Human Skin as Arrays of Helical Antennas in the Millimeter and Submillimeter Wave Range

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***Abstract* — Experimental evidence is henceforth presented indicating that human skin can be regarded as an array of low Q antennas. It is shown that physiological parameters such as blood pressure are mirrored in the temporal behaviour of the reflected spectral response to a high degree of correlation.**

I. INTRODUCTION And BACKGROUND

Recent studies of the minute morphology of the skin by optical coherence tomography (OCR) [1, 2] showed that the sweat ducts in human skin are helically shaped tubes, filled with a conductive aqueous solution. This, together with the fact that the dielectric permittivity of the dermis is higher than that of the epidermis [3], brings forward the supposition that as electromagnetic entities, the sweat ducts could be regarded as low Q helical antennas. Inherent to this supposition is the requirement that the duct possesses an electrical conductance mechanism that is effective at the extremely high frequency (EHF) range. A mechanism that qualifies for such a requirement is fast proton hopping through distributed *H*-bond networks [4] along the duct inner surface.

A typical section of the skin organ around the sweat duct that was obtained by OCR is presented in Figure 1. As was noted above, the sweat duct is indeed a helical conductive tube which resembles a low Q antenna (Fig. 1).

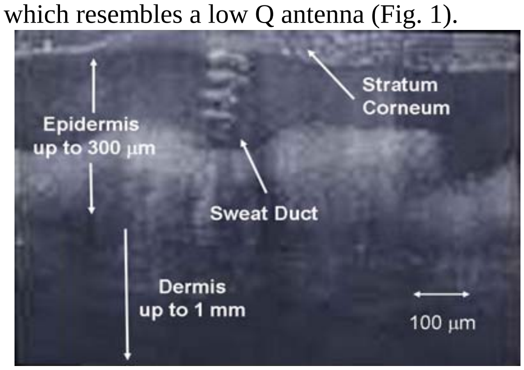

Figure 1 - 3D optical coherence tomography of a single human sweat duct in the human skin [1].

It is therefore expected that as an electromagnetic entity the skin organ will function as an array of such randomly spaced low Q antennas. Given this supposition, it is expected that the electromagnetic response of the skin will be determined by the geometry of the array, the typical dimensions of the helical tubes (the antennas) and by the dielectric properties and conductivity of their surrounding tissue. Applying basic antenna theory [5], we have estimated that the bandwidth of a typical surface element of the skin is in the sub-THz frequency range. Finally it is expected that the spectral response will be strongly dependent of the activity of the perspiration system through the latter effect on the conductivity of the duct.

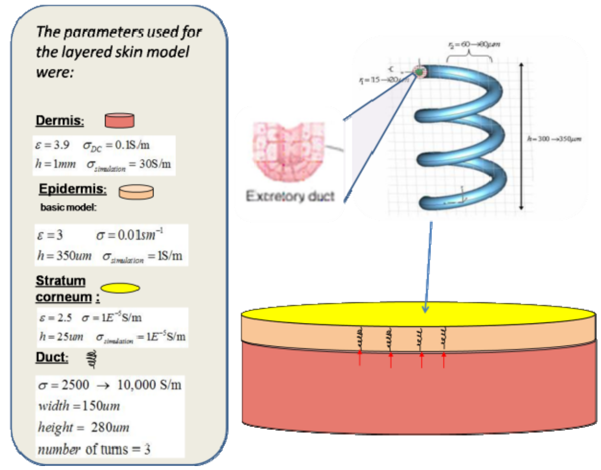

Figure 2 – The skin model used in the simulation study, consisting of three layers: Stratum Corneaum, Epidermis and Dermis. Eight sweat ducts are embedded into the model.

We investigated these possibilities by a series of detailed electromagnetic simulations (Fig. 2) [6] on a simplified skin model.

