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PIFA Antenna Design for MmWave Body Centric 5G Communication Applications

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Abstract

As a result of the upsurge in body-centric wireless communications devices such as augmented reality glasses, fitness tracker, wireless headset in the upcoming 5G network, compact antennas suitable for such application operating in the millimeter-wave frequency band with advantages including miniaturization and higher data rates are in higher demand. In this work, we design a novel compact planar inverted-F Antenna (PIFA) for wearable 5G wireless devices operating at 32GHz. The gain is 2dB with an efficiency of 86%.

Keywords - *5G, PIFA, mmWave frequency, body-centric devices.*

I. INTRODUCTION

Recently, there has been an upsurge in the use of smart devices with a huge demand for high data rate and compactness for convenient mobility for wireless communication and accessing the internet [1]. These include smartphones, tablets, and wearables such as the augmented reality glasses, smartwatches, body implants for tracking and health management, and internet of things devices for the machine to machine (M2M) communication. One of the expected contributors to such devices' achievement is the antenna, which is expected to be very light in weight, compact, and operate in multi-frequency bands [2], [3]. The miniaturization of such antennas has been assisted by the standard bodies' decision, such as the 3rd Generation Partnership Project (3GPP), to select the millimeter-wave frequencies as one of the destructive technologies for achieving the expected Gbps data rate of the 5G network [4]. The mmWave frequency band allows for more bandwidth, helps deliver faster and higher quality video and multimedia content aside from enabling the miniaturization of the antennas due to its very small wavelength [5].

MmWave is made popular due to the limited and scarce bandwidth within the below 6 GHz frequencies, whereas the mmWave carrier frequencies offer much larger spectral channels such as 2 GHz bandwidth in the 60 GHz unlicensed band [6] [7]. MmWave spectrum is between 30 GHz to 300 GHz [8]. The use of mmWave frequencies became potentially suitable for the development of upcoming body-centric wireless communication systems as a result of the resent favorable research outcome in the 60GHz and 94GHz band. However, there are issues to be overcome in the use of mmWave for wearable communication in terms of simulation. The reality that the human body becomes electrically large at such high frequencies is one of the challenges. This potentially makes the computational weight of full-wave simulations very tedious in resolving equations with a large number of unknowns. Other methods useful for body-centric communication and propagation analysis include the Ray-based method and Geometrical Optics/Uniform Theory of Diffraction methods, which have proved effective [9].

There have been a variety of single element as well as MIMO antenna designs for 5G communication applications with the use of diverse antenna structures such as Micro-strip patch antenna, Planar inverted-F Antenna (PIFA), or Dielectric Resonator Antenna (DRA). PIFA has several advantages when evaluated with other classical antennas as it is smaller with a compact structure, operates in multiband frequencies, and mechanically robust. It has a low cost with a reduced Specific Absorption Rate (SAR) value with the advantage of lower radiations been directed towards the user's body [10]. Many authors have worked on the PIFA antenna for 5G wearable devices, including the author of [10], which presented a MIMO PIFA antenna with 18mm ×10mm × 3.5mm dimension for wearable devices covering a wide frequency band appropriate for upcoming 5G systems. The authors in [9] [11] and [12] reviewed, designed, and fabricated a PIFA Yagi type antenna, which is then characterized in free space and on a skin-equivalent phantom at 60 GHz for [11] while [12] operates at 2.45GHz. The authors of [13] presented a six-element dual-band MIMO PIFA antenna operating 28/38 GHz. In this paper, we present the design of an 8 element quad-band MIMO PIFA antenna for 5G network devices. The rest of this paper is structure as follows. In section II, we consider the wearable PIFA antenna structure and the theory of its design. In section III, we presented our design methodology, while section IV presented the result of our simulation. We conclude in Section V.

II. WEARABLE PIFA ANTENNA

Improving the performance of antennas is a critical design consideration. One way of achieving this in a patch antenna design is by introducing shorting pins from the antenna patch to the ground plane at several points leading to the evolution of the planar inverted F antenna (PIFA) see figure 1. The insertion of the shorting pins introduces parallel inductance to the antenna impedance, thereby controlling the impedance via the feed's distance to the shorting pin. The impedance of the PIFA can thus be tuned with this distance called 'D' because the impedance decreases as the feed move closer to the shorting pin and increases as it moves away from the shorting pin. The PIFA resonates at quarter wavelength due to the shorting pin at the end, thereby helping to reduce the size of the antenna and space thus required for implantation or on the wearable device [2].

