Flexible Wearable Antenna for Body Centric Wireless Communication in ISM Band

Afyf Amal[1*], Bellarbi Larbi[1], Sennouni M. Adel[1]
[1] CR-STIS laboratory
Higher National School of Technical Education
(ENSET/ENSIAS), Rabat, Morocco
afyfamal@gmail.com

Yaakoubi Nourdin[2]
[2]UMR CNRS 661 LAUM
Le Mans, France

Errachid Abdelhamid[3]
[3]Institute of Analytic Sciences
Lyon Univesity
Lyon, France

***Abstract*— Passive Microwave Imaging (PMI) has been widely studied for breast cancer detection in recent times. Sensing dielectric property differences of tissues over a wide frequency band has been made possible by ultra-wideband (UWB) techniques. In this paper, a flexible, compact monopole antenna on a Kapton polyimide is designed and fabricated, using a Computer Simulation Technology simulator (CST) and MEMS technology, to be in contact with biological breast tissues over the S-Band (2-4 GHz). The antenna parameters are optimized to obtain a good impedance match over the required frequency range. Operation of the antenna close to the human body necessitates adjusting its design for the intended applications whereas the maximum SAR value estimated in such conditions has to respect the standards. In this context, simulation tools that can take into account specific biological models offer a range of possibilities for investigating and optimizing the performance of Body-Centric Wireless Networks (BCWNs) devices.**
Keywords— Passive Microwave Imaging, ultra-wideband flexible antenna, Kapton Polymide, MEMS, S-Band , CST, SAR, Body-Centric Wireless Networks.

I. INTRODUCTION

Due to its direct and beneficial impact both economically and socially in various application domains, body-centric wireless networks (BCWNs) have recently gained substantial recognition and interest in both academic and industrial communities [1]. The ever increasing use of wireless devices in personal health care, entertainment, security and personal identification, fashion, and personalized communications, etc. drives research to establish more reliable and efficient link between the devices mounted on the body.

Body centric communications takes its place firmly within the sphere of wireless personal area networks (WPANs), wireless sensor networks (WSNs) and wireless body area networks (WBANs). The topic of BCWN can be divided into three main domains: on-body (communications within on-body networks and wearable systems), off-body (communications from off-body to an on-body device or system), and in-body (communications to medical implants and sensor networks) [2].

Low frequencies provide deeper penetration (less loss) but the higher frequencies offer better range resolution (smaller antenna). However, there is a practical limitation in the deep penetration, the performances of antenna and the operating frequency, a penetration of 30mm can obtained using a frequency around 3GHz (Table & Figure 1).

TABLE I. THE PENETRATION DEPTH OF TISSUES VERSUS FREQUENCY.

2-4 GHz	**σ (S/m)**	1.464	0.1045	0.3943	1.7388
	Penetration depth(mm)	22.57	117.02	22.33	45.77
	ε_r	35.11	4.954	48.48	9.674

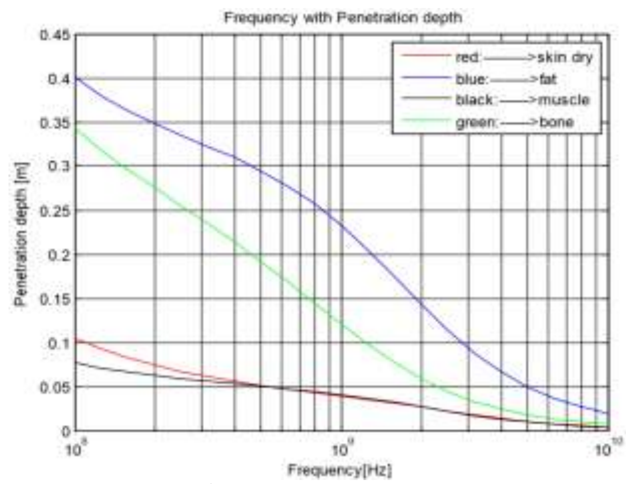

Fig. 1. The relation between frequency range(100MHz-10GHz) and penetration depth for the different tissues [3].

Antenna is the most important part in the field of wireless communication [4]. Due to growing technology, antenna requirement is also gaining heights. For this particular purpose, it has to be lightweight, low cost and small size [5].

II. ANTENNA DESIGN

A flexible CPW rectangular antenna (25X36X0.16 mm^3) with a Π- shaped slot in the medium of the radiator and two tuning stubs is designed. The extremely thin Kapton-substrate H_s used in the design makes the antenna suitable for being implemented or pasted on clothes. Fig.1 shows the geometry shape of the proposed antenna. The ungrounded antenna is etched on Kapton Polyimide substrate with a thickness of H_S and dielectric constant of 3.4. in order to maintain the flexibility of the antenna the excitation is made through a 50Ω CPW feed line. Then by using optimization solver in CST-MW Studio several optimization processes was applied until we got the desired performances of the antenna. Table below presents the optimized parameters of the developed antenna.

