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Design of a Textile Antenna Using Metasurface Technology for Wireless Body Area Networks

Perancangan Antena Tekstil Menggunakan Teknologi Metasurface untuk Jaringan Area Tubuh Nirkabel

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Abstract

Recently, continuous development and distinctive growth have been observed in implementing wearable sensors and flexible devices in real life. This paper shows a wearable textile antenna design based on a metasurface. It operates in the 3.5 GHz. A proposed model provides light on the metasurface's operation. The prototype of the textile antenna using taslan material was observed and exhibited a relative permittivity of 1.41. Based on these values, we designed a square antenna with an amount of parasitic square around modeled as a planar array. We observed the measured reflection coefficient of the three conditions and saw similar results of the reflection coefficient, which is around -25 dB at 3.5 GHz frequency, and the radiation diagram of the antennas reproduced the simulated one.

Keywords: Textile, WBAN, Wearable Antenna

Abstrak

Pengembangan berkelanjutan telah diamati dalam penerapan sensor yang dapat digunakan pada perangkat yang fleksibel dalam kehidupan nyata. Makalah ini menyajikan desain antena tekstil dengan mengadopsi teknologi metasurface. Antena yang dirancang beroperasi pada frekuensi 3,5 GHz. Model yang diusulkan memberikan penjelasan tentang pengoperasian teknologi metasurface. Prototipe antena tekstil didesain dengan menggunakan bahan taslan yang mana menunjukkan nilai permitivitas relatif sebesar 1,41. Kami merancang antena persegi dengan yang dikelilingi dengan desain persegi disekitarnya yang dimodelkan sebagai array planar. Nilai koefisien refleksi yang dihasilkan dengan mengamati ketiga kondisi dan melihat hasil yang serupa dari koefisien refleksi, yaitu sekitar -25 dB pada frekuensi 3,5 GHz, dan diagram radiasi yang dihasilkan pada pengukuran menunjukkan bahwa antena mereproduksi diagram yang telah disimulasikan.

Kata kunci: Tekstil, WBAN, Antena Wearable

I. INTRODUCTION

Recently, we have observed a tremendous development and remarkable growth in implementing wearable sensors and flexible devices in real life. These devices are exploited to monitor signals in healthcare applications, for the intent of geo-positioning the rescue, and in military personnel [1]. There are abundant frequency bands that have been introduced worldwide to enhance, expand, examine, and market the wireless body area network (WBAN) connection for the advancement of humanity [2]. To improve, extend, and commercialize the WBAN communication link, several frequency bands are allocated, such as the narrowband versions 2.36–2.40 GHz for the medical body area network, 2.40–2.48 GHz as the military, industrial, scientific, and medical band, and 3.1–10.6 GHz for the ultra-wide-band applications. The IEEE 802.15 TG6 group sets several standards for WBAN communication to optimize and standardize various low-power applications for on-body, in-body, and off-body communication [3-5].

Integrating antennas into textiles introduces challenges that necessitate a multidisciplinary approach involving expertise in electronics and textiles. Researchers are exploring novel techniques to embed conductive materials within textiles, allowing for the creation of lightweight, flexible, and washable antennas. This interdisciplinary effort has led to the emergence of wearable antennas that are both aesthetically pleasing and functionally efficient, catering to the growing demand for unobtrusive and comfortable wearable technology [4,6].

The progress of wearable sensors and flexible electronics has emerged and formed the foundation of WBAN. In designing wearable antennas, we find many challenges due to the practical implementation of antennas next to the human body. The human body presents very loose structures, and its presence affects the form of the antenna's radiation pattern and can also shift its operational frequency. Moreover, the placement of the antenna on convex structures with different curvature radii also affects its performance due to the overall change in electrical length. Hence, for wearable and flexible applications, the engineer of the antennas must take some extra considerations to prevent unacceptable dangers. At the same time, he must maintain his performance in severe surroundings [1].

The intersection of textile engineering and electromagnetic technologies has spurred remarkable advances, particularly in antenna design. Integrating textiles with metasurface technology has garnered significant attention for its potential to revolutionize the landscape of wearable and flexible communication systems [7]. Textile antennas, characterized by their lightweight, conformal, and unobtrusive nature, coupled with the metamaterial-inspired functionalities of metasurfaces, offer a synergistic platform for developing high-performance, adaptive, and multifunctional antenna systems.

