RF pin diode.

Acknowledgment

The work is supported by Universiti Teknologi Malaysia. The authors are grateful to Universiti Tun Hussein Onn Malaysia (UTHM) for supporting PhD studies of S. A. Hamzah. Simulations were carried out at Electromagnetic Compatibility Centre, EMC in UTHM.

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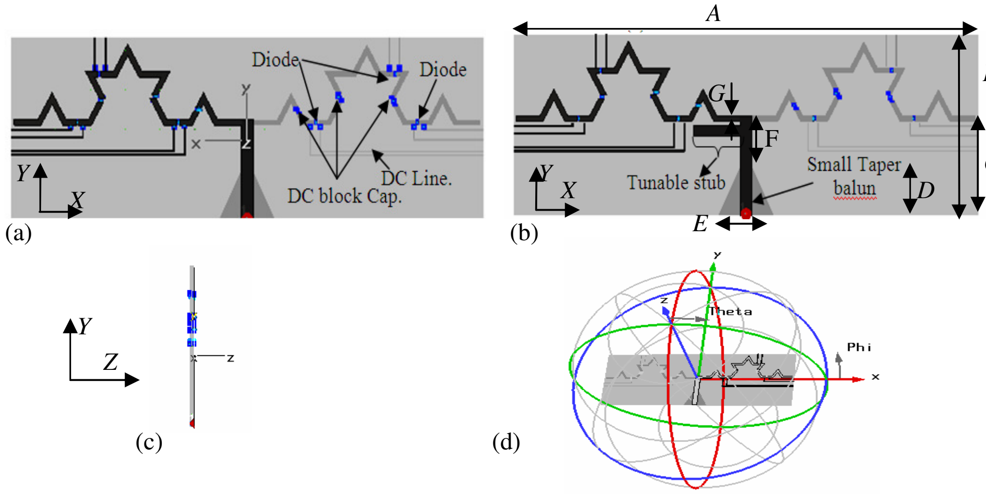
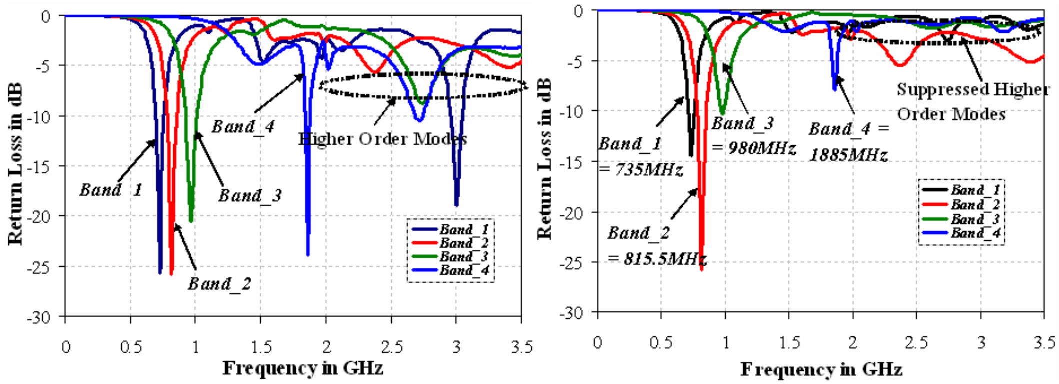


Figure 1: Geometry of TMFDB25 antenna (a) without stub (top view) (b) with stub (bottom view), (c) side view, and (d) spherical coordinate system for E-plane and H-plane definition.

Table 1: Antenna Dimensions. Unit is in mm.

A	*B*	*C*	*D*	*E*	*F*	*G*	Stub length	
137	48	35.5	25.5	16.5	10	1.5	Min=25	Max=27.7



(a) (b)

Figure 2: (a) TMFDB25 antenna with harmonic frequencies and (b) TMFDB25 antenna with suppressed harmonic frequencies.

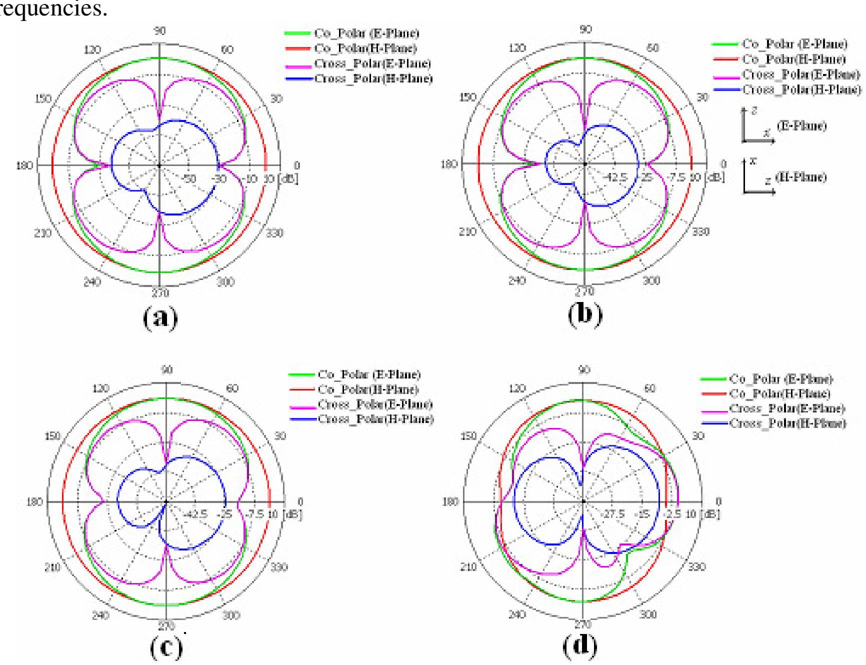
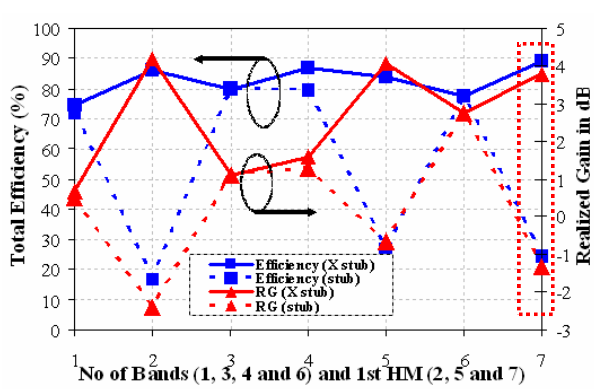


Figure 3: Radiation patterns on the E-plane and the H-plane of the TMFDB25 antenna with suppressed harmonic frequencies. (a) band 1, (b) band 2, (c) band 3, and (d) band 4. The axis of the E &H plane is given in (b).



Suppression level of 1st HM (band 4):
e.g. RG = 6.56 dB and %TE = 69.2 %

Figure 4: Total efficiency and realized gain of the TMFDB25 antenna at bands 1, 2, 3, 4 and 1st HM, respectively.