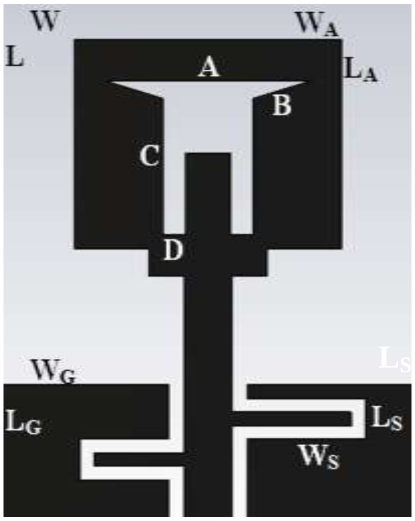

FIG. 2.The proposed flexible CPW antenna

The table below presents the various parameters of the antenna shown in the Fig.2.

TABLE II. PHYSICAL DIMENSIONS OF THE ANTENNA.

Parameters	Values (mm)	Parameters	Values (mm)
L	36	W	25
L_S	6	W_S	1
L_A	18	W_A	16
L_G	10	G	1
T_M	0.035	H_S	0.125
L_F	18	W_F	3.3
A	17	C	6
B	5.85	D	1.5

The antenna fabrication is carried out in the White Chamber of ENSIM, Le Mans University/ France. Measurements taken in the Anechoic Chamber of ESEO, Angers/ France are shown in the next section.


Fig. 3. Fabricated proposed antenna under measurement in Anechoic Chamber.

III. RESULTS AND DISCUSSION

This section mainly presents the major simulation and experimental results of the designed antenna. the optimum values of the antenna parameters were provides a good matching input impedance with a good return loss. From Figure 4 it is seen that the proposed antenna has a good impedance matching with a return loss of about -32dB at the operating frequency of 3.5 GHz. Then a comparison between the measured return loss and the simulated one is presented in Figure 4 It is quite clear that there is a good agreement between the measured and the simulated return loss of the proposed antenna which has been achieved from 3.23GHz to 3.75GHz with an impedance bandwidth of about 570MHz. Then the measured return loss has been achieved from less 2 GHz to about 4.1GHz with an impedance bandwidth of about 2GHz. This is 350.87% improvement over the simulation bandwidth prediction. The obtained result indicates that the transmitter and antenna are well matched and a maximum possible amount of energy is absorbed at the input terminal with a minimum reflected power.

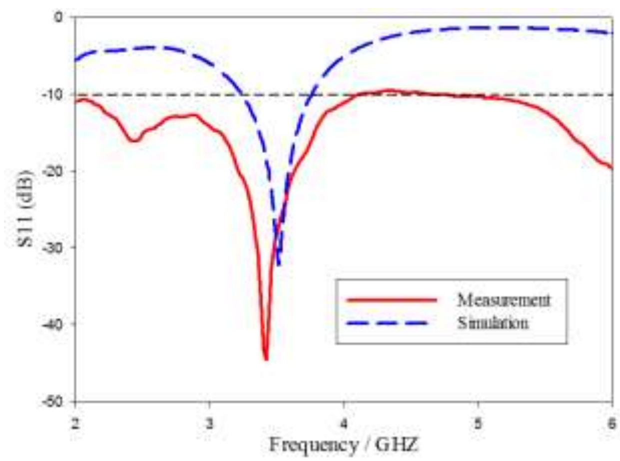

Fig. 4. Simulated & measured result.

IV. INHOMOGENEOUS BREAST MODELING

A miniature antenna in contact with biological tissues will have very different propagation behavior than one in free space [6]. The antennas must be designed taking into account the impact of the proximity to biological tissues. The multiple biological tissues in breast cancer detection have varying conductivity and dielectric constants leading to complex RF interaction [7]–[9].The breast as a communication media is modeled by several biological tissues and each biological tissue is defined as a dispersive dielectric in a homogeneous medium using three electrical parameters: relative permittivity, loss tangent and mass density. By stacking several homogeneous layers, the inhomogeneous environment is modeled with the CST-MWS. The multi-layer model that is used to design the breast phantom using CST-MWS and includes skin, fat, gland, and muscle, is shown in figure 4. The frequency dependent relative permittivity and loss tangent are plotted in figure 5 & 6 [10] for the entire S band. The loss tangent quantifies inherent dielectric dissipation when interacting with an electromagnetic wave. The mass density, i.e., the mass of each tissue per volume unit, is reported in [7] for different breast tissues; this parameter is needed for calculation of SAR.

