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# ELECTRICALLY SMALL ANTENNA FOR GLOBAL POSITIONING SYSTEM AND WIRELESS POWER TRANSFER APPLICATIONS

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**ABSTRACT**

*In this paper, an electrically small antenna for different applications is proposed. An electrically small, planar with broad side radiation pattern is presented. The design contains a segmented circular loop and a dipole which act as a magnetic dipole. For impedance matching, a circular patch with slots is provided. In general, electrically small antenna limits to a narrow bandwidth. In this paper, reconfigurability will achieve for two different applications at 1.5 GHz and 2.4 GHz respectively by using BAR 64-03W PIN diode to adjust resonant frequency. Near field resonant parasitic (NFRP) element were used to design electric and magnetic dipoles, which is helpful to design dual electrically small antenna bands having a wavelength of 0.25λ0. The size of the antenna is 35×35×1.6mm3 and a gain of 1.86dB.*

***Keywords:*** *Electrically Small Antenna, Near-Field Resonant Parasitic Element, Global Positioning System, PIN Diode, End Fire Radiation Pattern, WPT.*

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## Introduction

Due to the rapid advancement in the modern communication system and their necessities for miniaturization, mobile computing and terminals, electrically small antennas (ESA's) create more attentions now a days. Due to compact size and narrow bandwidth, they are suitable for many applications such as- communication system, RFID's, biomedical systems, global positioning system, Bluetooth, wireless power transfer (WPT) system, IoT's, energy harvesting etc. some specifications are there in antenna characteristics such as high gain, wide directivity, decent radiation pattern and efficiency. Also, they radiate circular polarization (CP) to minimize mismatch. For the designing of electric and magnetic dipoles which contribute to design ESA, NFRP elements were used. By using NFRP elements, we achieve reconfiguration capability of their radiation pattern. In [3], the design contains both electric and magnetic NFRP elements. By the inclusion of PIN diodes, electric ones are made reconfigurable. Pattern reconfigurability was obtained by switching the diodes in ON and OFF conditions. Similarly, in [12], authors demonstrated Huygen's Circularly Polarized (HCP) antenna. Here Egyptian Axe Dipole (EAD) and Capacitively Loaded Loop (CLL) are integrated into a crossed dipole configuration. It produces cardioid shaped radiation pattern.

This paper presents an electrically small reconfigurable antenna to produce a magnetic dipole which is combined with electric dipole to obtained the end fire radiation pattern. The size of the proposed antenna is 35×35×1.6 mm3. To obtain the frequency in an electric dipole reconfigurable, a PIN diode is inserting in the design. Here two frequency bands were achieved at 1.5 GHz and 2.4 GHz which can be used for GPS and wireless power transfer applications. We can charge the batteries in the equipment without the need for a wire connection by using wireless power technology. WPT can be carried out via microwaves or radio waves using communication technologies and system design. WPT is an extremely useful technology that has various benefits and applications. Mobile devices, Laptops, cell phones etc. could function without ever having to be plugged in, cars could drive on highways burning no fossil fuels. By using WPT technology we can solve the renewable energy issues we face.

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Components used in wireless communication systems, like there are antennas, filters, multiplexers, modulators etc. Constant short and intelligent frequency Reconfigurable electrically smaller antennas are often suitable and used for compact, wearable devices. An antenna with a wider front-to-back ratio and the E and H pattern equivalent to shown in plane radiation.

For Electrically small antenna

Ka < 1, where k, being the wave number at resonance and a, being the radius of the smallest sphere enclosing the entire structure. K= 2 π $f_r$ / $v_0$

Where $v_0$, being the velocity of the light, $f_r$, being the resonant frequency.

Conceptual block diagram of wireless energy harvesting system is shown in fig. (A). RF generator generates RF signal which is transmitted by the transmitting antenna via space. At the receiving end, signal passed to the impedance matching network for perfect matching. After that signal is passed to the rectifying circuit where we obtained a dc output, this output will reach to the power management system, where we can store our generated power. After that we can consume this power for different applications.

