Breast cancer detection feasibility with UWB flexible antennas on wearable monitoring vest

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***Abstract*—This paper presents a study on a monitoring vest embedded with multiple flexible ultrawideband (UWB) antenna elements used for detection of possible breast cancer tissue. The cancer detection is based on identifying differences in the UWB radio channel characteristics between several on-body antennas located around the breast. The antennas are small-sized, made of flexible material, operating at whole UWB band as well as in the ISM 2.4 GHz band, thus can be used in portable telemedicine applications. Additionally, the paper presents realistic simulation results on the impact of the cancer tissue on the signal propagation and channel characteristics at different frequency ranges using an anatomical voxel model. The simulations are carried out using electromagnetic simulation software CST Studio Suite, including power flow analysis and radio channel evaluations. The results show that, such as, tumor of size 1 cm causes a clear difference in a signal propagation through a breast tissue, which can be seen in a power flow variation in the vicinity of the cancerous area. This can be also seen both in frequency and time domain channel characteristics between different on-body antennas. The promising results show that flexible UWB antenna vest could be developed for self-monitoring of breast health and initial detection of breast cancers.**

Keywords—breast cancer detection, microwaves, self-monitoring, telemedicine, ultrawideband, wireless body area networks.

I. INTRODUCTION

Breast cancers are the most common women cancers causing more than 90 000 deaths in EU every year [1], [2]. Regular population-based screening decreases significantly mortality. If the malignment tumors can be found in early phase it improves prospects of the cure of the patient [3], [4].

Digital mammography, and in some cases additional ultrasound examination, are the most commonly used screening methods. Mammography devices are large and expensive and thus, can not be found in healthcare center but only in hospitals. According to European Commission Initiative on Breast Cancer (ECIBC), the recommended screening interval for women above 50 years is 2 or 3 years while many EU countries are following 2-year interval [3]. Although this 2-year regular screening has decreased breast cancer mortality evidently, the mortality could be further decreased by more frequent checks. However, only 43% of the invited women participate in these regular screenings [3]. The reasons for non-participation in mammographic screening may be distance, beliefs, fear of cancer, negative experiences regarding healthcare or encounters with the staff, pain during the procedure [5], [6]. However, aggressive breast cancer may appear and grow fatally rapidly in short time and thus, frequent regular breast health checks are necessary, especially for women with increased breast cancer risk.

In addition to these above-mentioned reasons for non-participation, pandemic situations may occasionally limit the possibilities for timely examinations in hospitals. Thus, it is important to develop methods for breast cancer detection that would be accessible in smaller healthcare centers or even suitable for home-monitoring.

Microwave based breast cancer detection techniques and imaging methods have been studied intensively in recent years [7]-[16]. Several solutions have been proposed using different antennas operating in selected frequency bands. Besides, there are few different techniques to construct images from the breast tissue, such as microwave tomography and ultrawideband (UWB) radar. Some of the microwave breast screening methods have been patented [12]-[13] and achieved clinical trial stage [14]-[16]. However, all of these solutions are of large size and targeted for hospital use.

Recently, there has arisen interest on developing self-monitoring devices for microwave -based breast cancer detection [17]. These kind of easily-accessible devices could reach better also those women who usually refuse from participation on invited regular screening, for instance due to the distance and fear of the pain in mammography. Besides, self-monitoring vest would enable women to check their breast health more often than every second year in regular checks which facilitates the timely detection of rapidly spreading and growing aggressive cancers. The published idea [17] has generated new approaches, such as portable device to be used in the ambulance [18]. Besides, some flexible antennas have been designed aiming for breast tumor detection [19]-[20].

However, the previous studies have not presented research results using multiple flexible UWB antennas embedded in the self-monitoring vest nor evaluated the impact of the cancer tissue on channel characteristics using an anatomically realistic voxel model. Besides, up to author's knowledge, other studies do not illustrate impact of the cancer tissue on the signal propagation using power flow visualization.

This study proposes using wearable, flexible small-sized antennas [21] on the breast cancer self-monitoring vest. The antennas operate at the standardized UWB band as well and in the ISM band 2.4 GHz. The usability of these antennas for the detection of breast cancer is evaluated by simulations using electromagnetic simulation software Dassault Simulia CST Studio Suite [22] with an anatomical voxel model. In addition, the second aim of this paper is to show how the use of flexible UWB antennas are suitable for detecting changes that cancer tissue causes in the channel responses. Moreover, the aim is to show with power flow analysis, how even small cancerous tissue changes signal propagation at different frequencies.