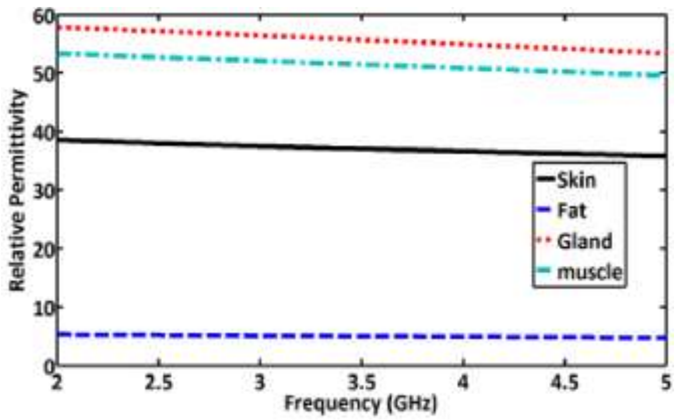

Fig. 5. Relative permittivity of different tissues in the breast.

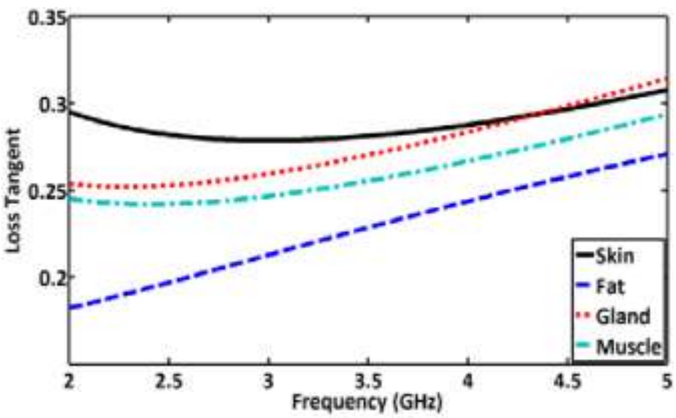

Fig. 6. Loss tangent of different tissues in the breast

The simulated geometrical parameters of the breast model are presented in Table III.

TABLE III. BREAST PHANTOM PROPERITIES FOR 3.5 GHz [11].

Phantom parts	ε_r	Rho (Kg/m^3)	Elect. cond. (S/m)	Thick. (mm)
Skin	37	1109	2.02	1.7
Fat	49.4	911	2.2	1.4
Gland	55.7	1041	2.93	7
Muscle	51.4	1090	2.56	5

The proposed antenna is designed to operate in contact with stacked layers of biological tissues in a detection system, to avoid power reflections (between tissues) caused by inhomogeneities in the breast media, should be designed with an inhomogeneous model to capture all phenomena during the design process. In this way, the antenna can provide as much energy as possible in order to receive transmitted signals with reasonable strengths from breast tissues. Using CST-MWS the breast phantom is designed (Figure 7), taking into account the characteristics cited in Table III.

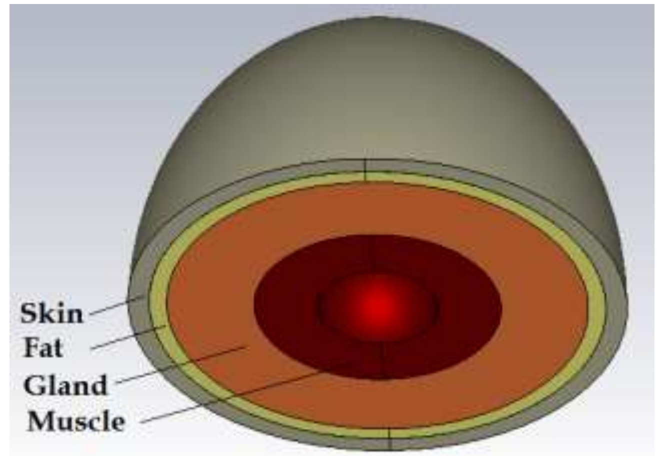

Fig. 7. Multi-layer inhomogeneous model of the breast.

The bended flexible antenna on the designed breast phantom is shown in figure 8.

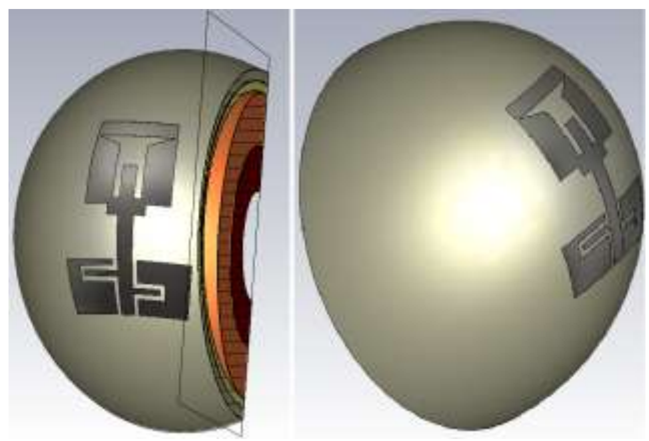

Fig. 8. The flexible antenna bended on the breast phantom.