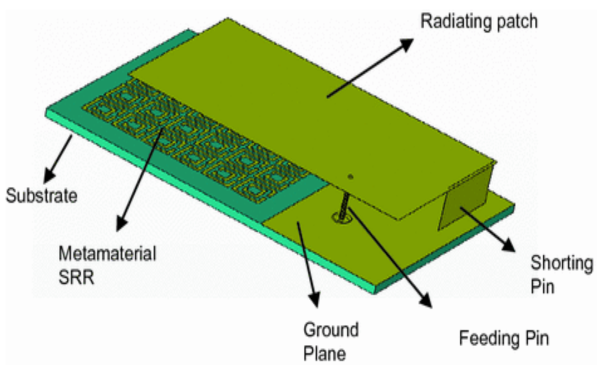

Figure 1: Schematic of the PIFA Antenna [2]

Designing classical antennas such as the planar dipoles, monopoles, planar inverted-Fs (PIFAs), and micro-strip patches for wearable antennas has been carried out in various researches [14] [15] [16] [17]. Designing an antenna for body-centric devices has a number of key challenges. One of which is avoiding the negative effect of interaction between the antenna and the dispersive organic tissue, which can lead to the alteration of the antenna radiation pattern, input impedance variation, and detuning of the resonant frequency [15]. The PIFA design as a wearable antenna for placement on clothing sleeves, as shown in figure 2, reveal that this challenge can be mitigated by the ground plane of PIFA forming a guard for organic contact in such a way that the antenna waves are not radiated towards the human body [18].

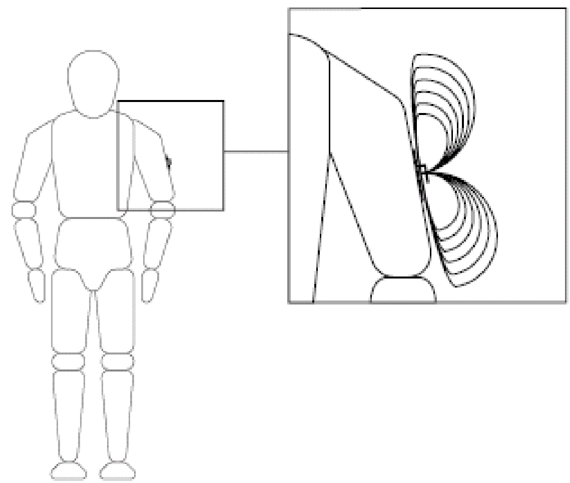

Figure 2: Wearable PIFA showing the location on the human body [18]

Generally, the parameters needed for the classical antenna design performance analysis are return loss, antenna radiation pattern, the gain of the antenna, and its efficiency. It is unnecessary to examine the bending characteristics of classical planar antennas since they are flat in structure. [18]. However, body-centric antennas needed other factors to be taken into thought to guarantee their performance in the context of the wearable scenario. Such other parameters include specific absorption rate (SAR), which define the amount of absorption by the human body, and the antenna bending characteristics, which under investigation shows that the antenna resonance moved in the direction of the lower frequencies. The bandwidth became smaller when bent [18] [19].

III. DESIGN METHODOLOGY

Antenna Dimension Description

Length — PIFA antenna length
Width — PIFA antenna width
Height — Height of substrate
Substrate — Type of dielectric material
G P Length — Ground plane length
G P Width — Ground plane width
Patch Center Offset — Signed-distance from the center along length and width of the ground plane
Short Pin Width — Shorting pin width of the patch
Feed Offset — Signed-distance of feed point from the origin
Load — Lumped elements
Tilt — Tilt angle of the antenna
Tilt Axis — Tilt axis of the antenna

The frequency of resonating of the PIFA is dependent on the width of the shorting PIN L_{short}. If L_{short} = L_{width} meaning that the L_{short} runs the whole stretch of L_{width} hence, the antenna resonates at maximum radiation efficiency. If

$$L_{short} = L_{width}\ therefore\ L_{lenght} = \frac{\lambda}{4}$$

Assuming that $L_{short} = 0$ and the shorting is just a pin or assuming it is << L_{width}, then the antenna resonates at

$$L_{short} = 0 = L_{length} + L_{width} = \frac{\lambda}{4}$$

Generally, we can estimate the resonant length of a PIFA as a function of its parameters as:

$$L_{lenght} + L_{width} - L_{short} = \frac{\lambda}{4}$$

Where

$$\frac{\lambda}{4} = \frac{c}{4f\sqrt{E_r}}$$

$$L_{length} + L_{width} - L_{short} = \frac{c}{4f\sqrt{E_r}}$$

The intended design is for 32GHz

$$L_{lenght} = x$$
$$L_{width} = \frac{x}{2}$$
$$L_{short} = \frac{x}{5}$$

$$x + \frac{x}{2} - \frac{x}{5} = \frac{c}{4f\sqrt{E_r}}$$

$E_r = 4$, C = Speed of light = 3×10^8, Hence

$$\frac{c}{4f\sqrt{E_r}} = 0.001172$$

$$x + \frac{x}{2} - \frac{x}{5} = 0.001172$$

$$13x = 0.01172$$

$$x = 0.00090$$

$$L_{length} = 0.00090$$

$$L_{width} = 0.000451$$

$$L_{short} = 0.00018$$

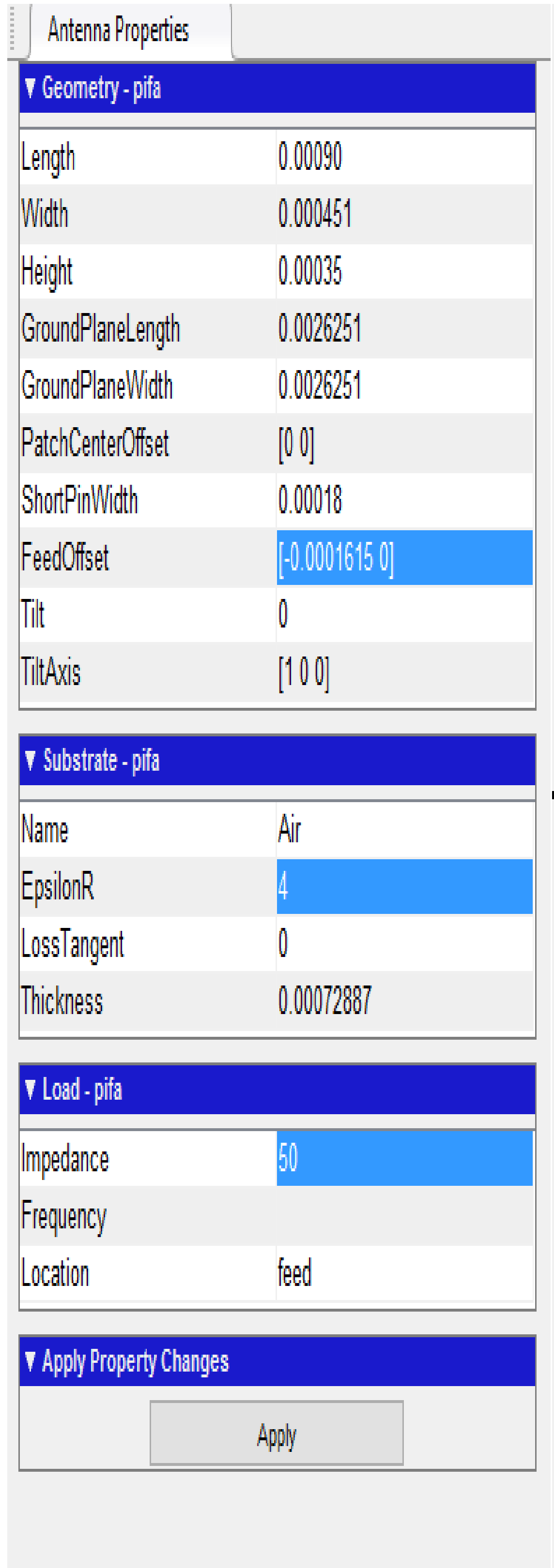

Figure 3: Antenna Dimensions

IV. SIMULATED RESULT AND DISCUSSION

The three-dimensional antenna pattern of the PIFA showing the gain and the directivity of the antenna is shown in figure 4 with a gain of 2dB and a maximum directivity of 2.3dBi at 32GHz.

