Skin Sarcoma Detection by Antenna Resonance Scale

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Abstract—In this paper, a small antenna is proposed to diagnose skin sarcoma from the embryonic stage to the metastasis stage. The prototype consists of a new antenna structure with a surface of 31.3 x 15.65 mm² and a 35 μm copper sheet engraved on a 1.6 mm FR-4 substrate. The diagnosis is based on the shift in resonance frequency when the antenna is positioned on malignant tissue. For the simulations, a three-layer body Phantom (skin, fat, and muscle) and a half-sphere tumor Phantom were considered. Simulations of antenna performances showed that for a tumor of 26.17 mm³, the resonance frequency decreases by 7.5 MHz. Measurements made on the prototype of the designed antenna show an adequacy between the results of the measurement and those of the simulation.

Index Terms—Body antenna, early cancer diagnosis, evolution scale of skin sarcoma, frequency shift detection, skin sarcoma, small antenna.

I. INTRODUCTION

Skin cancer is a form of cancer that is developing more and more due to the emergence of factors such as the aging of the population, the change in leisure habits and the fashion for tanned skin [1]. According to [2], skin cancer is on the rise in recent years. In about 20 years, the annual number of new cases in Belgium has indeed increased from less than 11,000 in 2004 to more than 43,000 in 2018. The skin structure is complex and the cancers that attack it are diverse. Healthy skin (1-4 mm) consists mainly of three parts: the epidermis, the dermis, and the hypodermis. Depending on their location in the skin, there are several types of cancer.

- Basal cell carcinomas constitute 70% of skin cancers. They develop when the keratinocytes located in the deepest layer of the epidermis (stratum basal) are altered. In their invasive state, basal cell carcinomas can reach 20 mm [3].
- Melanomas constitute about 20% of skin cancers. They arise from melanocytes and are the most serious form of skin cancer.
- Cutaneous sarcoma is a type of cancer that develops in the dermis and hypodermis. It accounts for 2% of all cases of skin cancer. The diagnosis of skin sarcoma is very complex, so it is recommended to have at least two expert opinions. The most used examination to detect a skin sarcoma is histology, which allows the tumor to be characterized by taking a sample and visually analyzing a piece of tissue (anatomopathology).

Regardless of skin cancer type, early diagnosis helps to avoid proliferation through metastasis or invasive cancer. Early detection of cancer increases the patient's chances of recovery.

In-depth knowledge of the dielectric characteristics of tissues today has facilitated the emergence of new cancer detection methods based on the analysis of these characteristics.

The dielectric properties of different tissues were analyzed by Joines and others in [4] over the 50-900 MHz band. Comparing healthy and diseased tissues, the authors observed respectively an increase in relative permittivity and conductivity of 6.4 and 3.8 S/m in malignant tissues compared to healthy tissues.

At the 244th conference of the Electrochemical Society (ECS), Sharki RIZMAN and his team proposed a broadband monopole antenna for skin cancer detection based on SAR analysis [5]. Their study showed that the SAR of the malignant tissue decreased by almost 0.029 W/Kg compared to the SAR of the healthy tissue.

In her thesis, Zahra KATBAY proposed a Hilbert Fractal Antenna (HFA) to detect breast cancer based on the variation of the resonant frequency of the antenna on the breast [6]. The simulation of the S11 parameter of her proposed antenna showed a 3.5 and 2.2% shift in the resonant frequency of the malignant tissue compared to the healthy tissue.

Several experimental protocols are implemented in the literature to validate the mathematical results (theory, simulation) obtained when designing the antennas used on human tissues. These protocols can be divided into two groups: in vitro and in vivo measurements.

In-vitro experiments consist of reconstructing the characteristics of human tissue from a chemical mixture (mimicking human phantom tissues) or using the flesh of animals whose dielectric properties are like those of human tissues. The products most

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used in vitro experimentation are ballistic gels [7], medical serums [8], and chemical mixtures based on salt, sugar, and various proportions of other ingredients [9, 10]. However, the best alternative to imitating human tissue is the use of the flesh of certain animals. The meat of pigs is widely used, as can be seen in [11–12].

In-vivo experimentation allows one to get into the real conditions of human tissues, but the manipulation of sick tissues can pose risks for the manipulator. Moreover, ethical issues require long steps to work on sick subjects. To alleviate these constraints, some studies have used healthy subjects, on whom they have mimicked the conditions of cancer tumor patients. For example, in [13], to detect a melanoma at 77 GHz, the authors used a dry hand and a wet hand. The difference in permittivity between wet and dry skin mimics that between dry skin and a tumor.

