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RESEARCH ARTICLE

Microwave Imaging for Breast Tumor Detection Using a CPW Antenna

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Abstract

Objectives: This work is devoted to the study and design of a small and flexible CPW patch antenna (26x30x0.64) mm^3 for microwave tumor detection. **Methods :** The suggested flexible CPW antenna for breast cancer detection is made with a Rogers RO 3010 substrate (0.64 mm thickness). The simulation was carried out using HFSS software and the experimental validation was done with liquid phantoms which have the same EM characteristics of breast and tumor. Two tumor phantoms of different sizes, 8 and 15 mm, were tested. Two scenarios for breast cancer detection are proposed. In the first scenario, the proposed CPW antenna is used only as a receiver of the RF signal traveling through the breast. In the second scenario, two CPW antennas are used, one as a transmitter and the other as a receiver. **Findings:** Both the simulation and experimental results in free space of the antenna performance show that the resonance frequency of the proposed antenna is around 4.5 GHz and there is a good agreement between the simulated and experimental results. In addition, the proposed antenna has a gain of 2 dB at the desired frequency. The achieved radiation efficiency of the antenna is 86%. The comparative study of the transmission coefficient (S_{12}) in the two scenarios yielded almost the same results, and the tumor detection was demonstrated at the frequency of 2.95 GHz with both tumor sizes (without tumors: S_{12} =-43.72 dB; with tumors: S_{12} =-55.36dB for the 15 mm tumor and S_{12} =-48.36 dB for the 8 mm one). **Novelty:** The proposed CPW antenna is useful as a sensor for tumor detection because of its relatively high radiation efficiency, flexible and small size.

Keywords: Microwave imaging; breast cancer detection; tumor; CPW antenna; Phantom

1 Introduction

Breast cancer is the most common type of cancer in women all over the world[1,2]. Nearly 1.7 million new cases are diagnosed each year in Asian/Pacific Islander[3]. Regular screening is of paramount importance for early diagnosis to reduce incidence and improve the results for the patient. In 2018, the death rate in women from breast cancer increased with around 92,700 deaths in Europe, hence the need to improve and develop new medical diagnostic techniques for early breast cancer detection[4].

Microwave imaging has become a very important research subject for tumor cell detection [5], given that it is inexpensive and uses non-ionizing radiation. The antenna is one of the most important components in a microwave imaging system [6]. Many antennas have been designed for early disease detection testing, such as a Vivaldi antenna [7], a horn antenna [8], a microstrip antenna [9], and a CPW antenna [10]. In [11] the authors presented a microstrip antenna with low cost and UWB frequencies (3.4-17.26 GHz) used for early breast cancer detection, but this antenna is not flexible and has a low Q factor. In [12], a UWB MIMO antenna with a textile substrate for tumor cell detection is proposed using the X-band at 10.2 GHz. This antenna has large dimensions of (44.33*37.5) mm^2. Also, in [13], an UWB Vivaldi antenna is proposed (51*42) mm^2. In [14], the authors presented an antenna array with sixteen antennas and frequency between 4 and 9 GHz for breast cancer detection. However, the problem of this antenna is its 3D design, which can become uncomfortable for patients. In [15], the authors presented a Hilbert Fractal Antenna (HFA) for breast tumor detection (60*60*30) mm^3. This antenna has low return loss less than 14dB. According to those literature studies, it can be said that the proposed CPW patch antenna is a good candidate for microwave breast cells detection, as it was designed to operate at 4.5 GHz, it has a good gain, small size (26*30*0.64) mm^3, it is based on a simple and planar model, it is able to transmit a wide range of frequencies with higher efficiency, and it can operate at both low and high frequencies. The proposed antenna provides an adequate penetration of human tissues and directive radiation of power.

In this paper, the design and fabrication of a new CPW antenna for tumor cell detection are presented. A miniaturized, planar CPW antenna with adequate frequency band and operating at 4.5 GHz is proposed. The results indicate that it can be a good candidate in microwave thermography for breast cancer detection. The presented paper is divided as follows: section II shows the microwave imaging system; section III shows the proposed breast phantom, its parameters and its modeling; section IV presents the fabrication of the proposed breast phantom; section V describes the design of the proposed CPW antenna and the simulation results. Finally, the experimental results are discussed in Section VI.