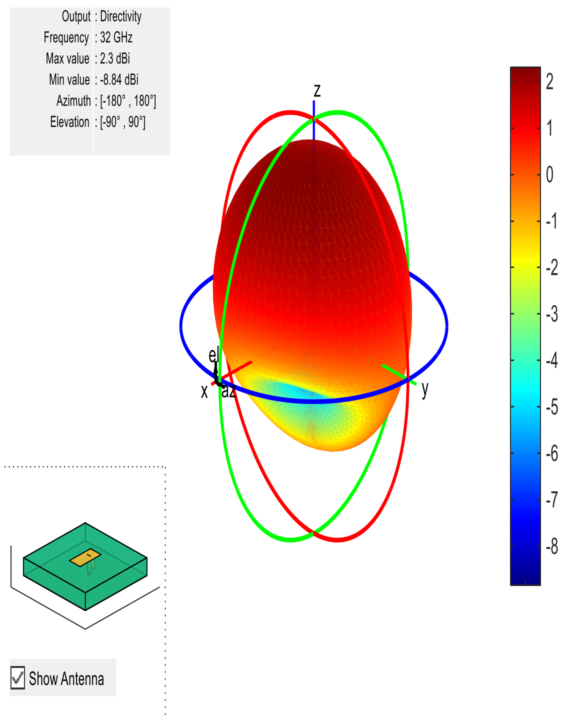

Figure 4: Antenna Pattern

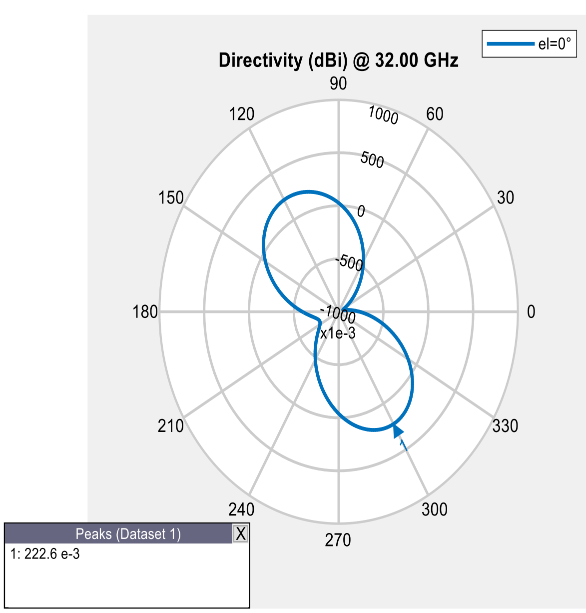

Figure 5: Antenna Directivity

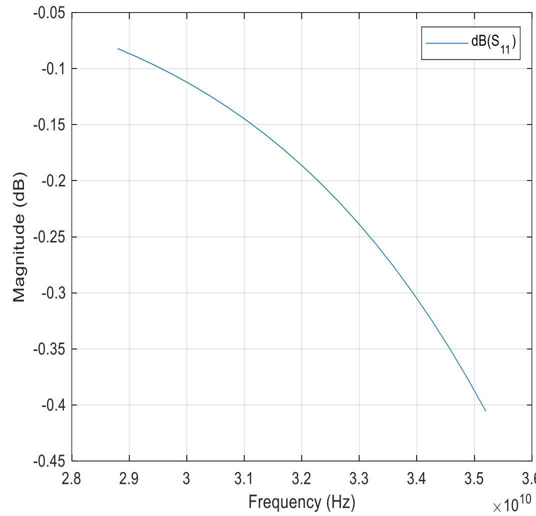

Figure 6: S_{11} Parameter Plot

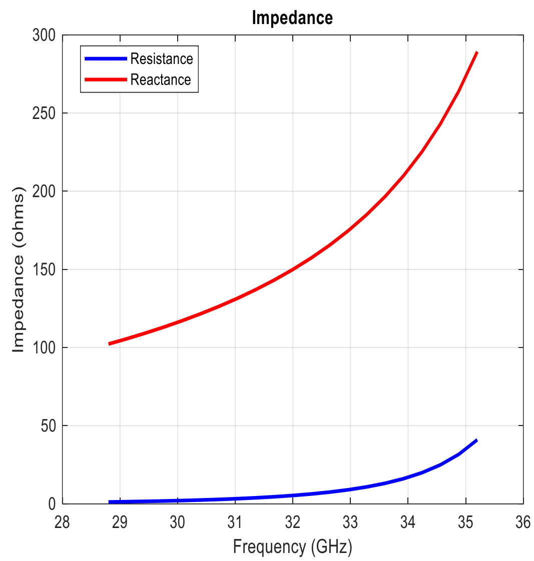

Figure 7: Antenna impedance Plot

Parameter	Result
Frequency (GHz)	32.0
Directivity (dBi)	2.3
Gain (dB)	2.0
Impedance (Ω)	5
Efficiency (%)	86
S - Parameter (S11)	-0.19dB

Table 1: Simulation Result

V. CONCLUSION

A single-band wearable and PIFA antenna operating at 32 GHz has been presented in this paper. The PIFA antenna is very efficient, with 86 % efficiency at 32 GHz. The antenna far-field pattern is approximately omnidirectional, with a reasonably good gain of 2 dB. This antenna is useable in wearable applications, including medical implants, remote patient monitoring, rescue, and military operations. Further work can still be carried out on the PIFA antenna, where we can configure the antenna in dual-band mode operations. Finally, we can also fabricate the prototype of the proposed antenna to validate the numerical results.

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