This study aims to explore and harness the intrinsic advantages of combining textiles with metasurfaces, unraveling novel possibilities for antenna engineering in diverse applications such as wearable communication devices and smart textiles. By examining the impact of metasurface technology on the performance and characteristics of textile antennas, this research contributes to the ongoing discourse on the convergence of materials science, electronics, and communications engineering.

This article proposes a square patch antenna based on metasurfaces for wireless body area networks. The type of the antenna is a metasurface implementation of microstrip antennas. In this way, we can significantly reduce the material's thickness to prevent the antennas' radiation efficiency. We will observe the effect of bending on the radiation characteristics of the antenna.

II. LITERATURE REVIEW

The need for technologies based on wearable devices has increased highly in the last few years [8]. As an essential part of the wearable system, the antennas are implemented in different applications, mostly as wireless body area networks (WBAN). In these networks, the antennas are mounted on the human body. The effects on the human body must be considered during the design process of the antennas [9]. More specifically, we must take into account some important implementation conditions for the antennas, from the fabrication process, such as the accuracy of the dimensions and inaccuracy of the material specifications, to mounting circumstances, such as structural deformation and the presence of foreign objects close to the antennas [10]. As the most common structural deformation, the bending of the antennas in the mounting situation should guarantee the antenna specifications are still within the required working range [11]. Moreover, the designed antenna must conform to the international safety rules for the human body [12].

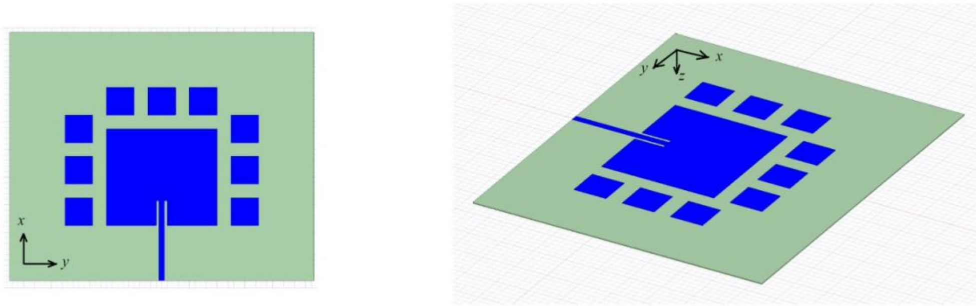
In the past, many research studies have been performed to explore the performance of flexible and wearable antennas with several design strategies. In [13] presented for the first time a complete fabric-based slotted planar inverted F antenna. The antenna shows a high bandwidth, more significant than 46%, and a gain of around 1.5 dB. The antenna works in the frequency interval of 1.8 to 3 GHz. [14] proposed a modified dewdrop-inspired radiator with a defective ground plane structure. This ultra wideband antenna has a considerable bandwidth from 3.1 GHz to 10.6 GHz. The authors implemented the antenna in four diverse substrates (teslin, denim, polyamide, and polyester) as basic materials for the antenna, which is attached to a cotton shirt and a high-end Res-Q jacket to check the stability of the antenna performance during applications. [1] presented a low-cost, flexible, and wideband wearable antenna for different WBAN applications. It ranges the medical BAN frequency of 2.4 GHz, ISM band in the region of 2.45 GHz, WiMAX at around 3.5 GHz, and WLAN band at around 5.2 GHz.

Determination of the material characteristics of the textile plays a significant role in designing wearable antennas. In the literature, we find different methods with diverse features involved in the procedure [15]. In [16], software based on electromagnetics performs a deep and comprehensive analysis of the optimal size of the sample and its placement on the top of the surface of a ring resonator. Then, the associated measurements were carried out with a vector network analyzer, and the value of the relative permittivity ε_r of the material was tested with an analytical model [17].

