Homogenous and multilayer electromagnetics models for estimating skin reflectance

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ABSTRACT

Reflectance measurements of human skin are widely limited over the millimeter wave (MMW) band in literature. This is due to the cost and technical difficulties of the experimental setup. This paper proposes homogenous and multilayer skin models for estimating the reflectance of the forearm and palm of the hand skin over the MMW band 30-100 GHz. The simulation results demonstrate that the differences in reflectance between the homogenous and multilayer models of forearm skin are limited to 0.014, indicating that the thin stratum corneum (SC) layer in the multilayer skin models has a minimal impact on the interaction with MMW of the forearm skin. However, in the palm of hand skin, there is a substantial difference in reflectance calculations between the homogenous and the multilayer skin models in the range of 0.099 to 0.143. These differences are attributed to the presence of a thick SC layer in the palm of the hand. Thus, the simulation results suggested that two-layer should be used for the palm of hand skin as it better captures the reflectance characteristics of this region. The importance of having those models are in calculating the skin reflectance that can be used for the non-invasive diagnosis of skin conditions.

Keywords: Electromagnetics modeling, Millimeter wave, Signatures, Skin diseases, Skin reflectance

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1. INTRODUCTION

The electromagnetic spectrum's millimeter-wave (MMW) is an area of radio waves ranging from 30 GHz to 300 GHz [1], [2]. Signatures of the skin in the MMW band were measured in two ways: active sensing [3]–[5], which involves exposing the target area of the skin to non-ionizing radiation [6], [7], and passive sensing technology [8], [9], which does not involve exposure to any form of artificial radiation. Active sensing uses MMW radiation to measure the skin reflectance and signature, while passive sensing collects MMW emission to quantify the reflectance of the skin [10].

MMW frequency band offers potential for novel medical applications such as body sensing [11], [12], non-invasive diagnoses of skin diseases [8], [13], [14], and early detection of skin cancer [15]. Researchers' findings in [3], [4], [16], [17] suggest that significant variations in the dielectric properties and reflectivity of the skin exist between different locations. This can be attributed to variation in water content, as skin with higher water content tends to have higher reflectivity and lower dielectric properties than skin with lower water content [18]. To measure the reflectance and dielectric properties of the skin, the researchers in [3], [4], [16] used open-ended coaxial probes. This approach has been used widely in the literature to measure the reflectivity and the skin properties such as the relative complex permittivity. Experimental measurements obtained in [19]...
showed a well define contrast in reflectance between healthy skin and skin with basal cell carcinoma (BCC). These results identified the tumor's boundaries, and this helping out the healthcare professional to identify the margin of the BCC accurately. This provides a more accurate treatment of BCC. Researchers in [4], [18] found that wet skin i.e. (skin after adding water) has higher dielectric properties and reflectance compared with normal skin. These results are consistent with the other studies conducted on normal and wet skin in [5], [20] and indicated that increasing the water content makes the skin more reflective. Reflectance measurements applied on ex vivo porcine skin samples in [21] indicated that the reflectance of burn-damaged skin was lower than that of normal skin. These differences in signatures between healthy and burn-damaged skin are due to lower water content in burn-damaged skin. These results prove that water content has a clear impact on the reflectance of the skin.

Although coaxial probes have been used widely in literature for the non-invasive diagnosis of skin diseases, there are many challenges and limitations for the use of the probe that can be addressed as follows: i) the probes are very sensitive to alignments and thus making it difficult to get accurate measurements as well as difficulty in calibrating the probes. ii) It is required to maintain constant pressure on the target area of the skin to get accurate and precise measurements [4], [22]. iii) The probes must be allocated in direct contact with the skin region and this makes it difficult to perform reflectance measurements on diseased skin such as burns and cancer [4], [22]. Figure 1 illustrates the use of the coaxial probe for measuring the dielectric properties of the human skin.