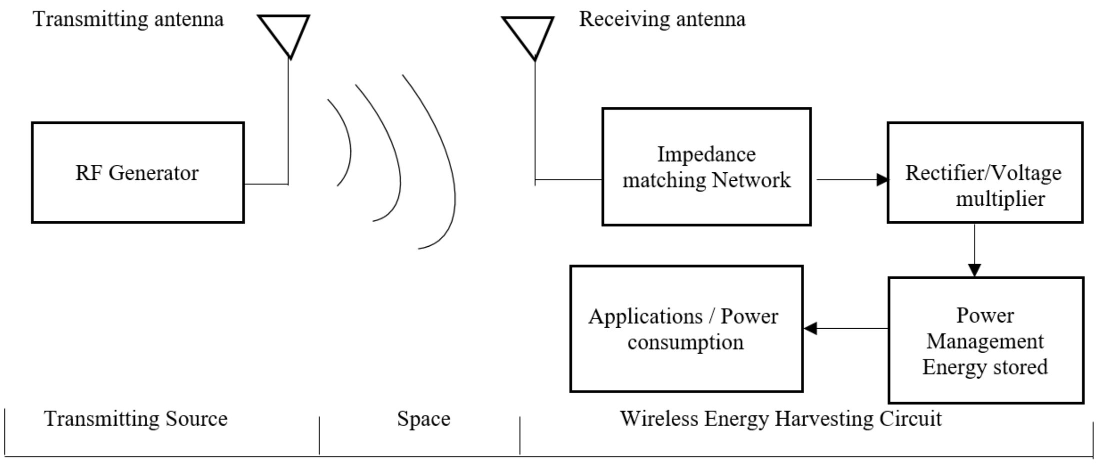



**Fig. A. Block diagram of Wireless Energy Harvesting system**

**Design Mechanism**

The magnetic dipole is considered to be a loop, which having uniform current distribution, due to its low radiation resistance and the higher the reactance, the worse its impedance matching. The diameter of the outer loop at the resonator is 16.8 mm. Frequency and current distribution is uniform and flows through along the y-axis. 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 circular loop on the top and bottom layers of the substrate are mounted at this end.

For antenna design, there are some factors that are very relevant to the performance of the antenna which determines the bandwidth, the size of the antenna and resonant frequency. These factors includes the length, width and height of the antenna and also the substrate used. From the transmission line model equation , the width of the antenna is given by

$$W = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \quad (1)$$

Where; $f_r$ is the resonant frequency, c is the speed of light, $\varepsilon_r$ is the dielectric constant of the substrate.

The effective dielectric constant of the antenna due to fringing affect is given by :

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2\sqrt{1+\frac{12h}{W}}} \quad (2)$$

The actual length of the patch is given by

$$L = L_{eff} - 2\Delta L = \frac{c}{2f_r\sqrt{\varepsilon_{reff}}} - 2\Delta L \quad (3)$$

Note that ΔL is given by

$$\Delta L = \frac{h(0.412)[(\varepsilon_{reff}+0.3)\left(\frac{W}{h}+0.264\right)]}{(\varepsilon_{reff}-0.258)\left(\frac{W}{h}+0.8\right)} \quad (4)$$

Where h is the height or thickness of the substrate. For this design, we have h = 1.6 mm and the dielectric constant is 4.4.

The actual length and width of the ground plane can be calculated

Lg = 6h + L (5)

Wg = 6h + W (6)

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

Length and width of the feed line are calculated by

$$W_f = \frac{60\pi^2}{\sqrt{\varepsilon_r Z_c}} \quad (7)$$

Where Zc is the characteristic impedance and $\varepsilon_r$ is 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:

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

Where, $$F = \frac{8.791\times10^9}{f_r\sqrt{\varepsilon_r}} \quad (10)$$

**Antenna Designing 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 R4 and an inner circle with radius R3 (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.