In recent time, there is a growing interest in implementing the antennas in a electromagnetic band-gap (EBG) structure [18]. In this way, the wearable antenna gives a higher degree of isolation from the human body to reduce the the specific absorbtion rate (SAR) significantly [19]. In [20], a wearable monopole antenna with a coplanar waveguide (CPW) feeding equipped with an integrated electromagnetic band-gap (EBG) array is proposed for three bands applications. The antenna works in three different bands, the 2.45/5.8 GHz for WLAN and for WiMax at 3.5 GHz. A 3 × 3 EBG array has been attached at the back side of the monopole antenna for reducing the influences of the antenna radiation to the human body. Alternatively, some researchers used the artificial magnetic conductor (AMC) [19,20] and the metasurface approaches [21,22]. A compact wide-slot circularly polarized antenna with a 2×2 AMC array on the back side is proposed for WBAN applications at 5.6 GHz [23]. The total dimension of the antenna is 30.9 × 30.9 mm2 board of RT-Duroid 5880 substrate. [24] presented a design for a compact textile antenna based on metasurfaces for wearable applications. The antenna works at the frequencies of 2.45 GHz and 5.5 GHz ISM bands. The antenna has an integrated reflector on the back side for reducing the back radiation and for lowering the SAR. The development of metamaterial-based antennas for wearable broadband applications, such as metasurface-based wearable antennas based on tunable metamaterials, and wearable antennas associated with composite right/left-handed transmission lines (CRLH TLs) [7].

III. RESEARCH METHOD

In this research, we would like to design a textile antenna consisting of rectangular microstrip antennas (Figure 1a) and the square parasitic in around. The antenna works at the frequency of 3.5 GHz. In order to reduce the radiation to the human body, a metasurface structure is embedded on the backside of the antenna (Figure 1b). The distance of each unit cell will be investigated through software, but we set it to 10 mm as the initial value. The total width of the antenna will be around *Wx*=110 mm and *Wy*=90 mm.



a) b)
Figure 1. Metasurface-based wearable antenna, a) radiating element in array, b) radiating element integrated on a metasurface structure.

The metasurface structure will be designed using the procedure described in [25]; however, we will use textile (taslan material) as the material.

In this section, the material characteristics are analyzed. Based on a microstrip ring resonator (MRR) structure (as given in Figure 2). The ring resonator has a mean radius r, approximately equal to small w (for moderate frequencies, we can choose 1 mm). Where, $r = r_1 + \frac{w}{2} = r_2 - \frac{w}{2}$. The resonator is fed by a 50 Ω microstrip line on the left side with a coupling through a small gap g (around 0.25 mm to 0.5 mm). On the right side, a similar feeding microstrip is built to measure the transmission coefficient of the structure. The width of the line w is selected for getting the characteristic impedance of 50 Ω. Several wavelengths, in example L_f could choose the length to avoid higher-order modes reaching the port on the left and right sides.

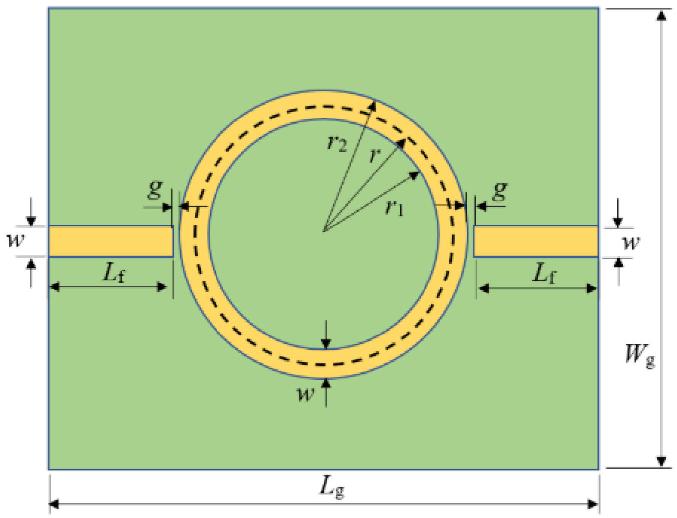


Figure 2. Microstrip ring resonator (MRR).

According to [15,26], there is a relationship between resonant frequency and the mean radius of the resonator as

$$f_r = \frac{c}{2\pi r\sqrt{\varepsilon_{r,eff}}} \quad (1)$$

where fr is resonant frequency, $\varepsilon_{r,eff}$ is effective relative permittivity of the material. In this research, we will fix the radius and observe the resonant frequency to obtain the effective relative permittivity of the material.

IV. RESULTS AND DISCUSSION

As described in section 3, to observe the material characteristics of the textile material, we apply the measurement of the transmission coefficient of a ring resonator structure, as given in Figure 3. For simulation purposes, it is important to know the material thickness. Here, we used a digital vernier caliper to obtain accurate result. The thickness of the used taslan material is 0.25 mm.