II. RESULTS

The underlying supposition was further investigated by a series of in vivo measurements of the reflection coefficient of the palm skin of several subjects. The measurements were done in the spectral range of 75 GHz to 110 GHz using a Vector Network Analyzer. In order to avoid parasitic reflections and diffraction effects the first set of measurements was done in a system that was configured for near field measurements. The initial measurement was done when the subject was fully rested. The subsequent measurement was done immediately after a period of 20 minutes of intense jogging, and was followed by a series of measurements at 1 minute intervals. The results indicated a pronounced difference between the reflectance spectra that were measured in the calm state and those following physical activity (see Fig. 3a,[6]). The results are attuned with simulations of wave propagation through structures embedded with helical antennas (Fig. 2 and Fig. 3b.[6]) with dimensions similar to the real sweat ducts. We calculated the integral signal power $\langle I(t) \rangle$ obtained from reflection coefficient measurements in the frequency band 75 GHz – 110 GHz of a palm of a person:

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$$\langle I(t)\rangle = \frac{1}{(f_2 - f_1)} \int_{f_1}^{f_2} |R(f,t)|^2 df \qquad (1)$$

where $R(f,t)$ is the palm reflection coefficient measured from a subject after physical activity, f_1=75 GHz and f_2=110 GHz. In Figure 4 the value $W(t)=\langle I\rangle_{max} - \langle I(t)\rangle$ at rest following 20 minutes of intense exercise is compared with the time behaviour of the person's pulse, and his skin temperature. It is seen that that the integral signal power is not correlated with the skin temperature of the subject during the rest period following the extensive physical training. At the same time a strong correlation with the pulse rate is observed.

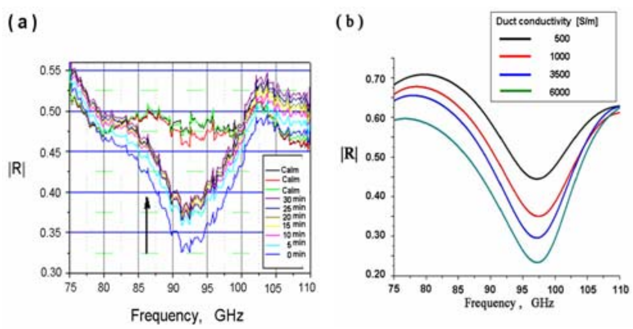

Figure 3 (a) Measurements of the modulus of the reflection coefficient *R* of the human palm in the frequency region 75 GHz to 110 GHz. The subject was measured using VNA HP 8510C in the near field in a calm state and then during 30 minutes relaxation after intense physical activity. The arrow on the graph indicates the direction of the time line and shows how the signal returns to the calm state with relaxation; (b) The simulation of the reflection coefficient from 8 coils embedded in an idealized skin.

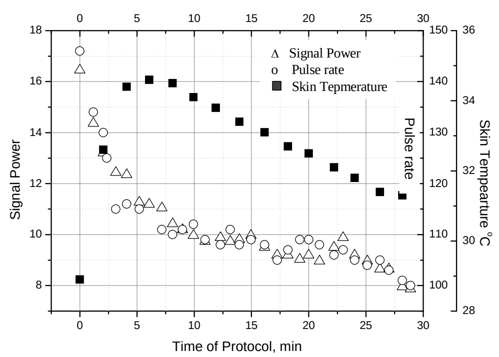

Figure 4 The typical time behaviors of the signal power obtained from the reflection coefficient of a subject's palm, a concurrent pulse of the same person at rest following intense exercise and the temperature of the subject's skin.

In a second set of measurements the palm was held steady by a stand that was placed 22 cm from the horn antenna at the input of the VNA, and a dielectric lens was used to collimate the beam. Sets of measurements were taken from an ensemble of 13 subjects differing in gender, age and ethnic origin. Each set included a measurement of the skin reflectance, and concurrent recordings of the pulse rate, the systolic blood pressure, and the skin temperature. A strong correlation was found between the temporal behaviour of the physiological parameters and the skin reflectance[6]. These experimental results substantiate the hypothesis put forward above, namely, that the electromagnetic (EM) response of the human skin in the sub-THz frequencies is governed by its morphology, i.e. the helical structure of the sweat ducts. It should be noted that, over the past 50 years, a number of phenomena indicating a non thermal mechanism[7,8,9] in the EM response at the sub-THz frequencies of various biological systems have been reported. It has been noted that there is a correlation between physiological test and mental effort. We expect therefore, that this methodology should also demonstrate sensitivity to mental or emotional stress.

The results reported above can form the basis for interpreting these observations, to which no satisfactory explanation has hitherto been offered. Furthermore, these results lead to the conception of a generic technology for real time remote sensing of biometric parameters such as the pulse rate and the blood pressure. As such this technology can become the basis for applications in the biomedical engineering arena where remote monitoring offers advantages

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