Radiometry as a passive and a non-contact sensor has been suggested to measure the reflectance and the emissivity of healthy and diseased skin in the MMW region [23] as illustrated in Figure 2. The study conducted in [12] indicated substantial differences in the reflectance between normal and burn-damaged skin, and these differences are found to be increased with the degree of the burn. This indicates the potential of using radiometry in the non-invasive diagnosis of diseased skin. Similarly, the study in [23] demonstrated for the first time the use of radiometry as a non-contact sensor for the early detection of skin diseases and disorders in tens of seconds and without the need of being in a healthcare clinic. The radiometric measurements in this study [23] were performed on healthy skin and non-healthy skin having burns, melanoma skin cancers, and eczema. Experimental results in [23] demonstrate the potential of using radiometry for detecting skin diseases and conditions. The study proposed in [24] indicates that the reflectivity of the skin at 45 GHz can provide a better assessment of diabetic neuropathy. Das et al. [25] proposes a simulation approach for estimating the absorption of the skin using the reflectance database. Monte Carlo simulation in [26] was used to assess the interaction of clothing with the skin at 60 GHz. The skin models in [27] were used for presenting the complex tissue structures of the skin.

Figure 1. Open-ended coaxial probe for measuring the dielectric permittivity

Figure 2. Radiometer measuring the skin reflectance
In the literature review, comprehensive research has been done to investigate the feasibility of MMW technology in the non-invasive diagnosis of skin diseases using reflectivity and dielectric properties measurements as summarized in Table 1. The main limitation of active sensing techniques is that they are incredibly expensive, as the devices are available over specific frequency bands, and changing the frequency band is required to change the devices to fit the frequency band and this needs significant financial resources. Not only is the initial cost high but maintenance can also be costly. Furthermore, depending on the frequency band in use, it may require a new device each time the frequency band is changed, which can add up quickly. As a result, these techniques can be a major financial burden as well as technical difficulties and complexity in conducting the measurements. As an alternative, this paper proposed electromagnetics models of the forearm (thin skin) and palm of the hand (thick skin) that can be used for estimating the reflectance of the skin in the whole MMW band.

<table>
<thead>
<tr>
<th>Frequency (GHz)</th>
<th>Method used</th>
<th>Skin type</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>30-40</td>
<td>Open-ended probe</td>
<td>Healthy skin</td>
<td>[4]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dry and wet</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Burn damaged skin</td>
<td></td>
</tr>
<tr>
<td>37-74</td>
<td>Open-ended probe</td>
<td>Healthy skin</td>
<td>[20], [28]</td>
</tr>
<tr>
<td>30-100</td>
<td>Open-ended probe</td>
<td>Healthy skin</td>
<td>[22]</td>
</tr>
<tr>
<td>30-60</td>
<td>Coaxial slim probe</td>
<td>Healthy skin</td>
<td>[29]</td>
</tr>
<tr>
<td>57-100</td>
<td>Free space method</td>
<td>Dry and wet skin</td>
<td>[5]</td>
</tr>
<tr>
<td>90-100</td>
<td>Free space method</td>
<td>Dry and wet skin</td>
<td>[5]</td>
</tr>
</tbody>
</table>

This paper proposes single and multilayer electromagnetics models of the forearm and palm of the hand skin. The models extracted reflectance of the skin over a wide range of frequencies (30 GHz to 100 GHz) using the dielectric permittivity of the skin that can be obtained directly from the debye equation described in section 2 (19). The proposed models herein can estimate the reflectivity of the skin automatically by converting the dielectric permittivity to reflectivity without the need of involving the human subject. Moreover, the models reveal that the interaction of MMW doesn’t go beyond the dermis layer of the skin. This is due to the low penetration of the millimeter wave radiation in the human skin as a result of the attenuation effect that is caused by the water content. This makes MMW frequency band suitable for assessing skin diseases and conditions.

