

Frequency Reconfigurable Antenna for Energy Efficient WBAN Application



Ridhima Puri, Nimisha Sharma, Asmita Rajawat, and Sindhu Hak Gupta

Abstract The paper presents dual-mode reconfigurable antenna that can toggle between 2.4 GHz (ISM Band) and 4.43 GHz (UWB) with the help of a PIN diode. The antenna resonating in medically approved ISM band and UWB band along with the judicious use of energy makes it appropriate for WBAN application. The main focus is laid on WBAN applications and power management techniques with the help of concepts of STEM and duty cycle. The value of S_{11} obtained when the antenna resonates at 2.4 GHz is -15.216 dB, and the value of S_{11} obtained when the antenna resonates at 4.43 GHz is -35.08 dB. Measured gain for antenna when PIN diode is switched to ON state and OFF state is 0.1068 dBi and 2.345 dBi, respectively. The performance of the antenna is assessed on the basis of return loss, gain of the antenna, energy, and power consumption values of the antenna for ISM and UWB.

Keywords ISM · Reconfigurable antenna · STEM · UWB · WBAN

1 Introduction

Wireless body area networks (WBANs) are a rising trend in today's time. WBAN is formed on the radio frequency, which connects the small sensor nodes to a sink node, i.e., energy constrained with additional processing capabilities. These sensor nodes deployed on/in human body help in identifying multiple abnormalities in early detection of diseases [1]. On account of characteristics like minimum consumption of power, no delay, high reliability, and independent functioning of the node, WBAN is

R. Puri · N. Sharma (✉) · A. Rajawat · S. H. Gupta
Amity University, Noida, Uttar Pradesh, India
e-mail: nimisha.17.sharma@gmail.com

R. Puri
e-mail: ridhima.17.puri@gmail.com

A. Rajawat
e-mail: arajawat@amity.edu

S. H. Gupta
e-mail: shak@amity.edu

used in the field of regular patient monitoring, bio feedback, defense, healthcare, and assisted living [2]. Reconfigurable antenna is the key feature in WBAN applications as they support wide area communication. In recent research, significant attention has been paid to reconfigurable antennas on account of their ability to resonate at various frequencies. Reconfigurable antenna is best used in WBAN applications due to their ability to improve antenna performance of RF system and change the geometry of the antenna with changing ecological conditions in a controlled manner and provide a compact design. In addition to this, reconfigurable antenna attracts the researchers as it holds the capability to tune the operating frequency of the antenna in order to change the operating bands and filter out interference signals [3]. Several reviews and publications have been published on the design of a reconfigurable antenna. The existing method provides ways to accurately and efficiently determine the type of antenna which can be used in the design to provide ease in fabrication. The usage of microstrip patch antenna in the antenna design has gained significant importance. The authors suggest that on account of planar configuration, ease in integration, robust design, and light weight, MSPA can be used over other types of antennas [4]. The procedure used for making the antenna operate on dual frequency is one of the most commonly used method of using a PIN diode which is a lumping element, as it provides ease of fabrication and reduced cost [5]. The authors suggest that good radiation pattern can be obtained in dual frequency antenna if the voltage biasness is kept in control. A series of research has been carried out to investigate the approach of providing power to the microstrip patch. It is observed that on account of characteristics like simplicity in modeling and impedance matching, inset feed can be incorporated in the design [6]. However, in this paper, the main aim is to utilize the antenna parameters to generate a cost effective, low power/energy consuming antenna by incorporating the protocols and concepts of STEM, which is a step toward creating sustainable technology.

The PIN diode in the antenna switches between ON mode and OFF mode at frequencies of 2.4 and 4.43 GHz. The first resonant frequency (2.4 GHz) is chosen in ISM band because it supports high data rate applications. The second resonant frequency is chosen to lie in UWB range as the band uses low energy level for short range communication. UWB is also useful in medical applications as it has low penetration radiation and consumes low processing energy [7].

