Novel Flexible and Wearable 2.4 GHz Antenna for Body Centric Applications

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***Abstract*—Novel flexible and wearable antenna for remote health monitoring is presented. The patch antenna simulated to operate at 2.4 GHz frequency for ISM band applications. Modern designing techniques using ploymide as a substrate that are not only flexible but efficient and low-profile and suited for wearable applications. The propose wearable antenna performance under mechanical bending as well as human body effects have been experimentally studied and evaluated, the antenna can operate under significantly bending angle and body effects attributed to its broad operating bandwidth. The simulated results, both in free space and on the vicinity of the human body show high radiation efficiency of 90%. The performance of the antenna is susceptible for numerous potential applications such as information exchange, personal security, health monitoring.**

***Index Terms*—antenna , wearable , flexibility, polymide,**

I. INTRODUCTION

The growing imbalance between patients and health service providers places tremendous strain on the health sector [1]. To tackle these modern-day healthcare challenges, new technologies should be utilised to enable the health sector to better manage their resources. Remote monitoring in day to- day healthcare shows great potential as it is easy to perform and is particularly beneficial increases involving frail, elderly and housebound patients [2]. Furthermore, it provides an efficient approach for monitoring patients with chronic disease through continuous assessment of symptoms and signs of the disease [3]. A wearable system is becoming more important because of the constantly increasing demand for tracking and monitoring during sporting events and training became more important to observe. Thereafter, the substrate material selection for a wearable antenna design is of crucial importance [4]. The substrate selection requires a low loss material to have better chances of increased antenna efficiency when placed on the body. Microstrip antennas are not a perfect arrangement when utilized in applications that require high levels of bending and rolling conventional for exible displays due to their narrow bandwidth which is a function of the substrates thickness [5]. However, Polyamide has attracted interests of many groups in antenna research and development activities due to its flexibility, light-weight, adaptability , low-cost (potentially low-cost devices), high temperature resistance (up to 400C), low coefficient of thermal expansion, low moisture uptake and high moisture release characteristics, excellent electrical properties [6]. On the other hand, human body is an extremely lossy, dispersive material with high permittivity that absorbs a large amount of the radiated electromagnetic power from the the wearable antenna. Therefore, it is normally for the antenna parameters to significantly decrease when the antennas work on the vicinity of a human body, which leads to deterioration of the wireless communication range of the radio system as well. Also, the body-absorbed electromagnetic power may cause unwanted, adverse biological effects [7].

In this paper, we present a compact thin and exible printed antennas for remote heart rate monitoring applications. The proposed antennas are based on a polyimide substrate which is known for its exibility, robustness. Comparative study based on simulation result (nobody and free space results) are introduced.

II. ANTENNA DESIGN AND SIMULATION

A. Antenna design

For designing of a micro strip patch antenna, we select the resonant frequency and a dielectric permittivity for which antenna is to be designed. The parameters of the antenna can be calculated as following. The width of the proposed patch is determined utilizing the following equation [8]:

$$W \approx \frac{C_0}{2f_r}\sqrt{\frac{2}{\epsilon_r+1}} \quad (1)$$

Where W is the width of the patch C_0 Speed of ligth, f_r the resanoant frequency and ϵ_r value of substrate permittivity. The effective refractive index value of a patch is significant parameter in the structuring strategy of a microstrip fix a patch antenna. The radiations traveling from the patch towards the ground go through air and some through the dielectric (fringing). Both the air and the substrates have different perimittivity, therefore in order to consider this, the value of effective dielectric (ϵ_{rff}) is calculated as the following [8].

$$\epsilon_r ff = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}[\frac{1}{\sqrt{\frac{1}{1+12\frac{h}{w}}}}] \quad (2)$$

Where h is the height of the substrate. because to fringing, electrically the size of the antenna is increased by an amount of ΔL. Therefore, the actual increase in length ΔL of the antenna is to be calculated using equation 3 [9].

$$\frac{\Delta L}{h} = 0.412 \frac{(\epsilon_r ff + 0.3)((\frac{W}{h}) + 0.264)}{(\epsilon_r ff + 0.258)((\frac{W}{h}) + 0.8)} \quad (3)$$

The length L of the patch is can be calculated using equation 4 [9].