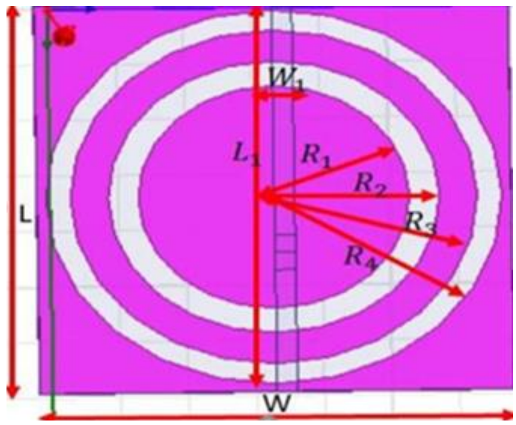



**Fig.1: The Designed Planar Electrically Small Antenna**

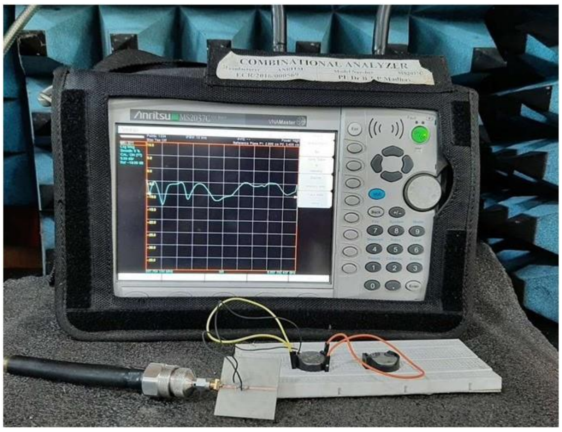


**Fig.2. Antenna parameter testing using VNA**

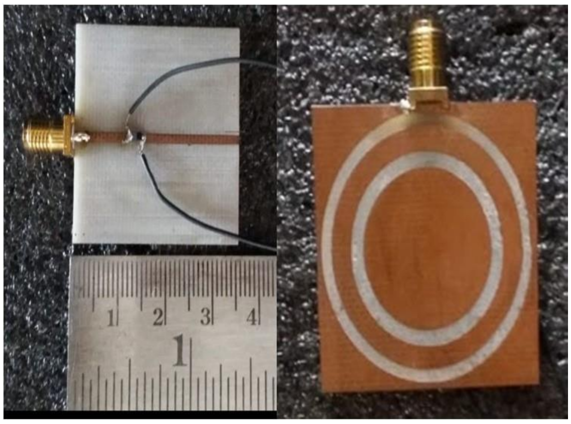


**Fig. 3: The Prototype of the Proposed Electrically Small Antenna Top view and Bottom View**

**Table 1: 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 |

**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 -15.8 dB for the simulated and -13.01dB 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 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 $\theta=0^0$. Figures 9-10 represent the patterns of the antenna at various azimuthal and elevation planes.