The feature of reconfigurable antenna, i.e., redirecting the radiation pattern of the antenna toward saving the power with the help of energy management techniques, is reviewed in the paper. STEM technology which stands for sparse topology and energy management holds major applications in energy and power consumption, namely two channels: wake-up and data channel which is used in STEM. These channels switch between monitor state and transfer state depending on whether the data is to be transmitted or received by the sensor node. The data channel sits idle and operates only when the wake-up channel senses some input signal. STEM improves the network lifetime by exploiting the fact that most of the time, the network is asleep and wakes up only after sensing its environment [8]. Another basic and most commonly used power management techniques is duty cycling, i.e., the ratio of listen period/ (listen period + sleep period) [9]. The two parameters, namely S_{11} and gain,

associated with the patch of the antenna are used to record the overall performance of the system. In order to simulate the antenna design, computer simulation technology (CST) studio software is used. The flow of the paper is as follows: the antenna design is briefly discussed in Sect. 2, the antenna simulation results is in Sect. 3 of the paper, reconfigurable antenna in WBAN scenario is discussed in Sect. 4, and the conclusion of the work is presented in Sect. 5.

2 Antenna Design

Figures 1 and 2 show the design of the microstrip patch antenna. MSPA offers three-fold design, consisting of microstrip patch, dielectric substrate, and the ground plane.

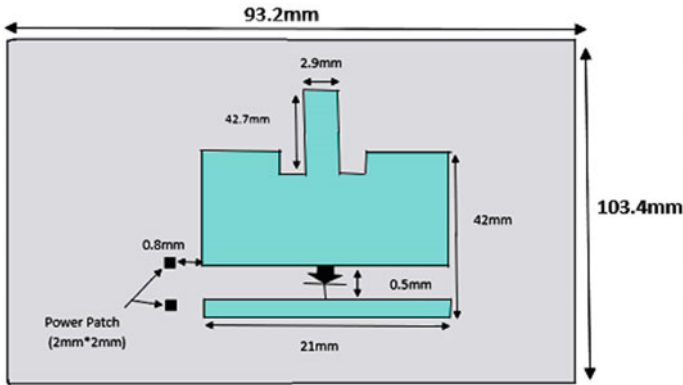
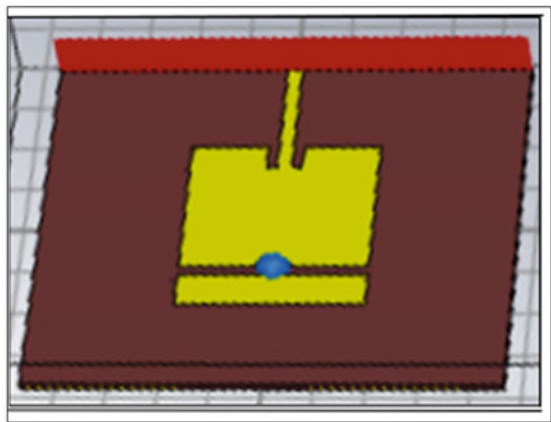


Fig. 1 Antenna dimensions

Fig. 2 Antenna in CST software



Microstrip patch antenna (MSPA) is used in the design because of its characteristics like low profile, ease of fabrication, and high-speed data transfer [10]. To supply power to the antenna, inset feeding technique has been incorporated which is easy to fabricate. The sinusoidal current distribution is more toward the center of the patch as compared to the edges. As there is an inverse relation between amount of current and impedance ($Z = VI$), thus the feed line has been placed toward the center of the patch to provide impedance matching to the antenna. The work on the antenna [11] has been extended by doing suitable modifications in the design to yield beneficiary results, suitable for WBAN applications. Two copper patches of size (2 mm * 2 mm) have been incorporated on the side of the patch at a distance of 0.8 mm away from the patch, for easy power supply to the design for further fabrication and testing. The defected ground structure is removed from the design of the antenna to significantly reduce the gain of the antenna. The patch dimension is (21 mm × 42 mm). The height of the substrate helps in reducing the amount of fringing in the antenna and also provides mechanical strength to the antenna. The dimensions of FR4 dielectric substrate is (93.2 mm × 103.4 mm). FR-4 has a dielectric constant of 4.4. The dimensions of copper ground plane is (93.2 mm × 103.4 mm). The antenna feed is of width 2.9 mm and length 42.7 mm.