2 Microwave imaging system

Microwave imaging is an advantageous technique for breast cancer detection, firstly because of its low cost, and secondly because it is easy to apply and it uses non-ionizing radiation. Figure 1 shows the different components of the proposed microwave imaging system. This system detects the difference in transmission signal S_{12} between normal breasts and breasts with tumors. For this, four antennas are used, one of which is used as a transmitter and the other is used as a receiver. The proposed IoT system is divided into three parts. The first part is dedicated to the design of the antenna array. The second part is the data collection process, which is controlled by a chip system with a Bluetooth module and transmits the data to the cloud. Finally, results such as tumor location and size will be displayed on the smartphone.

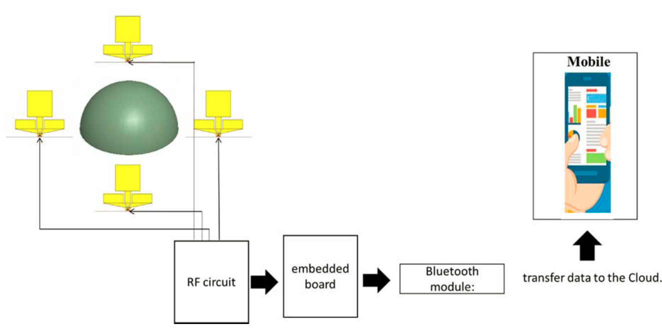


Fig 1. Proposed IOT system for breast cancerdiagnostic.

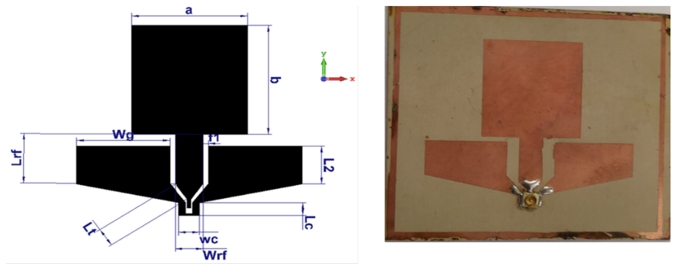
3 The proposed CPW antenna for Breast cancer detection

The purpose of this work is to produce a flexible planar antenna that is reliable and easy to place on the breast. This part is dedicated to the design of the proposed antenna.

3.1 Antenna design

Figure 2 shows the structure of the proposed CPW antenna, which is a rectangular patch radiating element. This antenna is adapted to 50 Ω at 4.5 GHz. It is composed of a copper conductor with a thickness of 17.5 μm and is mounted on a Rogers RO

3010 substrate with a thickness of 0.64 mm and relative permittivity



(a) (b)

Fig 2. (a)The geometry parameters of proposed CPW antenna, (b) Fabricated CPW antenna.

In order to summarize the antenna dimensions, Table 1 gives all the geometric parameters.

Table 1. Geometrical parameters of the proposed antenna in mm.

symbol	a	b	f1	Wg	L2	Lrf	Lt	Lc	wc	Wrf
Size (mm)	13	14	0.8	13.65	1.25	2.25	3.02	2.1	3	4.1

Geometrical parameters of the proposed antenna in mm.

Comparative study between the simulation and experimental results of the proposed antenna in free space.

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The feed CPW line is calculated using the equation (1), where K represents the elliptic integral coefficients, k and k1 are computed according to the line dimensions, and

3.2 Simulation and experimental antenna results in free space

Figure 3 shows the simulated and the measured reflection coefficients of the CPW antenna. The simulation results indicate that a good input impedance matching is achieved. The simulated return loss is equal to -30 dB at the resonance frequency of 4.53 GHz. Furthermore, as shown in this figure, the antenna provides a bandwidth between [3.4, 5.7] GHz. The measured return loss is -20 dB at the resonance frequency 4.48 GHz with bandwidth equal to [4.3, 4.8] GHz.