The paper is organized as follows: Section II describes the idea of self-monitoring vest for breast cancer detection. Section III presents the study case including description of simulation model and antenna model. Section IV presents simulation results including A. power flow evaluations, and B. Radio channel evaluations. Finally, Section V gives Conclusions and future work.

II. BREAST MONITORING VEST

This section describes the generic idea of the vest which could be used for independent breast health check for instance in health care centers or even as home monitoring device. The monitoring vest is based on detecting differences caused by cancerous tissues in the UWB radio channel characteristics between several on-body antennas embedded in the vest.

The basic idea of the functionality of the vest is divided in the following:

1. As the vest is turned on, the antenna reflection coefficients are measured and verified with the reference data set to check that vest is properly set on. If some of the reflection coefficients are out of reference range (which includes typical moderate variation due to the differences in body constitutions), the device advices to adjust the vest properly.
2. The channel parameters are measured between the different transmitter receiver antenna combinations.
3. The channel data is further transmitted to the terminal device which then further transfers the data for cloud servers for analysis or image construction.
4. Data analysis is performed using massive reference data set and artificial intelligence (AI). Massive reference data set is required to distract natural variations in the channel responses - such as variation due to the individual breast tissue constitutions – from the variation due to the presence of cancerous tissues. Besides, all the user's previous measurements results are gathered in the reference data set and they will be used as main reference in the measurements.
5. The simpler versions of this device only produce information whether some abnormalities can be detected from the channel data. The data analysis can be based on several different algorithms, e.g. described in [7]. The algorithm selection is out of the scope of this paper.
6. The more sophisticated version of this device produces an image based on the measured responses, as described e.g. in [11]. The selection of the image construction algorithm is out of the scope of this paper.
7. The results of the analysis are sent to the client immediately. Besides, the results are stored in the clients' health register which is also visible for health care personal. If the device detects abnormalities in the breast tissues, the patient is advised to contact clinicians for further examinations.

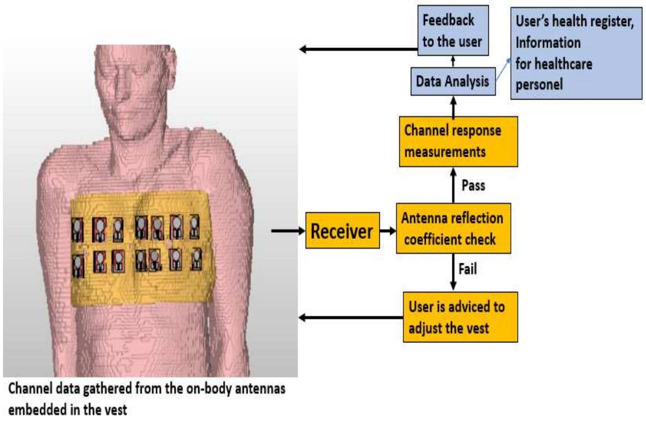


Fig. 1. A generic description of the basic steps self-monitoring vest equipped with several flexible on-body antennas.

III. STUDY CASE

A. Antenna model

This study proposes the use of the wearable and flexible antenna which is recently published in [21] for in-body and on-body communications. The antenna is illustrated in Fig. 2 and its dimensions are shown in Table I. The antenna has been designed to operate in the whole UWB band 3.1- 10.6 GHz as well as in the ISM band 2.45 GHz and thus, it meets the requirements for Wireless Body Area Network (WBAN) standard 802.15.6 [23]. The antenna has been designed to operate when tightly attached on the skin. Due to its flexible material, it is suitable to be used as a monitoring vest. More details of the antenna properties can be found in [21].

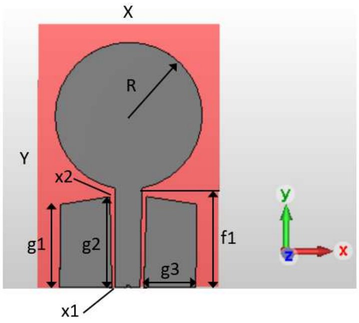


Fig. 2. Wearable flexible antenna.

