Innovative Design and Analysis of an Electrically Small Reconfigurable Antenna for GPS and Blue Tooth Applications

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Abstract-In this paper, an electrically small, planar antenna with broad side radiation pattern is presented. The design contains a dipole and a segmented circular loop which works equivalent to that of a magnetic dipole. A circular patch with slots is used to provide impedance matching. In general, electrically small antennas suffer from narrow bandwidth. In this paper, the reconfigurability of the small antenna for two different applications, 1.5GHz and 2.4GHz, is discussed. This reconfigurability was achieved by using a BAR 64-03W pin diode to adjust the resonant frequency. Two reconfigurable frequency bands were achieved at 1.5GHz and 2.4GHz with broad side radiation patterns.

Keywords-electrically small antenna; PIN diode; end fire radiation pattern; NFRP elements

I. INTRODUCTION

The components used in wireless communication systems such as antennas, filters, multiplexers, modulators, etc. are continuously miniaturized and intelligentized [1-3]. Frequency reconfigurable electrically small antennas are often suitable and are used for compact, wearable devices [4, 5]. An antenna with a broad front-to-back ratio and an equivalent pattern of E and H plane radiation is shown in [6]. The research groups in [7-10] and [11-15] have extensively researched antennas with the combination of electric and magnetic dipoles. The quarter wavelength patch with vertical orientation is commonly used in [7] as a magnetic dipole, which is coupled with the electric dipole to design complementary antennas with a wavelength of $0.25\lambda_0$ [8-12]. NFRP elements were used in [13] to design electric and magnetic dipoles, contributing to the design of dual band electrically small antennas. Most of the tiny electrically small antennas are not reconfigurable except from [4] and [5]. Three magnetic NFRP elements were paired with two electric NFRP elements in [5] to achieve the reconfigurability of their

radiation pattern. A planar, reconfigurable complementary antenna with a single layer pattern was indicated in [16]. In addition to the reconfigurability of polarization and radiation reconfigurability patterns, due to its powerful spectrum use, frequency reconfigurability has gained a lot of attention [17-20]. Utilizing appropriate antenna size, different frequency reconfigurable monopole antennas [17-19], patch antennas [20-22] and quasi-Yagi Uda antennas [23-24] have been created. In order to obtain a unidirectional radiation pattern which increases the antenna size, a broad ground plane is required. By eliminating the ground plane, the complementary Huygens source antenna is used to achieve high front-to-back ratios with less distance. This paper introduces an electrically small reconfigurable antenna. To produce the magnetic dipole that is combined with the rectangular bar electric dipole to obtain the end fire radiation pattern, a segmented circular loop is used. This antenna is 35mm×35mm×1.6mm in size and has a single coating. In addition, the design is expanded by inserting a pin diode in the electric dipole to achieve frequency reconfigurability. Two resonant bands were obtained at 1.5 and 2.4GHz and the end fire radiation pattern was maintained. This antenna was fabricated in order to obtain a practical realization of the results. A good agreement between the simulated and the experimental results was obtained.

II. ANTENNA MECHANISM

The magnetic dipole is considered to be a loop with a uniform current distribution. Due to its low radiation resistance and high reactance, its impedance matching is poor. The diameter of the outer loop is 16.8mm at the resonant frequency and the current distribution is uniform and flows along the Y-axis (Figure 1). The electrical and magnetic dipoles are excited in a perpendicular manner in order to design this planar, electrically small antenna. The strip line and the

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circular loop on the top and bottom layers of the substrate are mounted at this end. The length and width of the patch are calculated by (1)-(3).

$$W = \frac{v_0}{2F_r}\sqrt{\frac{2}{\varepsilon_r+1}} \quad (1)$$

where v_0 is the velocity of light in free space.

$$L = \frac{c}{2F_r\sqrt{\varepsilon_{reff}}} - 2\Delta l \quad (2)$$

$$\Delta l = 0.412h\frac{(\varepsilon_{reff}+0.03)(w+0.26h)}{(\varepsilon_{reff}-0.258)(w+0.8h)} \quad (3)$$

where Δl is the extension in length due to fringing effects.

The effective dielectric constant is given by:

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1 + \left[\frac{12h}{w}\right]\right]^{-1/2} \quad (4)$$

The actual length and width of the ground plane can be calculated by (5) and (6):

$$L_g = 6h + L \quad (5)$$

$$W_g = 6h + W \quad (6)$$

where L is the length of the patch, W its width, and h is the thickness of the substrate.