V. SIMULATION RESULTS

A. S-Parameters

The simulation result for reflection coefficient (S11) is shown in figure 9. The reflection coefficient is below -10 dB from 3.2 GHz to 6 GHz for each position. As is shown from results, the flexible antenna is not sensitive to bending.

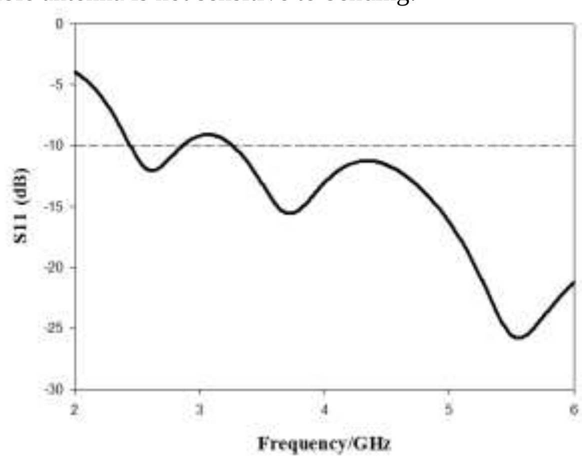

Fig. 9. S11 of the bended structure.

B. Specific Absorption Rate (SAR)

The investigations of the specific absorption rate SAR are recommended by regulatory organizations such as FCC for evaluating the RF exposure level [12] . SAR [W/kg] can be defined with the tissue density ρ [kg/m^3] and tissue conductivity σ [S/m] as [16].

$$SAR = |E^2|\, \rho / \sigma$$

The SAR of the proposed flexible antenna in the skin and fatty tissue of the breast is represented; The SAR value refers to power averaged over 10 g of tissue. Results are shown in figures 8 & 9; It is visible that the current SAR values over the skin and fatty tissue are lower. This study shows the proposed antenna can be used to effectively detect tumor inside breasts.

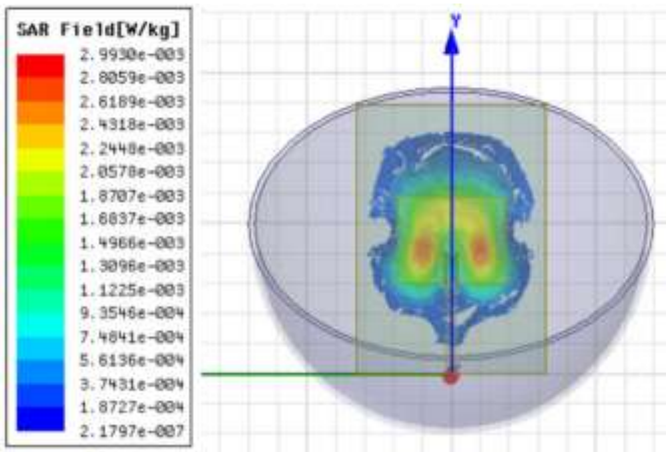

Fig. 9. SAR distribution on fatty tissue of breast phantom.

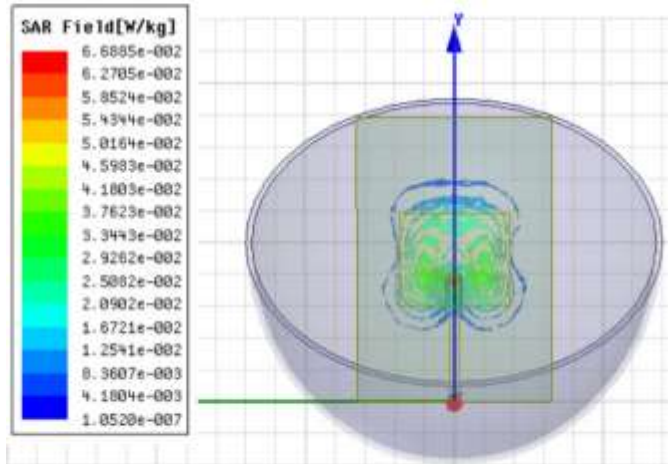

Fig. 8. SAR distribution on skin tissue of breast phantom.

VI. CONCLUSION

In this paper, a wearable flexible single polarization antenna for breast cancer detection has been presented. The new structure improves on previous passive microwave imaging systems in that it is highly flexible, cost-effective to fabricate, and light-weight. Simulations were carried out with CST, exploiting a layered (inhomogeneous) model with different dielectric constants and loss tangents to capture the effect of surrounding tissues.

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