In-vivo validation can also be done on certain live animals, such as pigs and rats. But for the diagnosis of cancer tumors, it is difficult to use these animals because it is necessary to find an animal subject with the same pathology.

Beyond the introductory section, the rest of this paper consists of six parts. Section 2 describes the structure of the proposed antenna and explains the diagnostic method. Section 3 compares the performance of the proposed antenna with that described in the literature. Section 4 presents the performance of the prototype antenna, and Section 5 analyses the Specific Absorption Rate. In Section 6, a link budget is carried out to determine the range of the signal, and Section 6 concludes the study. It also indicates the future direction of this research work.

II. DESIGN AND METHODOLOGY

2.1. Antenna Structure

In this study, we propose a meander antenna for the early diagnosis of skin sarcoma. The structure of the antenna is inspired by the one presented in the article [14]. It mainly consists of a thin layer of copper etched on FR-4 with 1.6 mm thickness. Table 1 contains the components of the antenna with their respective dimensions. The use of the proposed antenna involves placing it on the skin of the area under investigation and measuring the resonance frequency. The stage of the tumor is finally defined from the scale of the cancer tumor stage (Fig. 6).

To simulate the antenna parameters in the presence of the human body, a three-layer phantom (skin, fat, muscle) was used. This model was used because it is considered in several studies to be the closest to the reality of the human body [6, 15]. In this study, we considered the muscle, the fat, and the skin, with thicknesses of 27.5 mm, 8.5 mm, and 2.5 mm respectively. Figure 1 shows the geometry of the antenna spread out and placed on the 3-layer model.

The length (L) is 31.3 mm and that of the upper strands (L₁) and (L₂) is 5.34 mm. The diameter (D) of the arcs is 2.19 mm. The horizontal sections (S₁), (S₂) have common lengths of 5.71 mm, and the section (C) has 6.4 mm.

![Fig.1. Antenna geometry: a) spread antenna, b) profile view of the antenna on the 3-layer phantom.](image)

<table>
<thead>
<tr>
<th>Components</th>
<th>Materials</th>
<th>Area [mm²]</th>
<th>Thickness [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Substrate</td>
<td>FR-4</td>
<td>31.3 x 15.65</td>
<td>1.6</td>
</tr>
<tr>
<td>Superstrate</td>
<td>FR-4</td>
<td></td>
<td>1.6</td>
</tr>
<tr>
<td>Radiating element</td>
<td>Cooper</td>
<td></td>
<td>0.035</td>
</tr>
</tbody>
</table>

Our goal is to use the antenna to diagnose skin sarcoma at an early stage. The embryonic state of the tumor is considered in this study to be the time when a surface area of 15.7 mm² of the hypodermis changes electrical characteristics.

To mimic the behavior of the antenna, the tumor was modeled by a hemisphere placed on the upper surface of the fat. As a malignant tumor is a stack of dead cells with accumulated water, its electrical characteristics are therefore higher than those of
normal skin cells. Figure 2 provides a longitudinal view of the tumor modeled in the embryonic state, and Table 2 summarizes the characteristics of the tissues [16].

![Image of tumor model](image)

Fig. 2. Longitudinal view of the tumor, modeled in the embryonic state (the skin is transparent).

<table>
<thead>
<tr>
<th>Tissues</th>
<th>$\varepsilon_r$</th>
<th>$\sigma$ [S/m]</th>
<th>$\rho$ [Kg/m$^3$]</th>
<th>Thickness/ Sizes [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skin</td>
<td>44.62</td>
<td>1.04</td>
<td>1100</td>
<td>2.5</td>
</tr>
<tr>
<td>Fat</td>
<td>5.35</td>
<td>0.06</td>
<td>910</td>
<td>8.5</td>
</tr>
<tr>
<td>Muscle</td>
<td>54.11</td>
<td>1.14</td>
<td>1041</td>
<td>27.5</td>
</tr>
<tr>
<td>Tumor</td>
<td>51.02</td>
<td>4.84</td>
<td>1100</td>
<td>1</td>
</tr>
</tbody>
</table>

**2.2. Antenna Performance Simulation and Results**

- Reflection coefficients and radiation patterns

Antenna performances were simulated in free space, then in the presence of healthy tissue, and finally when placed on tissue affected by a tumor in the embryonic state. Figure 3 presents the results of these simulations.