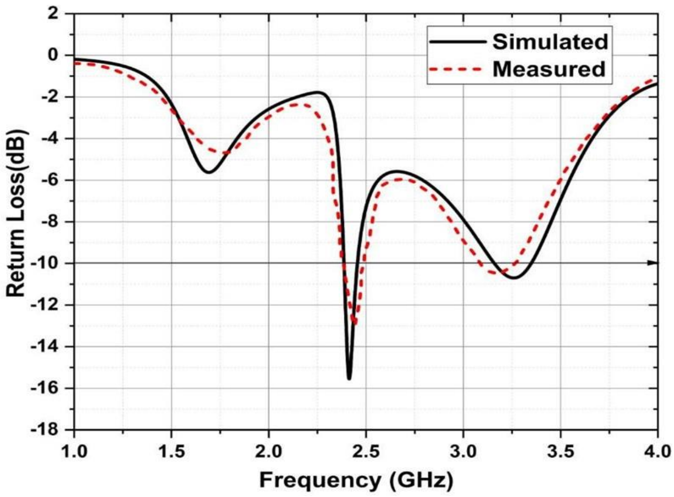



**Fig.4: Return loss of the antenna when the diode is in the OFF state**

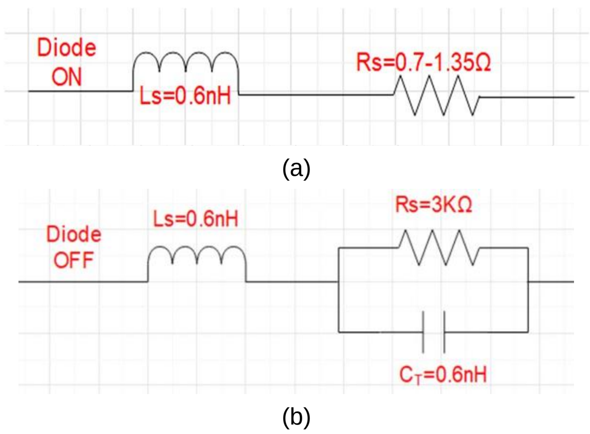



**Fig.5: Equivalent circuit diagram of PIN diode (a) ON state (b) OFF state**

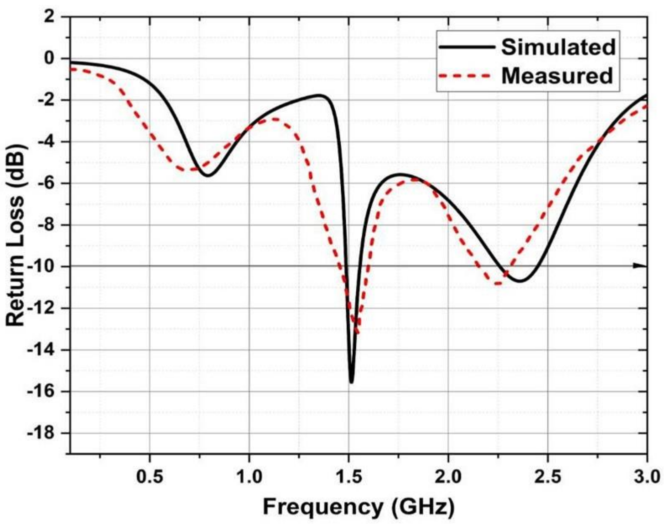



**Fig.6: Return loss of the antenna when the diode is in the ON states**

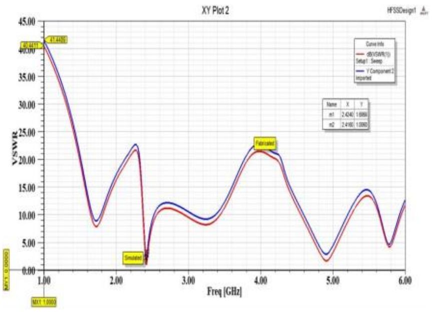



**Fig.7: VSWR of the Antenna**

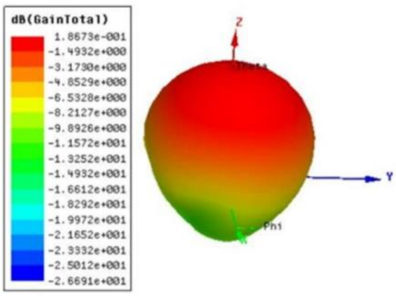



**Fig. 8: 3D Radiation Pattern of the Antenna**

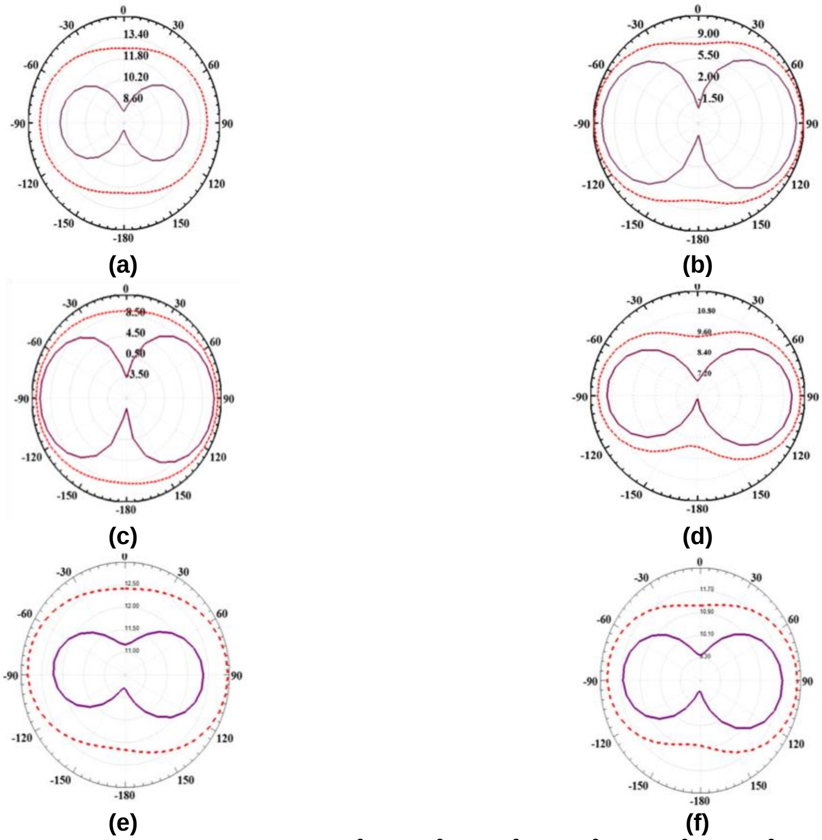
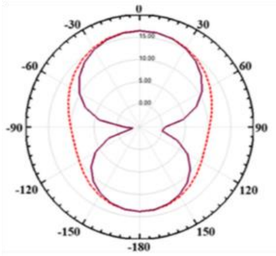
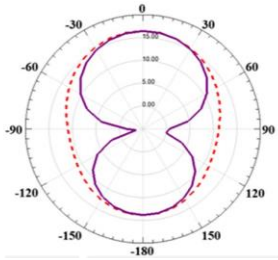



**Fig. 9: Azimuth Pattern at θ equals (a) $0^0$ (b) $30^0$ (c) $60^0$ (d) $90^0$ (e) $120^0$ (f) $180^0$ Purple line: Simulated Result, Red line Fabricated Result**




**(a)**

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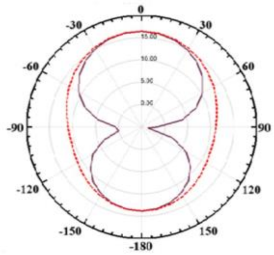


