Analysis on the Effects of the Human Body on the Performance of Wearable Textile Antenna in Substrate Integrated Waveguide Technology

Mariam El gharbi
Abdelmalek Essaâdi University,
Faculty of Sciences,
Tetuan-Morocco.
elgharbimariam93@gmail.com

Saida Ahyoud
Abdelmalek Essaâdi University,
Faculty of Sciences,
Tetuan-Morocco.
sahyoud@uae.ac.ma

Noura Aknin
Abdelmalek Essaâdi University,
Faculty of Sciences,
Tetuan-Morocco.
noura.aknin@uae.ac.ma

Ignacio Gil
Universitat Politècnica de Catalunya,
Department of Electronic Engineering,
Terrassa-Spain.
ignasi.gil@upc.edu

Raúl Fernández-Garcia
Universitat Politècnica de Catalunya,
Department of Electronic Engineering,
Terrassa-Spain.
raul.fernandez-garcia@upc.edu

Abstract— **A wearable textile circular ring slot antenna based on a substrate integrated waveguide cavity is presented. In this paper, the focus is on studying and understanding the technical behavior of the SIW textile antenna when located near the human body. Thus, based on the electrical properties of conductive material and the dielectric characteristics of the Felt substrate, a 5.5GHz electro-textile antenna was designed. The proposed antennas are simulated in free space, while the performance of antenna is investigated for on-body condition. The simulated impedance bandwidths of the proposed antenna in free space and on phantom are 120MHz and 110MHz at 5.5GHz respectively. The efficiencies of the antenna at 5.5GHz are 95.8% in free space, and 91.6% on phantom, respectively, meanwhile the gains of that are 8.64dB and 9.35dB, respectively.**

Keywords— SIW (Substrate Integrated Waveguide); Cavity-backed antenna; wearable antenna; Human body model.

I. INTRODUCTION

Wearable antennas are highly in demand to support several wearable technologies due to the advantage of being flexible, lightweight and easily integrated with clothing[1]. Creating structures that conform to body shape contribute to the development of smart textile systems for wearable applications. In the field of wearable and flexible electronics, the substrate integrated waveguide (SIW) technology is suitable for application into wearable textile systems and clothing, as this topology ameliorate the isolation of the electromagnetic fields from its environment[2]. Therefore, SIW based cavity-backed designs are promising due to their low-profile construction, low insertion loss, simple fabrication and planar structure[3].

These advantages have been the focus of various studies on cavity-backed SIW textile antennas in recent years. A SIW textile antenna for dual-band MIMO applications was presented in [4]. In[5], a wearable textile antenna in SIW technology was reported. Furthermore, a solar harvester based on integrated dual-band textile antenna using SIW technology was demonstrated in [6], and a leather substrate SIW textile tri-band antenna was proposed in [7].

In this paper, detailed analysis was carried out by studying the SIW textile antenna characteristics based on phantom of human body parts through the reflection coefficient, radiation pattern, gain and efficiency. Antenna design and performance evaluation have been realized using CST Microwave Studio. The proposed antenna has the advantages of higher gain than [4]–[8], due to the circular ring slot and the SIW cavity feed structure.

II. ANTENNA DESIGN AND THE PHANTOM MODEL

A. SIW Cavity-Backed Design

A substrate integrated waveguide structure is designed in a single layered dielectric substrate by implanting metallic via-array which realize the lateral walls of the SIW[9]. In order to reduce leakage of electromagnetic energy from the gap between two adjacent vias, it is important to satisfy $P \leq 2D$, where D is the diameter of the vias, P is the separation between consecutive vias [10]. The structure of the SIW cavity can be equivalently analyzed by the classical rectangular waveguide cavity. In order to calculate the dimensions of the SIW cavity required to excite the TE101 dominant mode, the dimensions of the cavity should be determined based on the following relations[11]:

$$f_r(TE_{101}) = \frac{c}{2\sqrt{\varepsilon_r}} \sqrt{\left(\frac{1}{W_{eff}}\right)^2 + \left(\frac{1}{L_{eff}}\right)^2} \qquad (1)$$