![Graph of S11 (dB) vs Frequency (MHz)](image)

Fig. 3. Antenna performances: a) reflection coefficients, b) realized gain in free space, c) on benign tissue.
In free space, the antenna resonates at 2057.5 MHz with a reflection coefficient of -11.87 dB and a realized gain of -3.17 dBi. On the healthy tissue, and on the affected one, it resonates, respectively, at 1430 MHz and 1422.5 MHz with reflection coefficients of -17.46 dB and -17.81 dB. The realized gain drops from -3.17 dBi to -7.24 dBi and then to -7.3 dBi. The presence of the tumor drops the resonance frequency by 7.5 MHz.

2.3. Tumor Detection in Invasive and Metastasis States

Diseased cells can multiply and spread in the same tissue, which is called invasive cancer. Skin sarcoma, which arises in the hypodermis, can be considered invasive if it spreads into the hypodermis and the dermis in both width and thickness. To simulate the reflection coefficient in the invasive state, we considered a half-sphere with a base diameter ranging from 5 mm to 20 mm and a thickness ranging from 1 mm to 1.5 mm. A thickness of 0.01 mm corresponds to a layer of cells.

Contaminated cells can also merge and evolve to contaminate all cells on a localized surface of the hypodermis and even reach the cells of the epidermis. In this case, it is said that the cancer is in a state of metastasis. In the case of this study, in the state of metastasis of the sarcoma, the set of dead cells is modeled by a half-sphere of thickness ranging from 1.5 to 2 and a central diameter of 20 mm. This diameter corresponds to the size that a skin tumor can reach. The modeled tumor in the terminal invasive and metastasis phases is presented in Figure 4.

![Fig. 4. Modeling of the tumor: a) invasive state, b) metastasis state (all tissues were made transparent).](image)

Figure 5 shows the variation of the reflection coefficient during tumor growth in the invasive and metastasis phases.

![Fig. 5. Reflection coefficients in invasive and metastasis state.](image)

In the presence of a metastasis tumor, resonances are obtained at frequencies of 1380 MHz and 1372.5 MHz for tumors with thickness of 1.7 mm and 2 mm, respectively. The observed reflection coefficients are -20 dB and -20.85 dB.

This study confirms that the presence of a cancerous tumor causes a fall in resonance frequency relative to the resonant frequencies of the same antenna in healthy tissue. The variation reached 57.5 MHz for tumors with metastases of 125.6 mm$^2$. This result is consistent with the 50 MHz resonance frequency variation observed in [6] for a side surface of 100 mm$^2$ (a cube of 5 mm). Furthermore, the minor difference between our results and those observed in [6] can be explained by the type of tissue. Our work considered the skin of flat organs such as the arm, forearm, back, and thighs, while the referenced work involved the breast.
2.4. Prediction Scale for the Lateral Surface of the Tumor.

We calculated the volume and the lateral surface of the tumor at each phase of its evolution. The lateral surface and volume analysis in relation to the evolution of the resonance frequencies shows that the resonance evolves according to the lateral surface of the tumor and not its volume (Fig. 6). This is a significant observation that can help surgeons determine the tumor extent during surgical interventions. In view of the results obtained, we have established Table 3, to serve as a reference in the diagnosis of skin sarcoma.

![Fig. 6. Scale for tumor lateral surface prediction](image)

The variation in resonance frequency depending on the lateral surface of the tumor is an affine decreasing function (Eq. 1).

\[ f = ax + 1429.97 \]  

(1)

With \( f \) the resonance frequency in MHz and \( x \) the side surface in \( \text{mm}^2 \). The inclination \( a \) of this equation is \(-0.4757\) MHz/\( \text{mm}^2 \). It represents the falling coefficient of resonance frequency per 1 \( \text{mm}^2 \) of cancer tumor surface. This variation is consistent with the 50 MHz drop observed in [10] for a cubic tumor of 5 mm stop and side surface equal to 100 \( \text{mm}^2 \).

<table>
<thead>
<tr>
<th>Resonance frequency ( F_0 ) [MHz]</th>
<th>Characteristics of the tumor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth ( h ) of tumor (mm)</td>
<td>Tumor states</td>
</tr>
<tr>
<td>1430</td>
<td>0</td>
</tr>
<tr>
<td>1422.5</td>
<td>1</td>
</tr>
<tr>
<td>( 1422.5 \leq F_0 &lt; 1385 )</td>
<td>( 1 &lt; h &lt; 1.5 )</td>
</tr>
<tr>
<td>( 1380 \leq F_0 &lt; 1385 )</td>
<td>( 1.5 \leq h \leq 1.7 )</td>
</tr>
<tr>
<td>( 1372.5 \leq F_0 &lt; 1380 )</td>
<td>( 1.7 \leq h \leq 2 )</td>
</tr>
</tbody>
</table>