Length and width of the feed line are calculated by:

$$B = \frac{60\Pi^2}{\sqrt{\varepsilon_r}Z_C} \quad (7)$$

where Z_c is the characteristic impedance and ε_r the relative permittivity of the substrate.

$$L_f = \frac{\lambda_0}{4\sqrt{\varepsilon_{eff}}} \quad (8)$$

The radius of the patch is calculated by:

$$a = \frac{F}{\sqrt{1 + \frac{2h}{\Pi\varepsilon_r}[\ln\left(\frac{\Pi f}{2h}\right) + 1.7726]}} \quad (9)$$

Small antennas are those in which the largest dimension is less than the one-tenth of the wave length ($\lambda/10$). Small antennas are those having $K.a < 1$, where K=wave number $= \frac{2\pi}{\lambda} = 0.0314$. For the proposed antenna the obtained $K.a$ value is: $K.a = 0.0314 \times 16.8 = 0.527 < 1$.

III. ANTENNA DESIGN CONSIDERATION

Figure 1 represents the configuration of the electrically small planar antenna. It mainly consists of a segmented loop and strip line fabricated on a FR4 substrate with 4.4 relative permittivity, 1.6mm thickness, 35mm length, and 35mm width. The top layer of the antenna is fabricated with a strip line and it is fed by an edge feed acting as an electric dipole. The bottom layer of the antenna, i.e. in the ground plane, contains an outer circle with radius R_4 and an inner circle with radius R_3 (see Table I). The proposed antenna was designed and analyzed experimentally. The prototype of the antenna was fabricated and the result was verified by a vector network analyzer (Figure 2). Figure 3 shows the fabricated antenna.
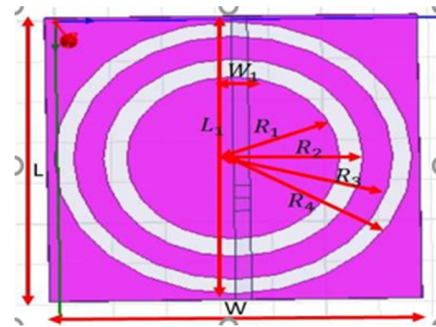

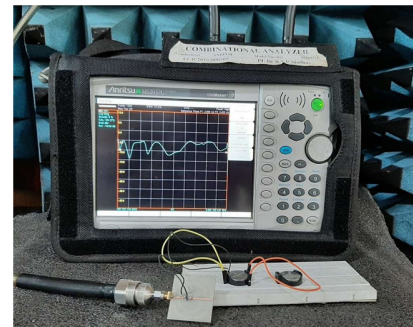Fig. 1. The designed planar electrically small antenna.

Fig. 2. Antenna parameter testing using VNA.

TABLE I. DIMENSIONS OF THE DESIGNED PLANAR ELECTRICALLY SMALL ANTENNA

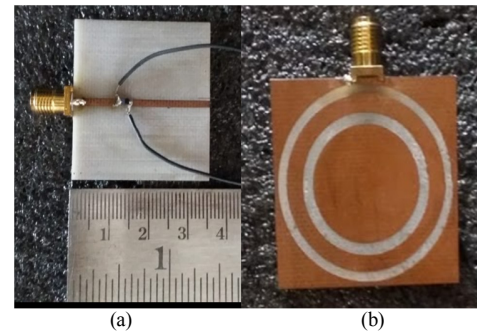| Parameter	L	W	L_1	W_1	R_1	R_2	R_3	R_4
Value (mm)	35	35	35	1.5	10	12.2	15	16.8

Fig. 3. Images showing the prototype of the proposed planar electrically small antenna: (a) top view, (b) bottom view.

IV. RESULTS AND DISCUSSION

Return loss is the most preferred parameter to test an antenna. Instead of using 2 different antennas at different frequencies, a single antenna can switch between 2 frequencies. In the proposed model, the antenna can switch between 1.5GHz and 2.4GHz. Figure 4 shows the return loss of the antenna when the diode is in the OFF state. During the OFF state, the antenna resonates at 2.4GHz, with a return loss value of -15.8dbm for the simulated and -13.01dbm for the actual antenna. Figure 5 represents the equivalent circuit diagram of a pin diode in ON and OFF state. During the ON state, the antenna resonates at 1.5GHz and only the resistor and inductor values are used. During the OFF state, the antenna resonates at

2.4GHz and the resistor, capacitor, and inductor values are used. Figure 6 shows the return loss of the antenna when the diode is at the ON state. The proposed antenna resonates at 1.5GHz with a return loss value of -15.07dB for the simulated model and -13.08dB for the fabricated model.