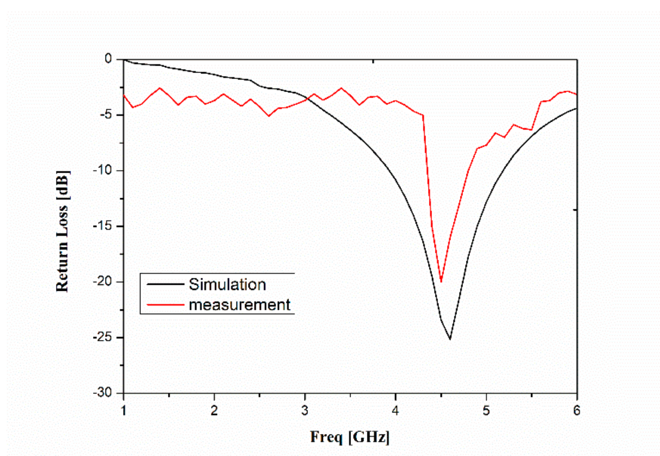

Fig 3. Return loss results of the proposed CPW antenna.

As shown in Figure 4, the simulated gain of the antenna is 2.25 dB (a) and the directivity is 2.53 dBi (b) at 4.5 GHz. The efficiency of the developed antenna is 97 %.

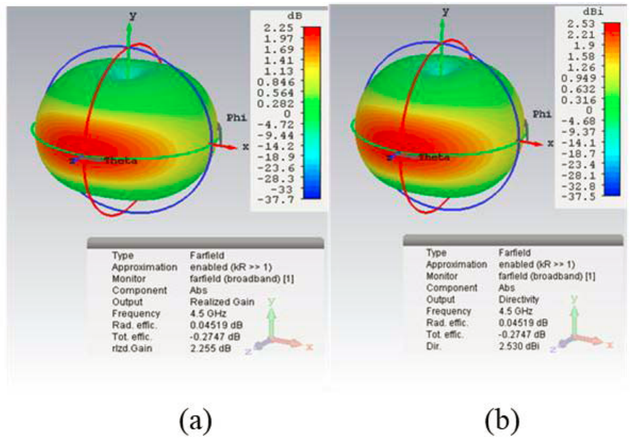

Fig 4. 3D view of the radiation patterns at 4.5 GHz

Figure 5 presents the radiation patterns of the antenna at 4.5 GHz. The results indicate that the antenna provides a directional radiation diagram in E-plane (phi=90°) and an omnidirectional radiation diagram in H-plane (phi=0°).

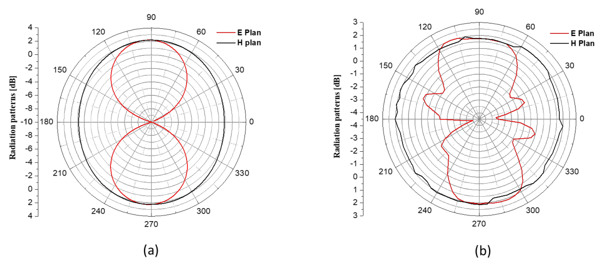

Fig 5. Simulated (a) and measured (b) radiation patterns in the E-plane (phi = 90°) and H‑plane (phi = 0°) at 4.5 GHz

Table 2 represent a comparative study between the simulation and experimental results.

Table 2. Comparative study between the simulation and experimental results of the proposed antenna in free space.

	Simulation	Experimental
fr [GHz]	4.53	4.48
S11 [dB]	-30	-20
[Fmin-Fmax] [GHz]	3.7-5.7	4.3-4.8
Gain [dB] at 4.5 GHz	2.25	2

4 Experimental validation of the tumor detection

Figure 6a presents the liquid breast phantom and Figure 6b and c presents, the liquid tumor phantom with 2 different sizes (respectively 15 mm and 8 mm). All the phantoms retain the same characteristics as the actual parameters which are found in [16]. The breast phantom was placed inside the top of a water bottle due to its shape and the fact that the plastic is thin enough to be transparent to microwaves. The tumor phantom is placed inside two thin rubber containers, which are also invisible to the RF signals. Two scenarios for tumor detection are presented in Figure 7.