Where ε_r, W_{eff} and L_{eff} are the relative permittivity and the effective width and length of the SIW cavity, respectively. The effective width and length of the SIW cavity can be approximated as follows[12]:

$$W_{eff} = W_{SIW} - \frac{D^2}{0.95\,P} \qquad (2)$$

$$L_{eff} = L_{SIW} - \frac{D^2}{0.95\,P} \qquad (3)$$

B. Antenna Topology

The geometry and design parameters of the SIW textile antenna is shown in Fig.1. There are two elements in the design of SIW textile antenna; conductive textile as the radiating element and non-conductive textile as the non-radiating (substrate) element. For the radiating element, consists of a top patch with a circular ring slot with a radius R and a bottom ground plane, these two conductors are connected by shorting vias. The felt textile material is chosen as the substrate due to its low dielectric constant (ε_r=1.2), loss tangent of 0.0013 and thickness of 0.7mm. The dimensions of the SIW cavity are determined to maintain the dominant resonant frequency around 5.5 GHz from equations (1) - (3) which are optimized under CST.
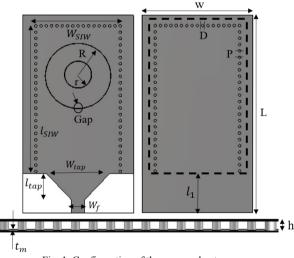

Fig. 1. Configuration of the proposed antenna.

TABLE I DIMENSIONS (MM) OF THE PROPOSED ANTENNA .

Parameter	W	P	R	W_{SIW}	W_{tap}	t_m	h
Value	42	2	12.5	30	22.1	0.035	0.7
Parameter	L	D	r	l_{SIW}	l_{tap}	W_f	l_1
Value	73	1	5	58	12	3.114	15

C. SIW Textile Antenna With The Phantom Model

The proposed antenna has been investigated for on-body conditions at 5.5GHz. SIW textile antenna should operate on the human body and be specifically placed at anybody locations such as the wrist, arm, leg or shoulder. For that reason, the effects must be investigated and analyzed. In order to understand the impact of on-body condition to a wearable SIW antenna, two situations (free space and with phantom) were simulated and studied in this article. The proposed antenna is placed on a three-layer tissue model to analyze the performance of antenna in biological environment while simulation. The model consists of skin, fat and muscle as shown in Fig.2. The dielectric properties of each tissue layer are listed in Table 2, the values of dielectric for tissue model are taken according to [3].
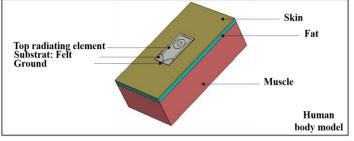

Fig.2. Proposed antenna with human tissue.

TABLE II PROPERTIES OF HUMAN TISSUES AT 5.5GHZ.

Tissues	Skin	Fat	Muscle
ε'	35.68	5.004	49.66
ε''	11.82	1.032	16.99
Thickness(mm)	3	7	60

III. RESULTS AND DISCUSSION

The reflection coefficients performance of the antenna in free space and on the phantom are illustrated in Fig.3. The resonant frequency shifted slightly to the left when the antenna was simulated in the presence of the human phantom. The simulated 10-dB reflection coefficient bandwidth of the antenna in free space was 120MHz ranging from 5.44GHz to 5.56GHz and on the phantom was 110MHz ranging from 5.40GHz to 5.51GHz.
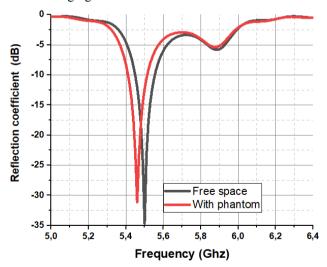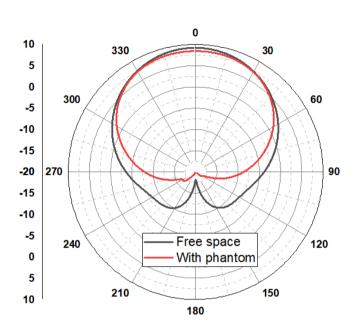

Fig.3. Simulated reflection coefficients of the antenna in free space and on human body equivalent phantom.