2. METHOD

This section provides details about the main methodology used for building the skin models as illustrated in Figure 3. The first step is data collection in which the dielectric properties of the forearm and palm of hand skin were collected from different resources in the literature [20], [28], [31]. The second step is building different electromagnetics models for the forearm and palm of hand skin namely: i) a homogenous model, ii) a two-layer model, and iii) a three-layer model. The third step is model validation in which the calculated reflectance from the three models was compared with reflectance measurements conducted in the literature. Finally, featured applications of the skin models are introduced in the area of medical applications to distinguish between non-healthy and healthy skin.

Figure 3. Methodology used in developing the forearm and the palm of the hand models

Data Collection: Dielectric Properties of the Human Skin

Model Building: Electromagnetics Model

Model Validation: Model Results vs Experimental Results

Medical Applications: Reflectivity Estimation Can Help in Assessing Skin Conditions

Human Skin Conditions:
- Acne
- Urticaria
- Psoriasis
- Fungus

2.1. Multilayer electromagnetics model

In this paper, the multilayer electromagnetic model is constructed and developed to calculate the reflectance of the palm of hand skin and forearm skin. Each layer of the model is characterized by three parameters: permittivity ($\epsilon$), permeability ($\mu$) and thickness of the layer ($h$). The first and the last layer of the model are semi-infinite. The structure of the multilayer electromagnetic model is presented as illustrated in Figure 4.

![Multilayer electromagnetic model](image)

Figure 4. Multilayer electromagnetic model; each layer of the model is characterized by three parameters and those are permittivity ($\epsilon$), permeability ($\mu$) and thickness of the layer ($h$)

The permittivity of the skin $\epsilon$ is described in (1). It is a complex quantity that is consisted of two terms, namely: the free space permittivity, $\epsilon_0 = 8.85 \times 10^{-12}$ F/m and the relative complex permittivity, $\epsilon_r$. The relative complex permittivity $\epsilon_r$ is described in (2). The real part of the complex permittivity, $\epsilon_r$ represents the dielectric constant of the skin. Whereas, the imaginary part of the complex permittivity, $\epsilon''_r$ represents the loss factor of the skin, $\omega$ is the angular frequency, and $\sigma$ is the conductivity of the skin.

$$\epsilon = \epsilon_0 \epsilon_r$$  \hspace{1cm} (1)

$$\epsilon_r = \epsilon'_r - j \epsilon''_r = \epsilon \left[ 1 - \frac{j \sigma}{\omega \epsilon_0} \right]$$  \hspace{1cm} (2)

The S-polarized plane wave propagating in the j-1 layer of an n-layer structure is presented in (3) and (4). The wave vector, $k_j$ is described in (5). Whereas, the wave number in free space, $k_0$ is expressed in (6). The speed of the light, $c$ is equal $3 \times 10^8$ m/s and $\theta$ is the angle of incidence in the semi-infinite incident medium. In (3) and (4) can be expressed in a matrix format as illustrated in (7). For simplification, the recursion relation can be written as illustrated in (8) and (9).

$$E_{0+j-1} = 0.5 \left( 1 + \frac{\mu_j-1k_j}{\mu_jk_j-1} \right) e^{-(ik_j-1h_j-1)} E_{0+j} + 0.5 \left( 1 - \frac{\mu_j-1k_j}{\mu_jk_j-1} \right) e^{-(ik_j-1h_j-1)} E_{0-j}$$  \hspace{1cm} (3)

$$E_{0-j-1} = 0.5 \left( 1 - \frac{\mu_j-1k_j}{\mu_jk_j-1} \right) e^{(ik_j-1h_j-1)} E_{0+j} + 0.5 \left( 1 + \frac{\mu_j-1k_j}{\mu_jk_j-1} \right) e^{(ik_j-1h_j-1)} E_{0-j}$$  \hspace{1cm} (4)

$$k_j = k_0 \sqrt{\epsilon_j \mu_j - \epsilon_j \mu_j sin^2(\theta)}$$  \hspace{1cm} (5)