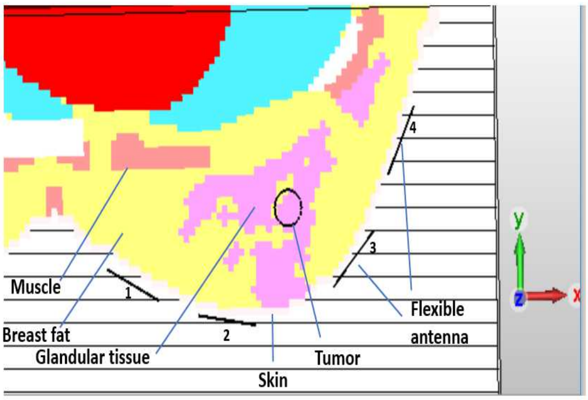
TABLE I. DIMENSIONS OF THE FLEXIBLE ANTENNA STRUCTURE

Parameter	X	Y	R	f1	g1	g2	g3	x1	x2
Dimension [mm]	20	30	8.1	11	9.1	10	5.7	0.4	0.6

B. *Simulation model*

The simulations are carried out using electromagnetic simulation software Dassault Simulia CST Studio Suite [22] which is based on Finite Integration Technique (FIT). An anatomical voxel model Laura, which is presented in Fig. 1 with the vest sketch, was chosen for the evaluations. Laura corresponds to a lean female body with resolution of 1.88 mm x 1.88 mm x 1.25 mm.

Fig. 3a presents the cross-section of the voxel model's breast area depicting corresponding tissues. Tumor locations A and B, presented in Figs 3a-b, respectively, are inside the glandular tissue where usually breast cancers start to grow. Additionally, Fig. 3b illustrates the locations in which power flow values are evaluated in Section III. The selected tumor locations are chosen to resemble among the most challenging tumor locations in the glandular tissue areas in terms of reachability of microwave signal multiple on-body antennas. Location A is in the middle of the breast area with propagation depth 3.5 cm to the closest on-body antenna (antenna 3). Location B is in the outer corner of the breast area with limited reachability of several on-body antennas. The distance between the tumor and the closest on-body antenna (4) is 2.5 cm. Relative permittivity of the breast tissues and cancerous tissue are presented at different UWB frequencies in Table II [19]. Additionally, the difference between the relative permittivities of glandular tissue and cancerous tissue are depicted as well. As one can note, the difference increases with the frequency.



a)

b)

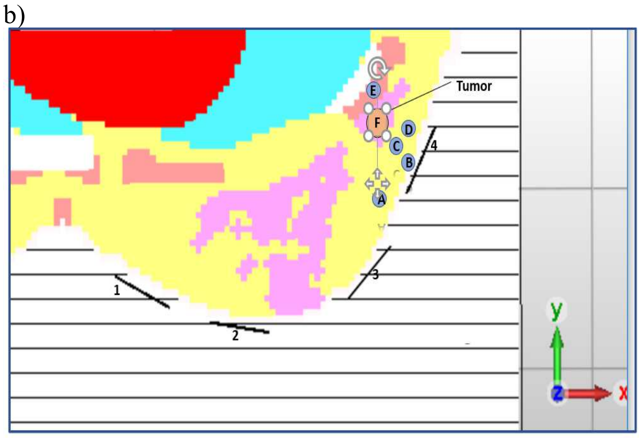


Fig. 3. a) Cross-section of Laura voxel model in the tumor location A, b) Cross-section of Laura voxel model in the tumor location B describing also points where power flow values are evaluated.

TABLE II. RELATIVE PERMITTIVITY OF THE CANCER TISSUE AND BREAST TISSUE.

Tissue	**Frequency**			
	2 GHz	**4 GHz**	**6 GHz**	**8 GHz**
Breast Fat	5.33	5.12	4.84	4.46
Glandular tissue	58.1	54.9	51.7	48.4
Breast Cancer	63.0	59.1	56.6	55.4
Difference between glandular tissue and cancer tissue	4.9	4.2	4.9	7

IV. POWER FLOW EVALUATIONS

In this section, in-body propagation from the flexible antenna is studied using the notion of power flow [24]. Power flow is the time-averaged magnitude of the Poynting vector [24]. The Poynting vector represents the directional energy flux (the energy transfer per unit area per unit time) of an electromagnetic field. The flux of the Poynting Vector through a certain surface represents the total electromagnetic power flowing through it. Here, the power flow values (expressed as decibels) have been normalized so that 0 dB is the maximum, i.e., the value at the transmitting antenna.