III. COMPARISON OF THE RESULTS WITH OTHERS

The performance of the proposed antenna is compared in Table 4 with those obtained in recent works. To our knowledge, the proposed method is the only one that gives a clear protocol that allows all practitioners to use it.
It’s safe to assume that the proposed antenna is smaller than the most usual antennas while resonating in a much lower frequency band (1430 MHz). In addition, our antenna detects cancerous tumors at an earlier stage than other antennas. The originality of the proposed diagnosis method lies in the ease of use of the diagnostic method, based on a scale and a table of reference values. The study also makes it possible to accurately determine tumor size, which will help surgeons make precise incisions during medical procedures.

### IV. STEPS OF THE MEASURES

A prototype of the antenna (Fig. 7a) was made on a FR-4 type substrate using the laboratory LPKF milling machine. The measurements were carried out with the Agilent 8714ES vector analyzer (Figure 7b, 7c), first in open space, then in-vivo on various healthy skins and on skins reinforced with a sodium and sugar solution.

The measurement of the in-vivo reflection coefficient on healthy skin consisted in placing the antenna on the skin of different organs (front, back of the shoulder, thigh) of three individuals. To mimic the dielectric properties of malignant skin, a solution composed of 500 ml of water, 76.5 g of sodium and 23.5 g of sugar [21] was deposited on an area of 11.2 x 11.2 mm² of the skin of each healthy subject. The deposition of the solution results in a slight increase in the permittivity and conductivity of the skin over the 125.44 mm², corresponding to the final phase of the tumor metastatic state. The results of those measurements are compared with the simulation results (Fig. 8).

![Fig. 7. Measurement: a) antenna prototype, b) experimental setup, c) reflection coefficient on benign tissue.](image)

### TABLE 4.
PERFORMANCE COMPARISON TABLE

<table>
<thead>
<tr>
<th>Ref.</th>
<th>Antenna sizes (mm³)</th>
<th>Resonance frequency (GHz)</th>
<th>Characteristics of the tumor</th>
<th>Methods of diagnosis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Organ</td>
<td>Vol. (mm³)</td>
</tr>
<tr>
<td>[5]</td>
<td>20 x 28 x 1.6</td>
<td>2.81</td>
<td>Skin</td>
<td>65.41</td>
</tr>
<tr>
<td>[6]</td>
<td>32.4 x 13.5 x 1.6</td>
<td>0.90 2.2</td>
<td>Breast</td>
<td>125</td>
</tr>
<tr>
<td>[17]</td>
<td>20 x 24 x 1.6</td>
<td>7.5</td>
<td>Breast</td>
<td>33.49</td>
</tr>
<tr>
<td>[18]</td>
<td>10 x 10 x 0.375</td>
<td>8</td>
<td>Breast</td>
<td>32.71</td>
</tr>
<tr>
<td>[19]</td>
<td>61 x 0.411 x no</td>
<td>2.4</td>
<td>skin</td>
<td>No.</td>
</tr>
<tr>
<td>[20]</td>
<td>40 x 40 x 0.15</td>
<td>8.3</td>
<td>Skin</td>
<td>523.33</td>
</tr>
<tr>
<td>This work</td>
<td>31.3 x 15.65 x 1.6</td>
<td>1.430</td>
<td>Skin</td>
<td>26.17</td>
</tr>
</tbody>
</table>
Results of the Reflection Coefficient

In free space (Fig. 8a), the antenna prototype resonates at a frequency of 2014.167 MHz with a tolerance of 0.1% and presents a reflection coefficient of -22.219 dB with a measured bandwidth of 69.18 MHz. Measurements on the healthy skin of three different individuals (2 men, 1 woman) and on three different organs (the forearm, back of the neck, and thigh) showed that the antenna resonates at a frequency of 1430 MHz with different values of the reflection coefficient. Furthermore, the best fit is obtained on the forearm of a 42-year-old man of 71 kg and 171 cm height, where the reflection coefficient reaches -26.576 dB. The bandwidth is 207.8 MHz. Given the low weight of the antenna, the fluctuation of the resonant frequency of the antenna on the skin reaches 0.1% compared to the value of the simulation.

In the presence of a tumor in its final metastasis state, the measurements showed that the antenna resonates at a frequency of 1372.5 MHz with a reflection coefficient of -28.259 dB. The measured bandwidth of the antenna under these conditions is 245 MHz. From the analysis of these results, it can be stated that the results obtained by simulations and those obtained by measurements agree perfectly.