$$k_0 = \frac{\omega}{c}$$  \hspace{1cm} (6)

$$E_j-1 = \begin{bmatrix} 0.5 \left( 1 + \frac{\mu_j-1k_j}{\mu_jk_j-1} \right) e^{-(ik_j-1h_j-1)} & 0.5 \left( 1 - \frac{\mu_j-1k_j}{\mu_jk_j-1} \right) e^{-(ik_j-1h_j-1)} \\ 0.5 \left( 1 - \frac{\mu_j-1k_j}{\mu_jk_j-1} \right) e^{(ik_j-1h_j-1)} & 0.5 \left( 1 + \frac{\mu_j-1k_j}{\mu_jk_j-1} \right) e^{(ik_j-1h_j-1)} \end{bmatrix} \begin{bmatrix} E_{0+j} \\ E_{0-j} \end{bmatrix}$$  \hspace{1cm} (7)

$$E_1 = M_2 ... M_{j-1} M_j E_j$$  \hspace{1cm} (8)

$$E_1 = M_2 ... M_{j-1} M_n E_n$$  \hspace{1cm} (9)

In (8) and (9) can be written in a matrix format for $j$ and $n$-layer as illustrated in (10). $G_j$ and $G_n$ in (10) are $2 \times 2$ matrix presented in (11). The two components of the electric field $E_{0+1}$ and $E_{0-1}$ are presented...

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Homogenous and multilayer electromagnetics models for estimating skin... (Amani Yousef Owda)
in (12) and (13). Since there is no reflected wave in the \( n \)th layer, replace \( g_{n1,2}E_{0-n} \) and \( g_{n2,2}E_{0-n} \) with zero in (12) and (13). This simplify the equations as illustrated in (14) and (15).

\[
E_i = G_i E_i \quad \text{and} \quad E_n = G_n E_n \tag{10}
\]

\[
G_j = \begin{bmatrix} g_{j,1,1} & g_{j,1,2} \\ g_{j,2,1} & g_{j,2,2} \end{bmatrix} \quad \text{and} \quad G_n = \begin{bmatrix} g_{n1,1} & g_{n1,2} \\ g_{n2,1} & g_{n2,2} \end{bmatrix} \tag{11}
\]

\[
\tilde{E}_{0+1} = g_{n1,1}E_{0+n} + g_{n1,2}E_{0-n} \tag{12}
\]

\[
\tilde{E}_{0-1} = g_{n2,1}E_{0+n} + g_{n2,2}E_{0-n} \tag{13}
\]

\[
\tilde{E}_{0+1} = g_{n1,1}E_{0+n} \tag{14}
\]

\[
\tilde{E}_{0-1} = g_{n2,1}E_{0+n} \tag{15}
\]

From (14) and (15), reflectivity \( \Gamma \) and transmissivity \( \tau \) can be expressed as illustrated in (16) and (17). The application of conservation of energy, results in the relationship between the reflectance \( R = |\Gamma|^2 \), and transmittance \( T = |\tau|^2 \) from the skin’s as shown in (18). The relative complex permittivity is required for reflectance calculations. The data of the relative complex permittivity for each model are calculated from debye equation i.e. (19) and the parameters of the equation are obtained from [20], [28], [31]. In (19); \( i = \sqrt{-1}; \quad \epsilon_s \) and \( \epsilon_{\infty} \) present the relative permittivity below and above the relaxation frequency respectively, \( \sigma_j \) is the static conductivity and \( \tau \) is the central relaxation time.

\[
\Gamma = \frac{\tilde{E}_{0-1}}{\tilde{E}_{0+1}} = \frac{g_{n2,1}}{g_{n1,1}} \tag{16}
\]

\[
\tau = \frac{\tilde{E}_{0+n}}{\tilde{E}_{0+1}} = \frac{1}{g_{n1,2}} \tag{17}
\]

\[
R + T = 1 \tag{18}
\]

\[
\epsilon_r = \epsilon_{\infty} + \frac{\epsilon_s - \epsilon_{\infty}}{1 + i\omega\tau} - i\frac{\sigma_j}{\omega\epsilon_0} \tag{19}
\]