A. *Power flow evaluations at tumor location B*

In this subsection, the power flow is studied in the tumor location B. Arrow-based power flow representation at 7 GHz is illustrated in the presence and absence of tumor in Fig. 4a-b, respectively. Power flow values in the vicinity of the cancer tissue are examined in the points A-F depicted in Fig. 3b.

Power flow evaluations show that the cancerous tissue clearly changes the signal propagation compared to the reference case. Since the relative permittivity of the cancerous tissue is higher than the glandular tissue, the signal is diffracted clearly as it reaches the cancerous tissue edge. This can be noted both in power flow representation as well in the power flow values presented in Table III, which provides values for cancerous and reference model as well as power flow difference between the cancerous and reference model.

The power flow values at the location A are same both for cancer and reference cases since it is located enough far away from the cancer. Instead in the locations B-E it can be noted that the power flow values in the cancer case is 2-8 dB higher compared to the reference case, since the average power around the cancerous tissue increases due to the reflected signals. However, the instant power inside the cancerous tissue is 4 dB lower than in the same location without the cancerous tissue, which is obvious due to changes in signal direction in the presence of cancerous tissue.

For the comparison, power flow comparison between the cancerous tissue and reference models are included in Table III. As one can note, the tendency is similar at 8 dB except the differences are even larger up to 20 dB deep inside the breast tissue. Also close to the breast surface, we can observe even 9 dB difference. Instead, at 3 dB, the differences are remarkably more moderate 0.5-3 dB. These results were expected since the wavelength in the tissues decreases with the frequency and hence the use of higher frequencies may improve the detectability of small tumors. Besides, as it was noted from Table II, the difference between the relative permittivity of tumor tissue and glandular tissue increases at higher frequencies which also improves the detectability of tumor tissue.

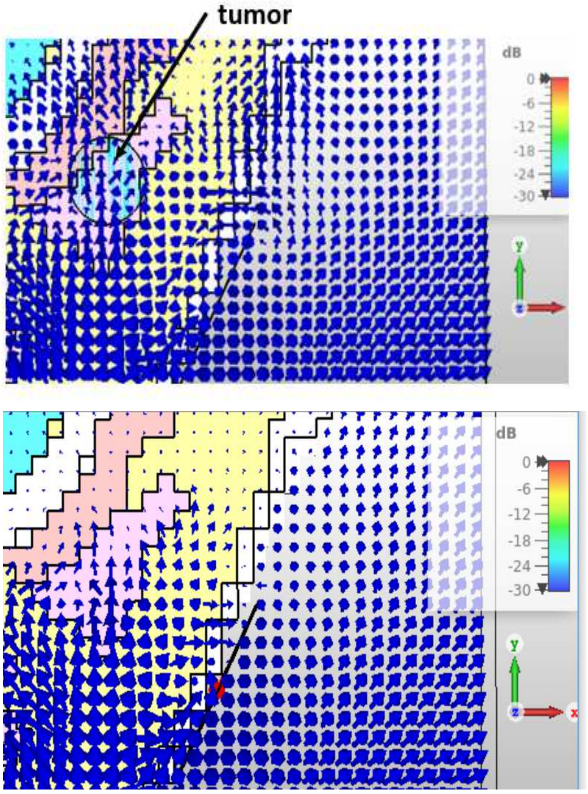


Fig. 4. Power flow representation at 7 GHz at tumor location B (a) and in the reference case (b).

TABLE III. POWER FLOW VALUES AT 7, 8, AND 3 GHZ IN THE LOCATIONS A-F FOR THE CANCER AND THE REFERENCE CASES.

Frequency	**Point** (Cancer / Reference / Difference)					
	A [dB]	**B [dB]**	**C [dB]**	**D [dB]**	**E [dB]**	**F [dB]**
7 GHz	-58 / -58 / 0	-76 / -79 / 3	-80 / -83 / 3	-82 / -84 / 2	-86 / -94 / 8	-85 / -81 / 4
8 GHz	-61 / -61 / 0	-75 / -84 / 9	-77 / -79 / 2	-82 / -84 / 2	-70 / -90 / 20	-80 / -77 / 3
3 GHz	-44 / -44 / 0	-53 / -53.5 / 0.5	-58 / -56.5 1.5	-63 / -61.5 / 1.5	-66 / -67 / 1	-62 / -59 / 3

V. RADIO CHANNEL EVALUATIONS

In this section, radio channel characteristics are evaluated for the tumor case and reference case in tumor locations A and B. Both frequency and time domain channel characteristics are studied. Due to brevity, we plot only the channel responses where the differences are the mostly visible.