$$L = \frac{C_0}{2f_r\sqrt{\epsilon_e ff}} - 2\Delta L \quad (4)$$

The proposed antenna was simulated using CST Microwave Studio software 2018. The three layers (ground plane, substrate and radiating patch) were created along with a50Ω microstrip feed line and a wave guide port for power supply. For the ground plane, radiating patch and feed line made of copper with thickness of 0.035mm. For the substrate, polyimide with a dielectric constant of 3.5 and loss tangent 0.0027 and thickness of 1mm. Copper was chosen for the ground plane and radiating patch as it is a highly conductive material. Polyimide substrate with excellent performance in flexible applications has been chosen. Fig1 and table I summarizes the detailed description of the optimized dimensions of the proposed antenna.

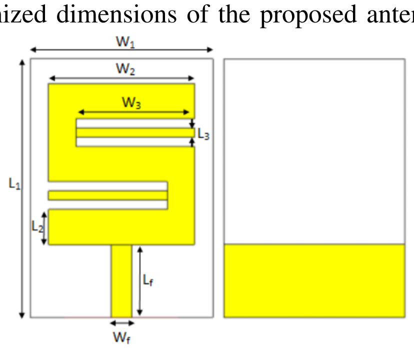

Fig. 1. Patch Antenna with a flexible substrate (a) the front view, (b) the ground plane

TABLE I
OPTIMIZED DIMENSIONS OF SIMULATED ANTENNA

Parameter	Dimension (mm)
L_1	28.4
W_1	20
L_2	3.84
W_2	16
L_3	1.017
L_f	8
W_f	2.3

B. Human Body Modeling

To evaluate the influence of the human body on the performance of the antenna, a simplified three-layer model of the human thorax was created in CST. The model, as shown in Figure, consists of a skin, fat and muscle layer with thicknesses of 0.96mm, 9.5mm and 13.5mm respectively. The thickness of the individual tissue layers was chosen based on the acceptable range for an average adult. Given that the human body is a heterogeneous and multi layer medium, it was important to take into account the dielectric properties of each tissue. Therefore, to accurately model the human thorax, the dispersion characteristics for each tissue were defined over the relevant frequency range. The dielectric properties of each tissue layer can be obtained from their measured complex relative permittivity, ϵ given by [10].

$$\epsilon = \epsilon^{-} - j\epsilon^{=} \quad (5)$$

where ϵ^{-} is the relative permittivity of the material and $\epsilon^{=}$ is the imaginary [11].

$$\epsilon^{=} = \frac{\sigma}{\omega} \quad (6)$$

where is σ the total conductivity of the tissue and $\omega$is the angular frequency of the field. To define the tissue layers in CST, both the real and imaginary parts of the complex relative permittivity were defined over the frequency range of interest 2-2.8 GHz. The values for the complex relative permittivity at 2.4 GHz are given in Table II.

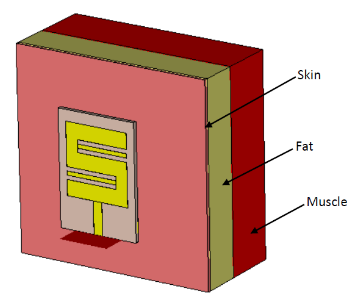

Fig. 2. Three layers model of the human skin designed in CST

TABLE II
DIELECTRIC PROPERTIES OF HUMAN TISSUE LAYERS AT 2.4 GHZ

Body Tissue	Permittivity	Conductivity(S/m)	Loss Tangent
Skin	38.1	1.44	$9.55 \times 10^{-}11$
Fat	10.8	0.261	$1.73 \times 10^{-}11$
Muscle	52.8	1.72	$1.14 \times 10^{-}10$

III. RESULTS AND DISCUSSION

A. Flexibility of the Antenna

For wearable applications When an antenna or sensor is placed on the body, there is more probability that the platform where the antenna is placed is not flat. Moreover, the antenna can bend at different angles because of subject movement. Hence, a compact, conformal antenna is needed that can operate well at all bending angles. It is important to characterize the proposed antenna on different bent angles therefor in order to understand the complex antenna bending electromagnetic characteristic and its impact on antenna parameters, a simulation bending antenna at desire frequency 2.45 GHz is presented. The antenna is bented at 20^o and 30^o and campered with flat state (0^o) as shown in Fig 3. As presented in Fig 4, the resonance frequency and operational bandwidth of the proposed antenna change slightly as the bending angle increased. However, the shift of resonant frequency would not affect reading as long as 2.4 GHz still falls within the -10 dB bandwidth.