Based on (3)-(18); the three models of the skin were developed to calculate the reflectance of the forearm and palm of hand skin. The relative complex permittivity is required for reflectance calculations. The data of the relative complex permittivity for each model of the skin are calculated using debye equation with single relaxation time [16], [31], [32]. Figure 5 shows the structure of the three models of the skin and those are: i) homogenous unilayer skin model, ii) two-layer skin model, and iii) three-layer skin model. In the homogenous unilayer model in Figure 5(a), the skin is assumed to have a single homogenous semi-infinite layer. In the two-layer model illustrated in Figure 5(b), the skin is assumed to have two layers and those are: i) finite thickness stratum corneum (SC) layer and ii) semi-infinite epidermis plus dermis layer. In the three-layer model in Figure 5(c), the skin is assumed to have three layers namely: i) finite thickness stratum corneum layer, ii) finite thickness epidermis plus dermis layer, and iii) semi-infinite fat layer. The thickness of each layer of the skin in multilayered models is specified as illustrated in Table 2. The thicknesses of skin layers in Table 2, show that the palm of hand skin is thicker than the forearm skin.

Figure 5. Homogenous and multilayer models used for estimating the reflectance of forearm and palm of hand skin; (a) homogenous model, (b) two-layer model, and (c) three-layer model
3. RESULTS AND DISCUSSION

Reflectance of the palm of hand and the forearm skin obtained from the homogenous model, two-layer model and three-layer model are presented and discussed in the following sections: i) section 3.1 presents reflectance of palm of hand skin, ii) section 3.2 presents reflectance for forearm skin, iii) section 3.3 presents models validation, and iv) section 3.4 shows featured application of the proposed models.

3.1. Reflectance of Palm of Hand

This section presents the reflectance of palm of hand skin obtained from the three models described in section 2. The reflectance of palm of hand skin is calculated over the frequency band 30-100 GHz using the three models as illustrated in Figure 6. Three models were used namely: i) homogenous skin model Figure 6(a), ii) two-layer skin model Figure 6(b), and iii) three-layer skin model Figure 6(c). Reflectance results in Figure 6 indicate differences in reflectance values obtained from homogenous skin model as in Figure 6(a) and multilayer skin models as in Figures 6(b)-6(c). Results in Figure 6(d) show that the differences in reflectance between the homogenous and multilayer skin models is substantial and it is varied in the range of 0.099 to 0.143 over the frequency band 30-100 GHz. The presence of thick SC layer in the two and the three-layer skin models makes the difference in reflectance substantial due to the significant interaction of the thick SC layer with the MMW [20], [28]. However, the differences between two-layer and three-layer skin models are not more than ~0.003 as the presence of semi-infinite fat layer in the three-layer skin model doesn’t affect the reflectance calculations since the penetration depth of the MMW in the palm of hand skin is reported to be (1.2-0.65) mm [20], [28]. This penetration is less than the thickness of epidermis plus dermis layer 1.85 mm [20], [28], [33]. In addition, the fat layer of the skin contains large amount of water that attenuates the MMW [20]. As a result of low penetration depth and attenuation, the fat layer in the three-layer model of the skin doesn’t cause significant difference in the reflectance calculations. Therefore, the results obtained from two and three-layers models are not dissimilar and this makes the two-layer model of the skin is sufficient for modelling the reflectance of palm of hand skin.