A. *Tumor location A*

Fig. 5a presents channel parameter S32 for the whole simulated bandwidth (BW) and Fig. 5b presents channel parameter S32 for the frequency range 7-8 GHz. As it can be seen, the largest difference between the tumor and reference case, i.e. approximately 2 dB, can be found at at 7.4 GHz (the notch area at 6.8 GHz is omitted due to the strong attenuation). This is evident since at higher frequencies, the wavelength in tissues is smaller enabling better resolution and hence, providing advantage for detectability of smaller tumors. Besides, dielectric property difference between the tumor tissue and glandular tissue is at largest at higher frequencies, as seen from Table II.

When comparing the levels of S21 parameter in the presence and absence of tumor, channel attenuation is noted to be minor in the presence of tumor. This is due to the fact that since the tumor has higher relative permittivity than the glandular tissue, it causes stronger reflections for the propagating signal as it reaches the cancerous tissue border. The reflections from the cancerous tissue border are beneficial for S32 parameter in this antenna location case since the reflected signal orientates towards the adjacent on-body antenna and thus, it can be seen as smaller channel attenuation in the receiver.

Next, the time domain channel results are evaluated by performing Inverse Fast Fourier Transform (IFFT) to the frequency domain channel parameter. Firstly, IFFT is performed for the whole simulated bandwidth 2-8 GHz. The obtained impulse responses are presenetd in Fig. 6a. Fig. 6b presents the impulse responses as IFFT was performend only for frequency range 7-8 GHz, in which the channel attenuation differences are the most evident. Similar tendency can be found in time domain as in frequency domain results: the channel attenuation is slighly minor in the presence of tumors than in the absence of tumors. As the IFFT window is squeezed to valid only for the frequency range 7-8 GHz, the differences in the time domain results increase as well.

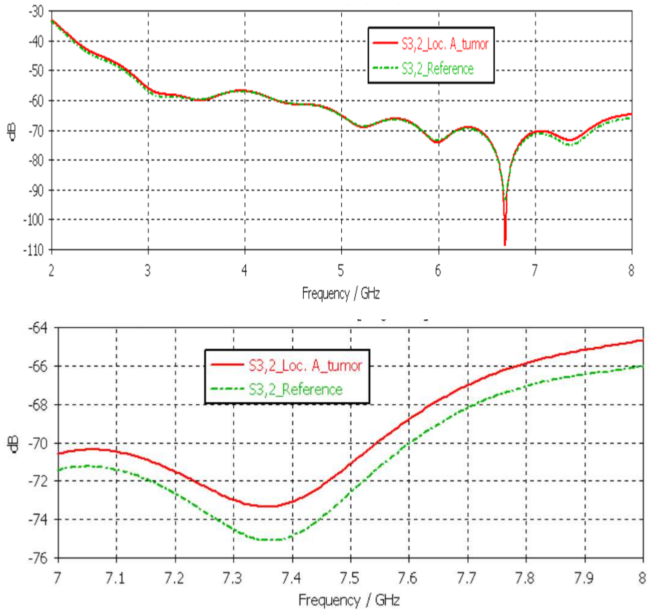


Fig. 5. S32 channel parameter in tumor location A a) for the 2-8 GHz simulated bandwidth, b) for the bandwidth 7-8 GHz.