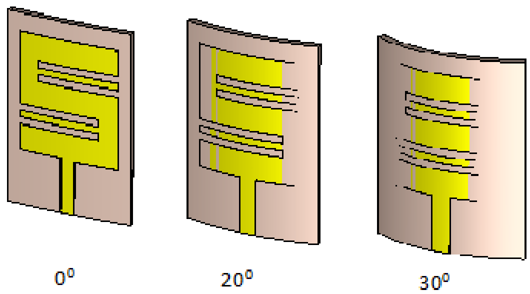

Fig. 3. Different bending angle for the purposed antenna

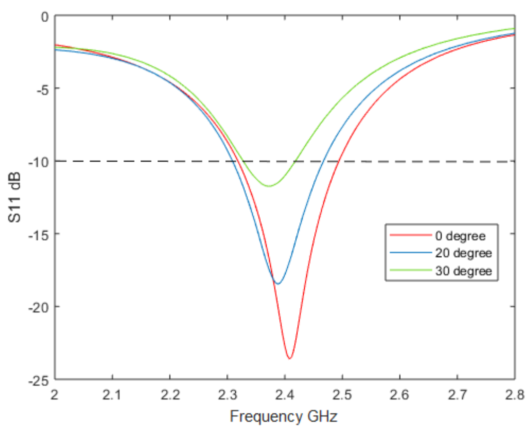

Fig. 4. S_{11} magnitudes for different bending angles shown in Fig. 3 and without bending

B. *Antenna Performance on Human Body*

To evaluate the performance of the antenna for free space and on-body conditions, results were obtained and compared with both cases. Fig 5 shows the simulated S_{11} profile for on body and fre space conditions. With the antenna in free space, the resonant frequency is 2.4 GHz with S_{11} of -24.38 dB. When the antenna placed on the human body, there is a shift in the resonant frequency toward 2.48 GHz and a increase in the S_{11} to -29.86 dB. This detuning of the frequency is likely a result of the high dielectric constant property of the human tissue layers. It is clear from Fig 7 that for the antenna in the on-body case, the value of radiation efficiency at 2.4 GHz almost the same as free space (90%) which a most advantage of this antenna design. On the other hand there is a significant decrease of the total efficiency for on body condition, whereas the total efficiency decrease from almost 89% to about 33%. Therefore, the total radiated efficiency of the proposed antenna on flat body phantom decreases by (46%). This is due to the higher conductivity of the outer layer human skin. From the fig 6, the surface currents are found to be aligned and equally distributed in the same direction. Such current distribution in the vertical direction of the antenna generally creates an eight-shaped radiation pattern for the E plane and an omnidirectional radiation pattern for the H-plane. The simulated of the radiation pattern at both condition of the purposed antenna is illustrated in Fig 8 and 9 for the two principal planes(H plane and E plane). An omnidirectional radiation pattern has been observed from the normalized H plane. A high main lobe magnitudes and lower side-lobe levels can be observed from Fig8 and 9. The main lobe magnitude of 2.4 dB was observed at resonate frequency on free space case. At the on body condition main lobe increase to , 4.13 dB with side lobe of -4.13 dB.

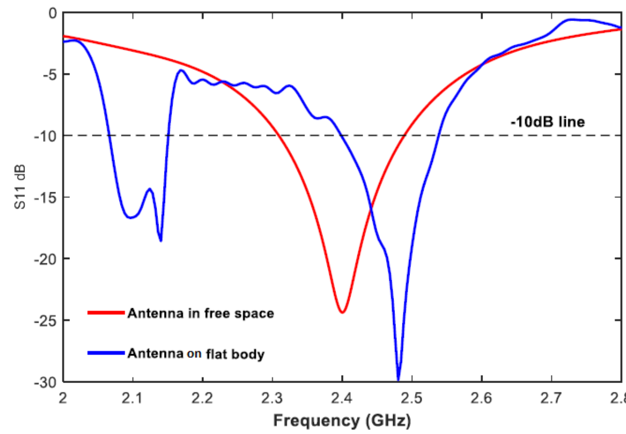

Fig. 5. Simulated S_{11} profile of antenna for free space and on-body conditions