<table>
<thead>
<tr>
<th>Region</th>
<th>Two-layer</th>
<th>Three-layer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forearm skin</td>
<td>SC thickness: 0.015 mm [20], [28]</td>
<td>Epidermis plus Dermis thickness: 1.45 mm [20], [28]</td>
</tr>
<tr>
<td>Palm of hand skin</td>
<td>SC thickness: 0.43 mm [20]</td>
<td>Epidermis plus Dermis thickness: 1.85 mm [20]</td>
</tr>
</tbody>
</table>

Figure 6. Reflectance of palm of hand skin using: (a) homogenous model, (b) two-layer model, (c) three-layer model, and (d) the results obtained from the three models are compared with each other’s
3.2. Reflectance of forearm

This section presents the reflectance of the forearm skin obtained from the three models described in section 2. The reflectance of forearm skin is calculated in the frequency band 30-100 GHz using three models of the skin as illustrated in Figure 7. Homogenous skin model as in Figure 7(a), two-layer skin model as in Figure 7(b), and three-layer skin model as in Figure 7(c). The simulation results in Figure 7(a) show the variation in the reflectance of forearm skin over the MMW frequency band 30-100 GHz. The reflectance of forearm skin was found to be varied in the range of 0.61 (at 30 GHz) to 0.47 (at 100 GHz). The results obtained from three models are consistent as illustrated in Figure 7(d). The differences in the reflectance between homogenous and multilayer skin models was found to be not more than 0.014. The presence of thin SC layer and semi-infinite fat layer in the three-layer of forearm skin model doesn’t affect the reflectance calculations of the forearm skin. This is due to the penetration depth of the MMW in the forearm skin that is reported to be 0.8 mm to 0.35 mm in the band (30-100) GHz [23]. This penetration is less than the thickness of the epidermis plus dermis layer of the forearm skin that is reported to be 1.45 mm [20], [28]. As a result of low penetration depth; the interaction of the MMW with the fat layer is very limited and it can be neglected since most of the MMW radiation is attenuated close to the skin surface [8]. Therefore, homogenous unilayer skin model is found to be sufficient for modelling the reflectance of forearm skin.

![Figure 7](image_url)

Figure 7. Reflectance of the forearm skin using; (a) homogenous skin model, (b) two-layer skin model, (c) three-layer skin model, and (d) the results obtained from the three models are compared with each other’s

3.3. Models validation

The reflectance calculations from the proposed models were compared with experimental measurements from the literature review. Table 3 shows a comparison in reflectance between two-layer palm of hand skin model and experimental measurements in [18], [20], [28]. The comparison in Table 3 indicates that reflectance calculation from two-layer model of the palm of the hand is very closed to that obtained from the experimental measurements in the literature. This indicates that the two-layer model gives an accurate estimation of the reflectance of the palm of hand skin.

Table 4 shows a comparison in reflectance between homogenous forearm skin model and experimental measurements in [18], [20], [28]. The comparison in Table 4 indicates that reflectance calculation from homogenous model is very closed to that obtained from the measurements in the literature review. This indicates that the homogenous model can provide precise estimation of the reflectance of the forearm skin.
Table 3. Reflectance comparison for palm of hand skin from two-layer model proposed in this paper and experimental measurements performed in literature

<table>
<thead>
<tr>
<th>Frequency (GHz)</th>
<th>Palm of hand multilayer models</th>
<th>Palm of hand measurements</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>0.574</td>
<td>0.565</td>
<td>[20], [28]</td>
</tr>
<tr>
<td>40</td>
<td>0.554</td>
<td>0.547</td>
<td>[20], [28]</td>
</tr>
<tr>
<td>50</td>
<td>0.515</td>
<td>0.516</td>
<td>[20], [28]</td>
</tr>
<tr>
<td>60</td>
<td>0.486</td>
<td>0.484</td>
<td>[20], [28]</td>
</tr>
<tr>
<td>70</td>
<td>0.459</td>
<td>0.456</td>
<td>[20], [28]</td>
</tr>
<tr>
<td>80</td>
<td>0.434</td>
<td>0.435</td>
<td>[18]</td>
</tr>
<tr>
<td>90</td>
<td>0.410</td>
<td>0.412</td>
<td>[18]</td>
</tr>
<tr>
<td>100</td>
<td>0.388</td>
<td>0.385</td>
<td>[18]</td>
</tr>
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</table>