Following equations are taken into consideration for calculating the dimensions of the design [12]:

$$W = \frac{C}{2f_0\sqrt{\frac{\epsilon_r+1}{2}}} \quad (1)$$

$$L = \frac{c}{2f_0\sqrt{\epsilon_{\text{eff}}}} - 2\Delta L \quad (2)$$

$$\epsilon_{\text{eff}} = \frac{\epsilon_r+1}{2} + \frac{\epsilon_r-1}{2} \left[1 + 12 \frac{h}{w} \right]^{-\frac{1}{2}} \quad (3)$$

where

$c = 3 \times 10^8$ m/s, speed of light,

$f_0 = 2.4$ GHz, resonance frequency;

$\epsilon_r = 4.3$, relative permittivity of substrate;

$h = 1.6$ mm, height of the substrate;

ϵ_{reff} = effective dielectric constant;

Antenna is simulated for different values of feed line width, and an optimized value of 2.9 mm is used to provide the best impedance matching at the desired frequency bands. A gap after three-fourth length of the microstrip patch is introduced in the antenna in order to insert the lumping element, i.e., PIN diode. The circuit model of PIN diode at RF frequencies for ON/OFF state is shown in Fig. 3. The pin diode behaves like a variable resistor at ON/OFF state. Figure 3 shows that the ON state has low resistance R_s which is a major reason for insertion loss. The OFF state circuit is reverse biased and has a parallel combination of reverse bias resistance R_P and total capacitance C_T , which leads to isolation of the circuit.

Fig. 3 RLC equivalent circuit for ON state and OFF state, respectively

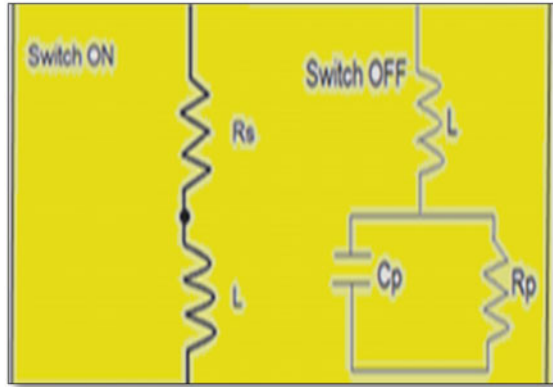


Table 1 Measurements of elements used in designing the antenna

Element	Length (mm)	Width (mm)	Thickness (mm)
Ground plane	93.2	103.4	0.4
Dielectric substrate	93.2	103.4	1.6
Microstrip copper patch	21	42	0.1
Feed line	42.7	2.9	0.1

3 Antenna Simulation Results

Return loss (S_{11})

The scatter parameter of an antenna describes the relationship between the input and output terminals. The S_{11} parameter varies with frequency. It is defined as the power reflected from the antenna, and thus, it is also referred to as the return loss [13]. When S_{11} equals to zero, it is an indication that no power is radiated. When S_{11} is obtained as -10 dB, out of the value, -7 dB is reflected, and 3 dB is radiated. The value of S_{11} obtained for antenna operating in ON state is -15.216 dB where antenna resonates at a frequency of 2.4 GHz as shown in Fig. 4a, and value of S_{11} obtained for antenna operating in OFF state is -35.08 dB where antenna resonates at a frequency of 4.43 GHz (UWB band) as shown in Fig. 4b.