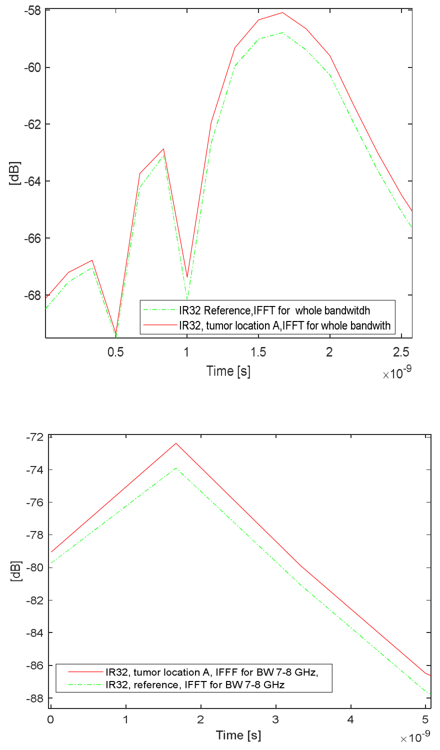


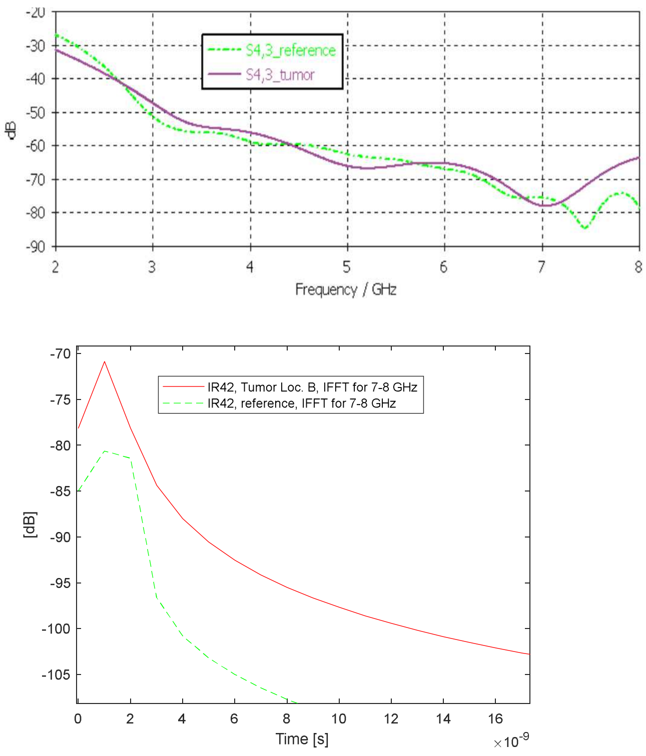
Fig. 6. Impulse responses obtained from S32 channel parameter by performing IFFT a) for whole simulated bandwithd, b) for 7-8 GHz.

B. Tumor location B

Finally, the frequency domain channel characteristics are evaluated in tumor location B. The frequency domain and time domain channel responses (IFFT for the BW 7-8 GHz) are presented in Figs. 7a-b, respectively.

As it is noted, the differences between the tumor and reference cases in channel responses are more visible than in tumor location A. This is due to the shorter distance between the on-body antenna and tumor tissue in the tumor location B than in the tumor location A. The channel attenuation difference is at maximum, roughly 10 dB.

The presented results prove that the flexible antennas are suitable for detection of even small-sized breast tumors (less than 10 mm), which can be located deep inside the breast tissue. The use of flexible antennas could potentially enable vest-type portable device for tumor detection which would be essential and timely for telemedicine's advanced applications.



a) S43 channel parameter in tumor location B for the whole simulated bandwith 2-8 GHz, b) Impulse response obtained from performing IFFT for the 7-8 GHz bandwidth.

VI. DISCUSSION

This paper presents a study on using UWB flexible antennas in a breast cancer self-monitoring vest which could be employed for independent breast health check for instance in health care centers or even as home monitoring device. The vest is based on the detecting differences in the UWB radio channel characteristics between several on-body antennas embedded in the vest. The realistic radio channel evaluations and power flow analysis, conducted using an anatomical voxel model, show that even small-sized cancerous tissue (diameter 1 cm) can cause clear differences in the signal propagation and UWB radio channel characteristics between multiple on-body antennas embedded in a monitoring vest. In the case of small tumors, the differences are largest at higher frequencies since the smaller wavelength in the tissue enables better resolution. Besides, the difference between the relative permittivity of cancer tissue and breast glandular tissue is larger at higher frequencies. In this case, the promising frequencies for breast tumor detection would be 7-8 GHz.

The differences in the radio channel data can be detected with sensitive receivers, and the data could be analyzed in server computer with AI-based approaches. AI is needed to get extensive reference data set to understand which variations in the channel responses are due to the differences in the physical characteristics of the breast (amount of fat and glandular tissue), and which are due to tumors of different sizes.

UWB technique is already well-known and standardized technique which enable low-cost, low-power, small-size devices and thus, this kind of monitoring vest could be made affordable and easily accessible even for small healthcare centers and for home-monitoring use.

The next steps in this study will involve extensive simulations with different tumor sizes and locations using several voxel models having different size and body constitutions. Additionally, different antennas and antenna types, e.g., directional antennas, will be used to verify the impact of the antenna properties on the channel response differences. Finally, we will prepare human tissue mimicking phantoms for the breast area and conduct measurement with several antenna prototypes for the verification of the simulation results.

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