Table 4. Reflectance comparison for forearm skin from homogenous model proposed in this paper and experimental measurements performed in literature

<table>
<thead>
<tr>
<th>Frequency (GHz)</th>
<th>Forearm homogenous model</th>
<th>Forearm measurements</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>0.603</td>
<td>0.601</td>
<td>[20], [28]</td>
</tr>
<tr>
<td>40</td>
<td>0.583</td>
<td>0.577</td>
<td>[20], [28]</td>
</tr>
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<td>50</td>
<td>0.561</td>
<td>0.562</td>
<td>[20], [28]</td>
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<td>60</td>
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<td>0.520</td>
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<td>90</td>
<td>0.486</td>
<td>0.484</td>
<td>[18]</td>
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<tr>
<td>100</td>
<td>0.470</td>
<td>0.470</td>
<td>[18]</td>
</tr>
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</table>

3.4. Featured application: non-invasive diagnosis of skin diseases

In this research, the dielectric permittivity of healthy and diseased skin that measured in literature [34] were used to estimate the reflectance of healthy and diseased skin using homogenous skin model of forearm skin as illustrated in Figure 8 (for dry and healthy skin) and Figure 9 (for healthy skin and skin with malignant lesions). The models proposed in this research provide us with the reflectance values of the skin over a wide range of frequencies (30-100 GHz) for healthy and diseased skin. These values will help us to determine a threshold of healthy skin reflectance values over a wide range of frequency bands so, any deviations from this threshold can be identified as either high or low levels of the reflectance values. The main advantage of relying on reflectance as a quantity for assessing the skin conditions is that it can be measured using a non-contact sensor (radiometry) whereas the dielectric permittivity of the skin requires a coaxial probe in direct contact with the skin and this makes the probe not suitable to be used in the cases of diseased skin as it is painful and not comfortable to a patient suffering from skin conditions or diseases such as burn and malignancy.

Simulation results of the reflectance in Figure 8 indicate that there is 0.023 difference in reflectance values between healthy skin and dry skin over the frequency band from 30 GHz to 100 GHz. Dry skin here means any skin having lower water content due to age, eczema or psoriasis. These findings are in a good agreement with the reflectance measurements at 90 GHz [23]. The model presented herein allows us to extract the reflectance over a wide range of frequencies rather than at a single frequency.
Simulation results of the reflectance in Figure 9 indicate that there is 0.05 difference in reflectance values between healthy skin and skin with malignant lesions over the frequency band from 30 GHz to 100 GHz. These differences are due to variations in water content between healthy and diseased skin. These results agree with the reflectance measurements at the frequency of 90 GHz [23]. This indicates that the reflectance of the skin can be used for non-invasive diagnosis of skin diseases.

Figure 9. Reflectance calculation of skin with malignant lesions and healthy skin

4. CONCLUSION

This paper proposes electromagnetics models for calculating the reflectance of the forearm and palm of hand skin. The reflectance of forearm skin was found to be varied in the range of 0.61 (at 30 GHz) to 0.47 (at 100 GHz), whereas it is in the range of 0.57 to 0.39 for the palm of the hand skin over the same frequency band. The importance of creating such a model for estimating skin reflectance across a wide range of MMW frequencies in which we can identify the range of reflectance across the human body. This will help in identifying abnormal reflectance values that will give indicators about the state of health of the human body as well as early detection of skin diseases. Moreover, MMW technology and devices are very expensive, and proposing skin models that can provide accurate calculations for human skin reflectance will be beneficial for healthcare professionals. For future work, it is recommended to collect more data and calculate the reflectance of the skin and then use these calculations to identify the threshold for healthy skin so any value that deviates from the norm will consider as an exceptional data point that indicates unhealthy skin.

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