Gain

The amount of power transmitted in the direction of the peak radiation of an isotropic source is known as gain of antenna. Gain in ON and OFF state is found to be -0.1068 dBi and 2.345 dBi, respectively. The value of gain signifies the amount of power transmitted and the amount of RF energy which is being radiated by the antenna. The antenna has a very low gain in ON body state which prevents the adverse biological effects that can be caused due to high RF radiations. Tissue rupture can occur in

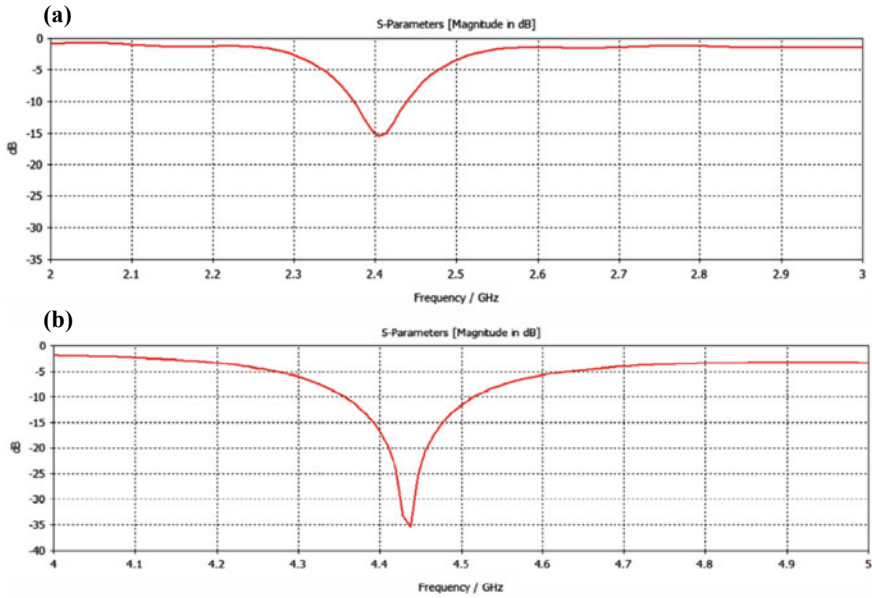


Fig. 4 a S_{11} obtained for ON state, b S_{11} obtained for OFF state

the body due to the inability of the body to cope up with the high thermal heat if the wearable antenna used has significantly high gain. Sensitive areas such as eyes are vulnerable to relative heating because of less blood flow, which is required to overcome the heating effect. However, for negligible value of gain, for which the body is not adversely affected by the RF radiation and the antenna can be said to produce ‘non-thermal’ effects. The gain obtained for antenna for ON state is 0.1068 dBi which is significantly low to have non-thermal effects on the body, making the antenna suitable to be used in wireless body area network (WBAN) applications. The value of gain obtained from the simulation of the microstrip patch antenna is shown in Fig. 5a, b.

When the antenna is resonating at 2.45 GHz, the main lobe magnitude is -0.106 dBi, the main lobe direction is 1.0 deg, and the side lobe level is -20.0 dB. When the antenna is resonating at 4.43 GHz, the main lobe magnitude is 2.35 dBi, the main lobe direction is 44.0 deg, and the side lobe level is -10.7 dBi as shown in Fig. 6a, b, respectively.

Surface Current

Surface current of an antenna is an approximation of the amount of surface charge that exists on the surface of the conductor to charge the antenna with a specific electric potential. The plots for surface current have been shown in Fig. 7a for ON state and Fig. 7b for OFF state.