Voltage Standing Wave Ratio (VSWR) is a significant parameter for estimating the behavior of the RF components at high frequencies. The proposed antenna resonates at 2.4GHz with circular polarization when the diode is in the OFF state. Figure 8 shows the 3D radiation pattern of the antenna with broad side radiation. Maximum radiation exists in the XY plane. The maximum possible gain is about 1dB at θ=0°. Figures 9-10 represent the patterns of the antenna at various azimuthal and elevation planes.

Fig. 7.   VSWR of the antenna.

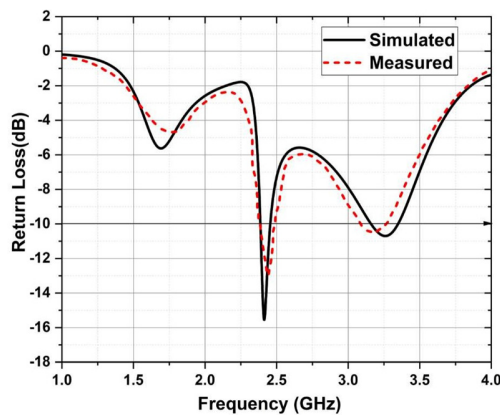Fig. 8.   3D radiation pattern of the antenna.

Fig. 4.   Return loss of the antenna when the diode is in the OFF state.
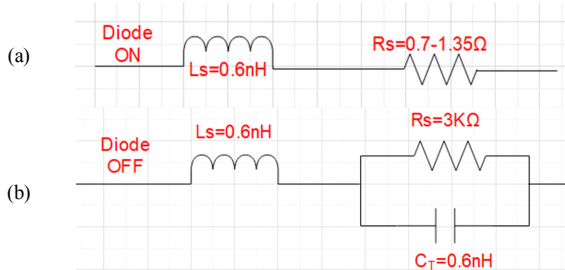
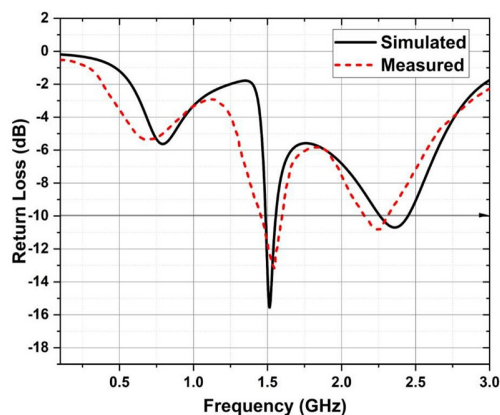Fig. 5.   Equivalent circuit diagram of a pin diode. (a) ON, (b) OFF.