4.1 Test 1: horn antenna transmitter and CPW antenna receiver

The first scenario is shown in Figure 7a when the proposed CPW antenna is used as a receiver and the horn antenna is used as a transmitter. The measurement results presented in Figure 9 show the difference between the various scenarios without tumor

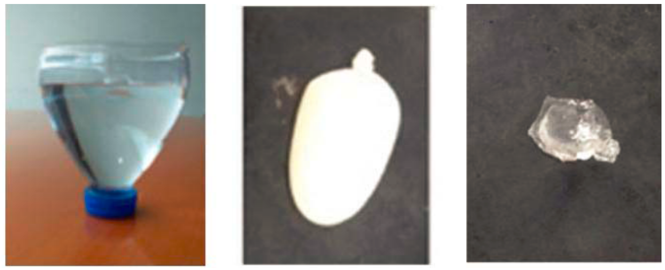

Fig 6. The phantom of (a) the breast (b) the tumor size 15 mm (c) the tumor size 8 mm

and with two tumor sizes respectively in terms of the Return Loss (Figure 8a) and the Insertion Loss (Figure 8b). As it can be seen, the most significant difference in S_{12} was registered in the frequency band [2.5, 3.3 GHz] at 2.9 GHz, and it demonstrates that it is possible to detect the presence of the tumor in this setup. Indeed, when the tumor size is 8 mm the transmission loss is -49.4 dB at 2.9 GHz, when it is 15 mm the transmission loss is -54.8 dB at 2.9 GHz and without tumor, it is equal to -43.8 dB at 2.9 GHz.

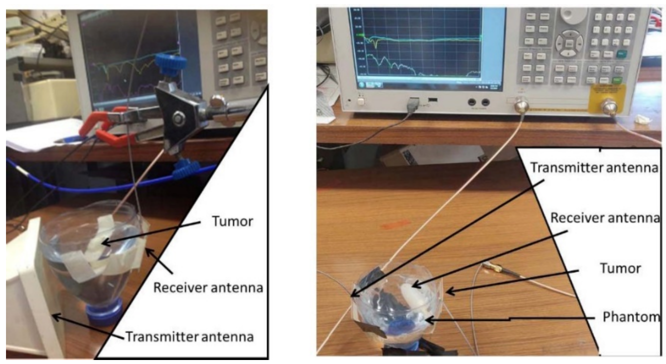

Fig 7. The measuring bench for tumor detection: (a) horn antenna for transmission and CPW antenna for reception and (b) two CPW antennas as transmitter and receiver.

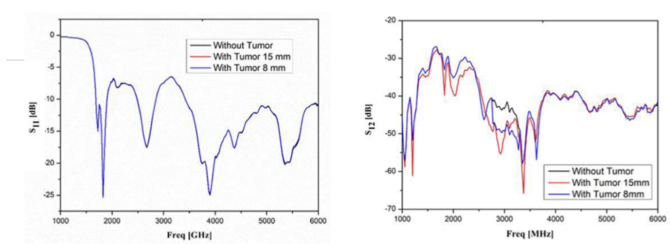

Fig 8. Experimental results of the Transmission loss without tumor and with 2 tumor sizes (test 1)

4.2 Test 2: Two CPW antennas, one transmitter and one receiver

In the second scenario, which is shown in Figure 7 (b), the two CPW antennas were used: one as a transmitter and the other as a receiver.