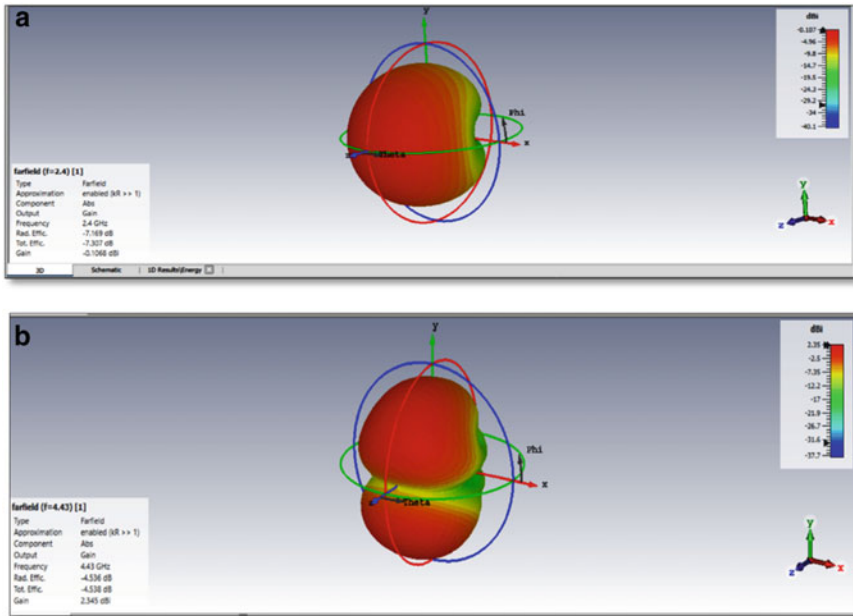


Fig. 5 a ON state gain for antenna, b OFF state gain for antenna

4 Reconfigurable Antenna in WBAN Scenario

Wireless body area network (WBAN) is a key technology to enable information communication in patient-centric tele-health [14]. STEM innovation that represents sparse topology and energy management holds significant application in the antenna design. It uses wake-up and data channel to switch between monitor and transfer state depending on whether the data is to be transmitted or received by the sensor node. Wake-up channel transmits the date to the receiver after informing the receiver. Data channel transmits data using various MAC protocols. This technology extends the system life [15]. Duty cycling is another technique to manage. Duty cycle is the ratio of listen period/ (listen period + sleep period). Ideal duty cycle value helps in avoiding high delay and transient energy that can be caused due to startup cost [16]. The average duty cycle calculated for 10 s is observed as 0.15 in the paper. To calculate the transmitted power by the antenna, the Friss equation as shown in Eq. (4) is used.

$$P_t = \frac{(E_b/N_o) * N_o * R(4\pi*)^2 * d_o^2 * L * (d/d_o)^\gamma}{G_t G_r \lambda^2} \tag{4}$$

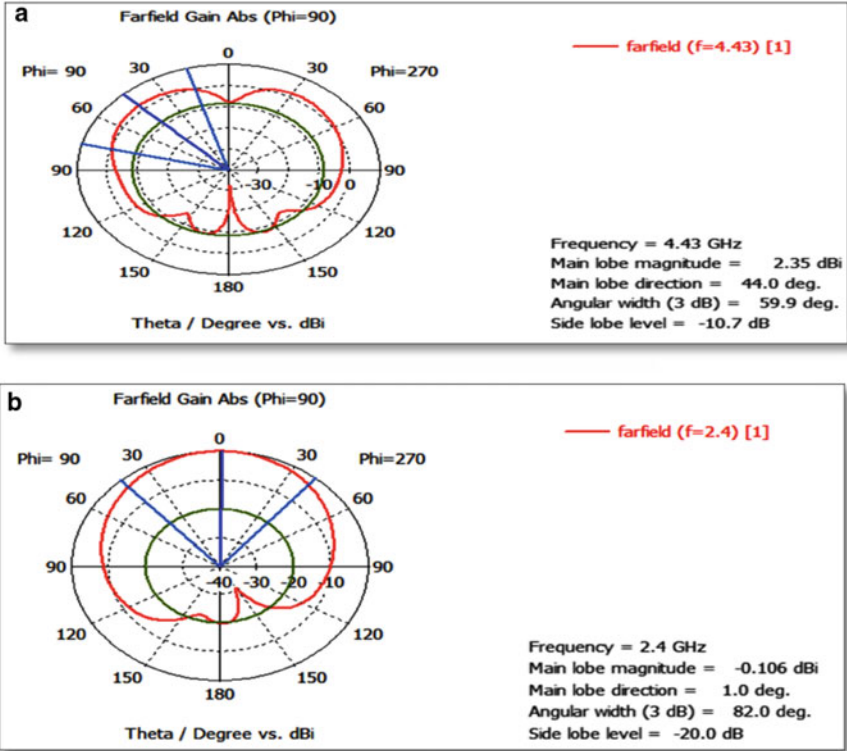


Fig. 6 a Polar plot for radiation pattern of ON state, b Polar plot for radiation pattern OFF state