Fig.4 shows the radiation pattern of the SIW textile antenna for both cases in E-plane and H-plane, respectively. Based on the diagrams, slight deformation in radiation pattern was remarked which indicates that in terms of radiation behavior, the on-body condition did not give highly influence as compared to the free space environment. The performance of the proposed antenna appears to be in good conformity when in free space and with human phantom.
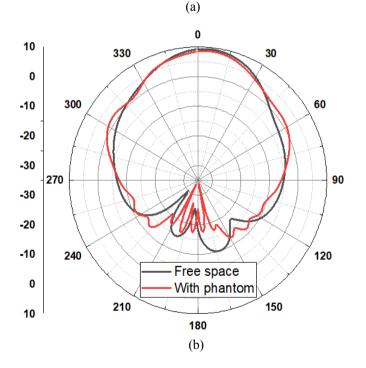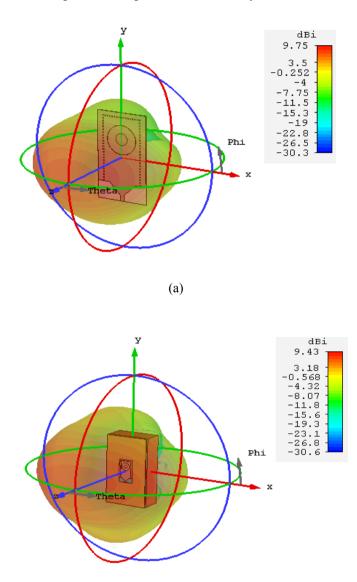
To analyze the directivity of the SIW textile antenna in free space and while mounted on the human tissue, Fig.5 represents the 3D directivity of the proposed antenna. The main direction of propagation is outward from the antenna which is good for using with the human body.

(a)

(a)

(b)

Fig. 5. 3D radiation pattern for the proposed antenna at 5.5GHz: (a) Free space, (b) with phantom.

Fig.6 presents the gain and efficiency of the proposed SIW textile antenna. It achieves up to an 95% efficiency in free space and up to a 90% efficiency when mounted on the phantom at 5.5 GHz, it also obtains more than an 8 dB gain in both cases.

A comparison between the specifications of the proposed SIW cavity-backed textile antenna and those of previous works can be seen in Table 3. As shown in the table, the proposed SIW textile antenna exhibits improvements in gain and efficiency.
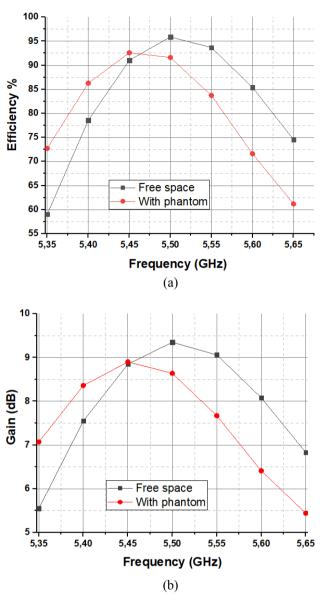
Fig.4. Simulated radiation pattern at 5.5GHz: (a) Electric field plane (E-Plane); (b) Magnetic field plane (H-Plane).

(a)

(b)

Fig. 6. (a) Efficiency, (b) Gain of the proposed antenna.

TABLE III COMPARISON OF RELATED WORKS IN THE LITERATURE.

Properties		Matching band (MHz)	BW (MHz)	Gain (dB)	Eff (%)
[13]	Free space	5725-5875	170	5.8	85.6
	With phantom	5725-5875	170	5.7	69
[14]	Free space	5150-5850	700	6	--
	With phantom	5110-5980	870	6.08	--
[4]	Free space	2367-2530	163	3.2	55
		5147-5863	716	5.8	61
	With phantom	2374-2535	161	2	50
		5154-5867	713	5.6	58
This Work	Free space	5440-5560	120	9.35	95
	With phantom	5400-5510	110	8.64	91

IV. CONCLUSION

In this paper, a wearable textile circular ring slot antenna based on a substrate integrated waveguide cavity is presented. The proposed antenna performance is studied both in free space and on the human tissue model. The SIW textile antenna exhibited higher gain and efficiency in both cases. In addition, this structure is light weight, flexible and low cost, thus making this antenna wellsuited for on-body use.

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