V. SPECIFIC ABSORPTION RATE (SAR)

It's important to analyze the power absorbed by tissues for any system radiating close to the body to understand the potential ionization risks of tissues. So, we generated the power lost in the copper and the power absorbed by the various tissues (skin, fat, and muscle). Figure 9 shows the distribution of power lost in each tissue. Observation of the power loss density shows that the skin absorbs the
maximum power at around 2.5 × 10^5 W/m^3, i.e., less than 0.227 W/g. This value is well below the maximum value of 1.6 W/g authorized by the American National Standard Institute (ANSI) [22]. It may be noted, however, that the central arcs of the antenna generate the greatest power loss.

VI. LINK BUDGET

Today, technology can only be sustainable if it is scalable and easy to use by many users. We therefore wanted to see if the proposed antenna could be implemented in an IoMT (Internet of Medical Things) sensor to establish OB2OB (Out of Body-to-Out of Body) communication. The antenna could then be used to transmit measurements directly to a connected Gateway.

To ensure this capability, we have evaluated the range of the signal generated by the antenna when it is excited with a power of -20 dBm. When the antenna is well matched, the range of the signal can be estimated with Eq. (2) from the article [23].

\[
P_t[dBm] = EIRP[dBm] + G_t[dBi] - L[dB]
\]

(2)

Where

\[
EIRP[dBm] = P_t[dBm] + G_t[dBi]
\]

(3)

\[
L[dB] = 10n\log(d) + 10\log(\frac{4\pi\pi d}{\lambda_0})
\]

(4)

Where EIRP is the Equivalent Isotropic Radiated Power, \( P_t \) is the transmitted power, \( G_t \) is our proposed antenna gain at 1430 MHz and \( G_r \) is the gain of an IoT node, \( L \) is the path loss, and \( n \) is the propagation exponent which is 3 in NLOS (None-Line-Of-Sight) situation.

NLOS propagation is the mode of wave propagation in media with obstacles. Obstacles can cause losses in the signal level due to propagation mechanisms (reflection, refraction, diffraction, and absorption). The direct consequence of the loss of the signal level is the decrease of the range of the radio waves. From Eq. (2) and Eq. (4) we can derive Eq. (5).

\[
d = (\frac{\lambda_0}{4\pi})^{\frac{1}{1+n}} * 10^{\frac{L}{10}}
\]

(5)

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Quantity</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pt</td>
<td>Transmitter power [dBm]</td>
<td>-20</td>
</tr>
<tr>
<td>Gt</td>
<td>Transmitter antenna gain [dBi]</td>
<td>-7.24</td>
</tr>
<tr>
<td>Gr</td>
<td>Receiver antenna gain [dBi]</td>
<td>3.6</td>
</tr>
<tr>
<td>L</td>
<td>Free space loss [dB]</td>
<td>-103.79</td>
</tr>
<tr>
<td>S</td>
<td>IoT node sensitivity [dBm]</td>
<td>-136</td>
</tr>
<tr>
<td>M</td>
<td>Margin</td>
<td>10</td>
</tr>
<tr>
<td>n</td>
<td>Path loss exponent</td>
<td>3</td>
</tr>
<tr>
<td>Pr</td>
<td>Receiver power [dBm]</td>
<td>( Pr = S + M )</td>
</tr>
<tr>
<td>d</td>
<td>Distance between transmitter and receiver [m]</td>
<td>118.90 m at 1430 MHz</td>
</tr>
</tbody>
</table>

The range of the wave generated by the proposed antenna can reach 118.90 m in a complex environment when fed with only -20 dBm. This shows that the antenna can equip sensors communicating with an IoT gateway in a large hospital. This antenna is therefore a good candidate for the vulgarization of IoMT.
VII. CONCLUSION

In this paper, a miniature antenna for early diagnosis of skin sarcoma is presented. The proposed antenna allows to overcome the constraints of the usual methods of detection of hypodermal cancer tumors at all stages of their evolution. Compared to the antenna performance on the healthy tissue model, the results of the Phantom malignant tissue simulation showed a decrease in the resonance frequency of 7.5 MHz in the presence of a cancer tumor of 26.17mm³. To validate the simulation results, the antenna was manufactured on a FR-4 substrate, and the results of measurements on the affected skin of a tumor at the final state of metastasis confirm the fall in the resonance frequency of 57.5 MHz, and an improvement of -1.683 dB in impedance adaptation. In parallel to cancer detection, the antenna can also be used to establish 118.90 m body links. In future work, we will test the antenna on a significant population.

References