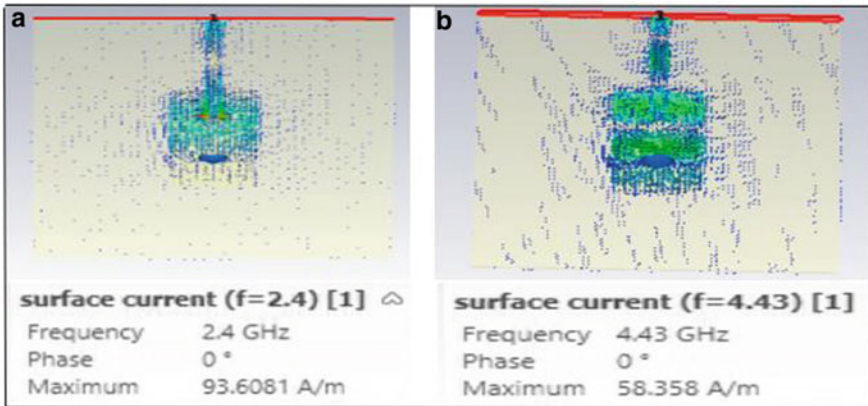


Fig. 7 a ON state surface current, b OFF state surface current

where:

G_t, G_r = gain of transmitter and receiver of antenna, respectively, R = data rate, (E_b/N_o) = Ratio between energy per bit and the noise level for different M-ary modulation schemes, λ = Path loss component, P_t = Power transmitted.

The values taken of the above-mentioned parameters in the paper are:

$(E_b/N_o) = 14$, $N_o = -201$ dB, $d_o = 10^{(-4)}$, $d = 50$, $\gamma = 3.5$, G_t, G_r = ON/OFF state gain achieved, i.e., 0.1068 dBi for ON state and 2.345 dBi for OFF state.

Using Eq. (4), the power and energy which is required by the antenna is calculated. ON state power is 1.0693×10^{35} W, and energy is 1.0693×10^{36} J. OFF state power is -2.0041×10^{30} W, and energy is -2.0041×10^{31} J.

Using Eq. (4) and the above-calculated results, it is observed that the power and energy consumption of the antenna can be reduced if the antenna mode is switched to ON state via PIN diode only when the information is being received, and the power flow to the antenna is stopped in OFF state when there is no input signal, as compared to an antenna which is sensing at all the time. This inference can also be observed by taking an example of patient monitoring system [17]. In this system, the antenna enters a low duty cycle in ON state. Other transmitting/ receiving antenna continues to work in OFF state (sleep cycle) till the time an alarming situation occurs. Once the alarming situation occurs, the antenna goes back to a mode less than the threshold. The antenna switches back to the ON state that is low duty cycle and goes back to the OFF state (sleep cycle) when the body conditions are normal.

5 Conclusion

The paper presents the design of a reconfigurable antenna which works on the principle of energy conservation, operating at 2.4 GHz in ISM band for ON state and 4.43 GHz in ultrawide band for OFF state in WBAN application. It is observed that the mode in ISM band is suitable for a long-range communication while the mode in the ultrawide band range is suitable for short-range communication. The antenna resonates at a frequency of 2.4 GHz (ON state) when sensing data and resonates at 4.43 GHz (OFF state) during no data transmission, in order to save the power or reduce the battery consumption. The S_{11} parameter evaluated for ON state is -15 dB and in OFF state is -35 dB. The antenna gain achieved is -0.1068 dBi when PIN diode is in ON state and 2.345 dBi when diode is switched to OFF state. With the help of Friss equation, the power consumed by the antenna when diode is switched between the two states is also calculated. The power which is required by the antenna when the PIN diode is switched ON is 1.0693×10^{35} W. The ON state acts like data sensing cycle. When diode is switched to OFF, the power consumed is 2.0041×10^{30} W. The OFF state with less power consumption as compared to ON state acts like data channel and sits idle until an input signal is received.

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