Figure 9 shows the results of the second scenario: figure 9.a and 9.b present respectively the magnitude of S_{11} and S_{12}. It is noticed that, similar results were obtained in this scenario and the first one. Due to this, it can be concluded that the proposed CPW antenna can function both as a receiver and transmitter in the breast cancer detection networks. An increase in transmission loss is noticeable, and it is explained due to the presence of the tumor. In addition, when the tumor size increases the transmission loss increases too. Indeed, when the tumor size is 8 mm the transmission loss is -46.7 dB at 2.9 GHz and when

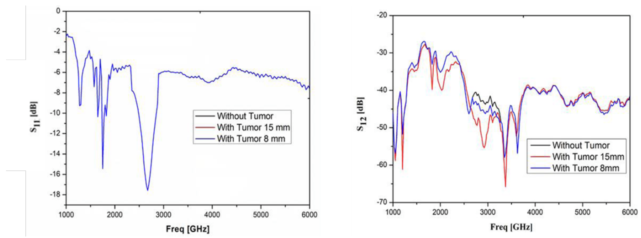

Fig 9. Experimental results of the Transmission loss without tumor and with 2 tumor sizes (test 2)

it's 15 mm the transmission loss is -56 dB at 2.9 GHz.

Table 3 presents a comparative study of the proposed CPW antenna with some published results. To demonstrate the performance of the proposed CPW antenna, the following table summarizes the advantages of the CPW patch antenna comparing to some antennas in the literature.It can be seen that the proposed CPW antenna presents a small size (32x32) mm^2, which is very important to develop an antenna array for good and precise tumor cell detection, a good return loss of 20 dB and a higher quality factor. An antenna with a high-quality factor radiates very effectively at the radiation frequency over a very narrow frequency band, which can limit out- of- interference band. However, if the bandwidth is too narrow, any signal sent or received near the limits of the operating frequency band will be attenuated. An antenna with a low-quality factor is wide band but collects the noise present on the operating band, thus degrading the quality of the received signal. Also, the proposed antenna is easy to fabricate and has a flexible structure. The direction of radiation is perpendicular versus the patch antenna; this configuration increases the ease of the antenna positioning on the breast and allows good tumor cell detection. These results indicate that the proposed antenna is a good candidate to develop an antenna array for early microwave breast cancer detection.

Table 3. Comparative study between the simulation and experimental results of the proposed antenna in free space

	Types of antenna	[F_{min}, F_{max}] [GHz]	RL (dB)	Quality factor: Q	Gain [dB]	Size [mm]	Complexity	Direction of radiation versus the patch	Flexibility
(12) 2020	Microstrip antenna	[9.8,10.6]	28.7	12.75	6	44.33 x 37.5	++		++
(14) 2009	3D antenna	(5,7) [8.4,10]	17 22	3 5.75		23 x 29 x 17	++		–
(17) 2018	Vivaldi antenna	(3,11)	25	0.875	7	40 x 40	+-		–
(18) 2018	Microstrip antenna	[1.6,11.2]	21	0.67		70 x 60	++		++
(19) 2016	Vivaldi antenna	[0.8,1.2] [2.1,2.5]	14 13	2.5 5.75		32.4 x 13.5 Box: 60 x 60 x 30	++		-
(20) 2021	Spiral antenna	[3.5,4]	40	7.5		43 x 44 x 1.6	++		-
(21) 2021	Dielectric resonator antenna	[4.3,12.6]	32	1.01	6	20 x 15 x 5.6	++		–
This paper	CPW antenna	[4.3,4.8]	20	9.1	2	32 x 32	–		++

5 Conclusion

In this work, a new CPW antenna for microwave breast tumor detection was presented. It has a planar structure, a small size of $26x32mm^2$, and it is flexible, low cost, light weight, low profile and easy to fabricate. Considering the performance of the proposed antenna, it can be concluded that it is a good candidate for early breast cancer detection.

The simulation and experimental results show that the proposed antenna achieves a good return loss, sufficient gain and efficiency. The experimental results lead to the conclusion that the proposed antenna can be used for microwave detection of a tumor inside a breast phantom, as the transmission loss between the two antennas placed on opposite sides of the breast phantom resulted in a difference between the cases where there were two different tumor sizes present (respectively -46.7 dB and -56 dB at 2.9 GHz) and where there was no tumor (-43 dB at 2.9 GHz). To have a very precise resolution in the microwave imaging, it is necessary to have an antenna network.

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