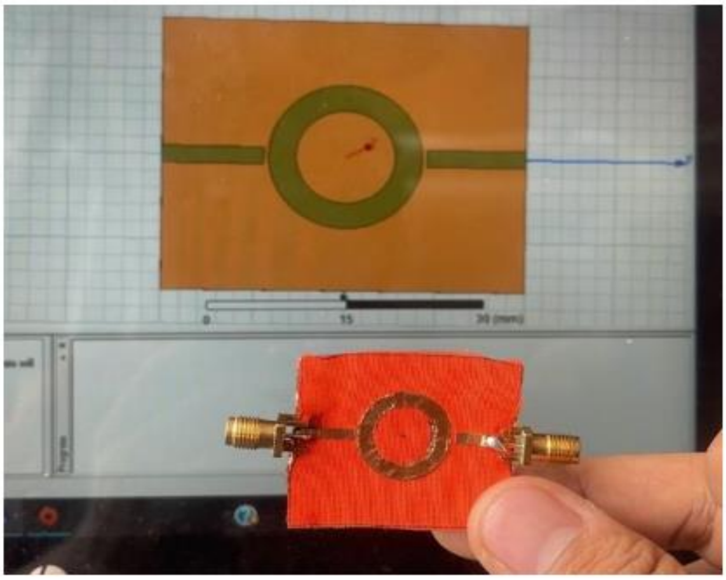


Figure 3. Determination of the relative permittivity of taslan material.

By measuring the resonant frequencies for given radius of the ring resonator, with eq. (1), we can calculate the effective relative permittivity of the materials. We used the program Txline to calculate this. After some iteration, we got the value of 1.41 as the relative permittivity of the material taslan. We use this number for calculation with HFSS.

We designed a simple rectangular antenna with parasitic in around at 3.5 GHz frequency, again with a pair of slots for matching. We used copper tape as a conductive material instead. The model of the antenna and its fabrication are depicted in Figure 4.

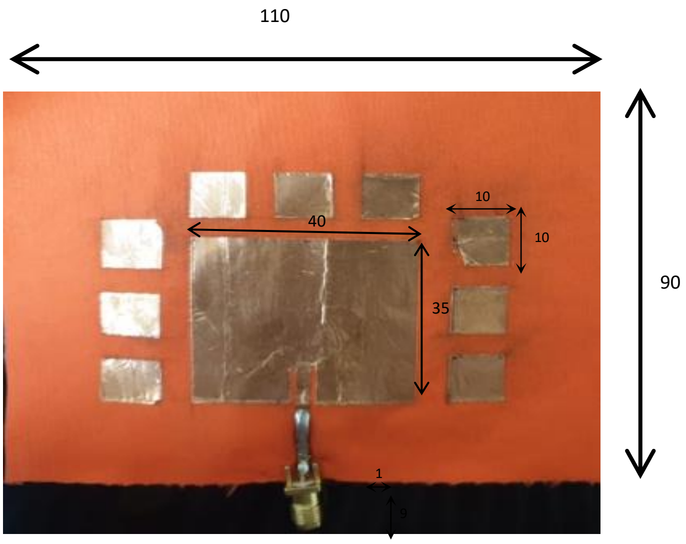
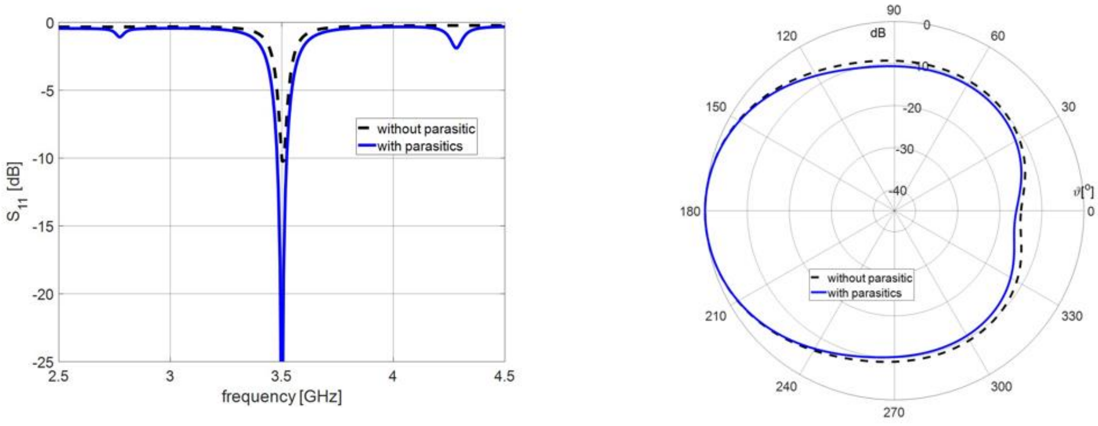