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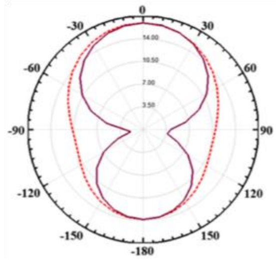
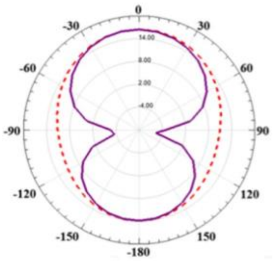
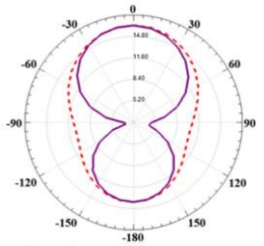



**(d)**




**(e)**




**(f)**

**Fig. 10: Elevation pattern at φ equals (a) $0^0$ (b) $30^0$ (c) $60^0$ (d) $90^0$ (e) $120^0$ (f) $180^0$ Purple line: simulated results, red line fabricated results**

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

**Table 2: Performance Comparison of the Proposed Antenna with Other, Known Antennas**

| Ref | Substrate | Reconfigurable | Area ($mm^3$) | Centre 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 | 95×100×1.4 | 1.71GHz | -------- |
| Proposed | FR4 | Frequency | 35×35×1.6 | 1.5GHz 2.4GHz | 1.86dB |

## 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 35×35×1.6 $mm^3$. 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 GHz and 2.4 GHz.

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