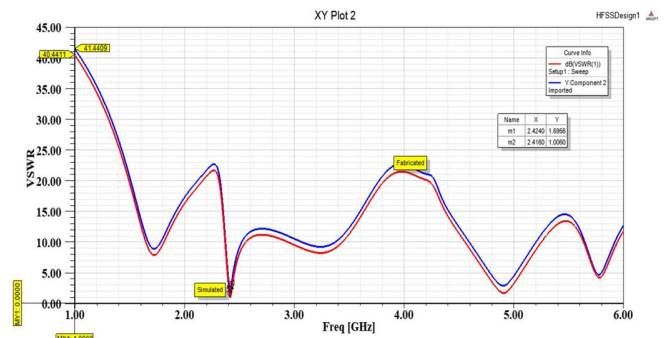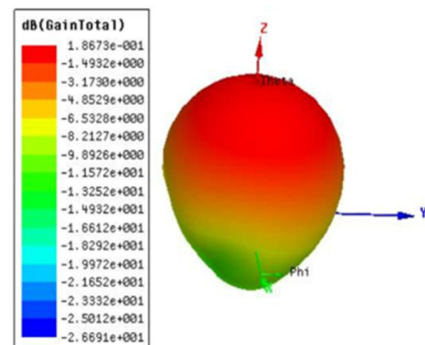Fig. 6.   Return loss when the diode is in the ON state.
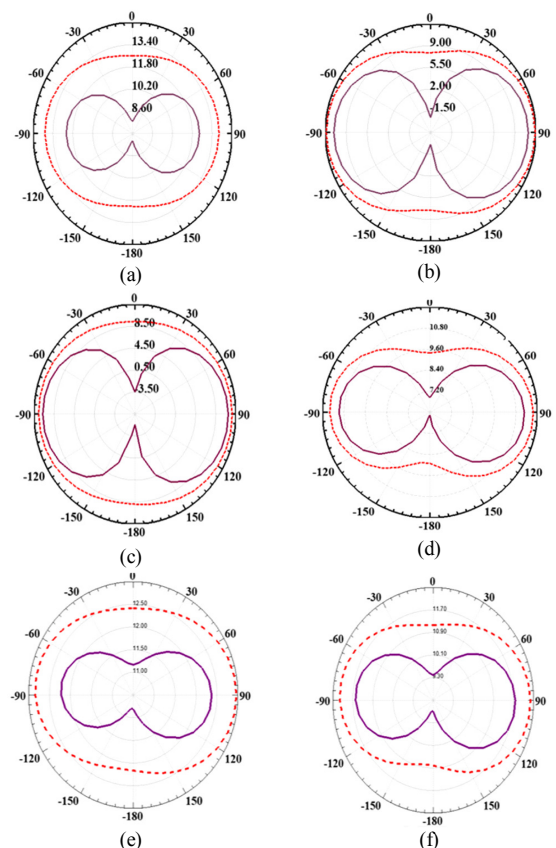
Fig. 9.   Azimuth pattern at θ = (a) 0°, (b) 30°, (c) 60°, (d) 90°, (e) 120°, (f) 180°. Purple line: simulated results, red line: measured results.
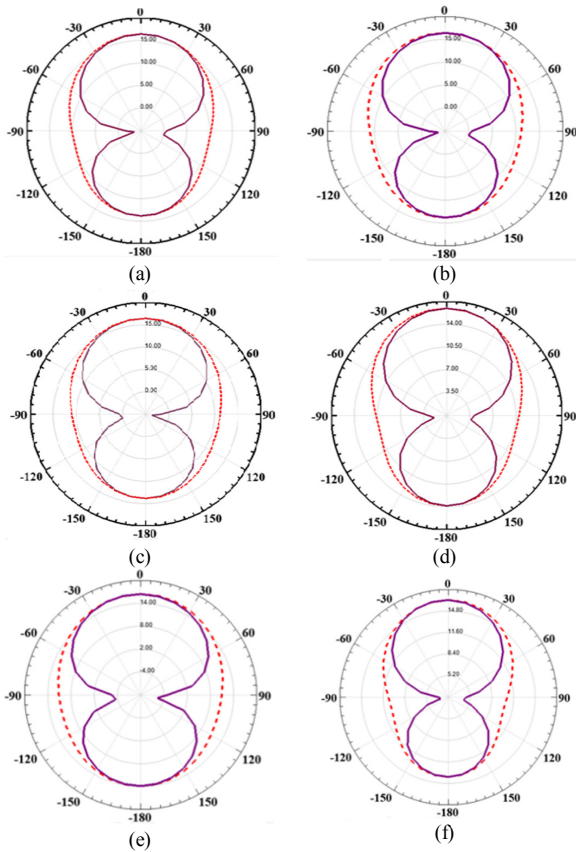
Fig. 10.   Elevation pattern at φ= (a) 0°, (b) 30°, (c) 60°, (d) 90°, (e) 120°, (f) 180°. Purple line: simulated results, red line: measured results.

The comparison with other proposed designs in Table II shows that that the proposed antenna offers better results in terms of return loss and gain.

TABLE II.   PERFORMANCE COMPARISON OF THE PROPOSED ANTENNA WITH OTHER, KNOWN ANTENNAS

Ref	Substrate	Reconfigurable	Area (mm³)	Center Frequency	Gain (db)
[1]	FR-4 Epoxy	Frequency	45×40×1.6	1.28GHz 1.62GHz	-------
[6]	RT Duroid 5880	Frequency	45×38×0.254	2.4GHz	-------
[7]	Polyimide	Frequency	45×35×3.2	1.6GHz	0.9dB
[8]	FR4	Frequency	95×100×14	1.71GHz	--------
Proposed	FR4	Frequency	35×35×1.6	1.5GHz 2.4GHz	1.86dB

V.   CONCLUSION

Based on the complementary concept, an electrically small, coplanar antenna was realized by combing the equivalent magnetic dipole of a segmented loop and the electric dipole of a strip line. The antenna is designed on a FR4 epoxy substrate, having a small area of 35×35×1.6mm³. The antenna showed satisfying broadside radiation performance, exhibiting a gain of 1.86dB. It has been found that the resonance frequencies of

both the electric dipole and the magnetic dipole (segmented loop) can be easily tuned with PIN diodes. Therefore, a frequency-reconfigurable complementary antenna was further developed. Two reconfigurable broadside radiation bands have been achieved at 1.5 and 2.4GHz.

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