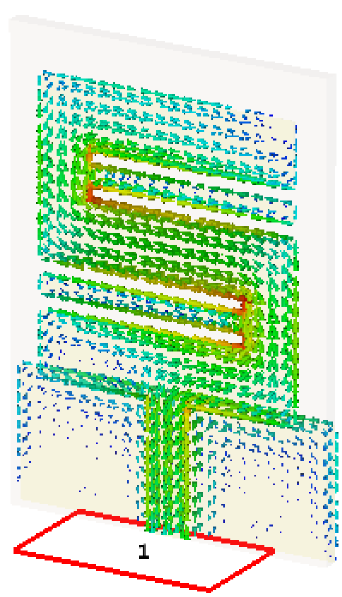

Fig. 6. Surface current distribution of the proposed antenna.

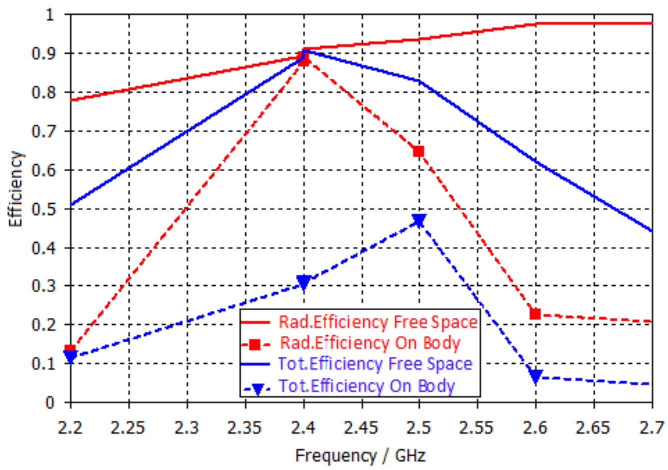

Fig. 7. Efficiency of the antenna on free space and human body

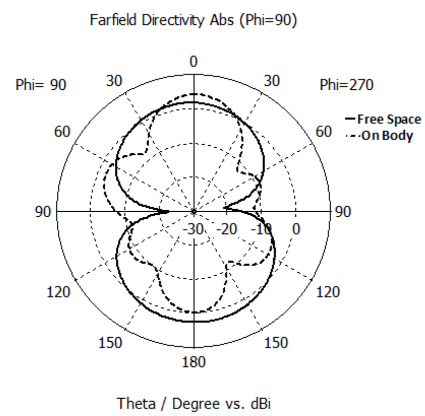

Fig. 8. Simulations of the normalized field patterns in the H plane on free space and on body

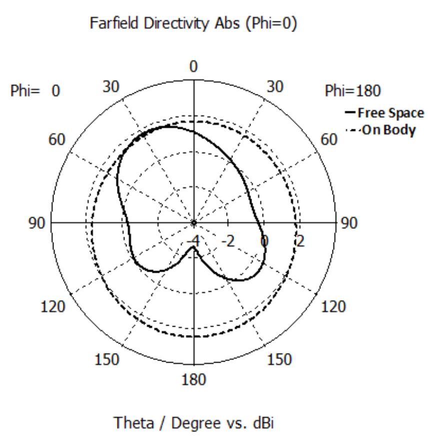

Fig. 9. Simulations of the normalized field patterns in the E plane on free space and on body

Conclusion

The design and simulation of a small flexible microstrip patch antenna, operating at 2.4 GHz for ISM band applications, was presented. The simulated antenna showed good performance in free space, with a return loss of -24.38 dB at 2.4 GHz and an omnidirectional radiation pattern. However, when placed in the vicinity of the human body, the performance of the antenna was affected in terms of frequency detuning and radiation pattern deformation. The presented antenna not only possesses good properties, but it is also easy to manufacture,The results make a new ground in using the cost effective and commercially available poylmide film as the flexible substrate. proposed in this work is highly desirable for applications, such as personal security, health and wellbeing monitoring, big data and IoTs.

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