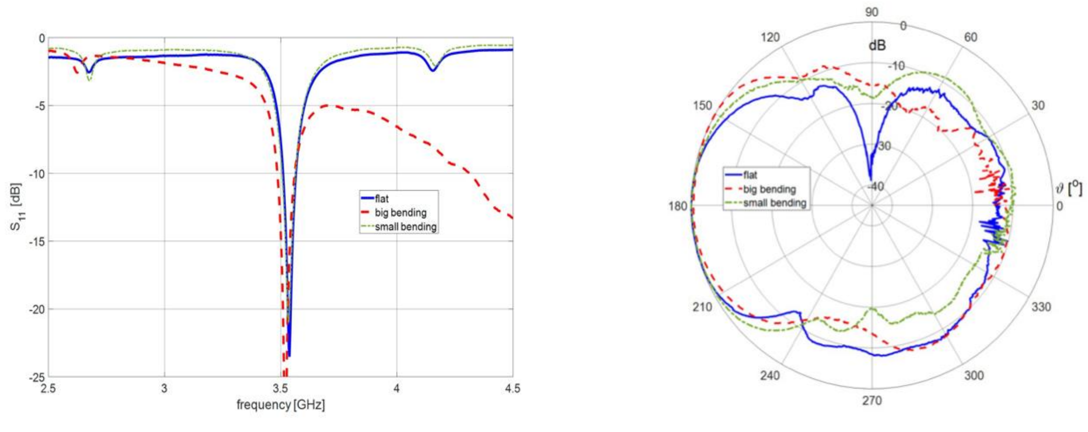
Figure 4. Rectangular antenna model in taslan (all dimensions in mm).

Figure 5(a) compares the simulation results between the simple rectangular patch antenna (without parasitic) and the rectangular patch antenna with parasitic in around. We see very similar results in 3.5 GHz frequency; the reflection factor of the antenna is -10 dB and -25 dB, respectively. Figure 5(b) compares the calculated radiation diagram of the antenna of the two models. We see some coincidences in the results, especially in the main beam; we have similar results between parasitic and without parasitic, that the power level is around -10 dB.



(a) (b)

Figure 5. Comparison of calculated reflection coefficient and radiation diagram of the wearable antenna with taslan material with and without parasitic element.



(a) (b)

Figure 6. Comparison of measured reflection coefficient and radiation diagram of the wearable antenna in taslan.

Figure 6(a) gives the comparison of the reflection coefficient in three conditions, that is flat (blue line), big bending (red dashline), and small bending (green dashline). We see very similar results, the reflection coefficient is around -25 dB at 3.5 GHz frequency. Figure 5(b) gives the comparison of the three conditions in measured radiation diagram of antenna in material taslan. We see some coincidences in the results, especially in the main beam, and some minima at around 90°.

V. CONCLUSION

In this work, we have characterized taslan for antenna material, by determining the relative permittivity with a ring resonator. By taking some measurements and calculations, we found that the relative permittivity of taslan around 1.41. Based on these values, we designed a rectangular patch antenna with parasitic in around. We observed that the measured reflection coefficient of the three condition and see the similar results of the reflection coefficient, that is around -25 dB at 3.5 GHz frequency and the radiation diagram of the antennas reproduced the simulated one.

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AUTHOR CONTRIBUTION

NS and FF were simulated, and the antenna was fabricated. MA and UU study designed the proposed antenna. MA and UU prepared the manuscript and revised the final version of the paper. NS and FF have read the final manuscript and approved the submission. NS, FF, MA, and UU are the abbreviations of the First, Second, Third, and Fourth Authors respectively.

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