Human Physical Condition RF Sensing at THz range

A. Vorobyov[1], E. Daskalaki[1], C. Hennemann[1], J.-D. Decotignie[1]

***Abstract*— The skin response to high radio frequency has been associated with the human physical condition and most prominently with the stress. The objective of this study is to investigate the possibility to detect mental and light physical stress through the measurement of skin reflectance in the mm-wave/sub-THz band. Two frequency bands have been considered, 75-110 GHz (Band-I) and 325-500 GHz (Band-II), while the measurements have been performed in the three different locations, the arm, the dorsal side of the hand and the fingertip. The measurement setup is discussed in detail and the reflectance spectrum is demonstrated. The results illustrate a difference in skin reflectance under rest and stress in Band-II which ranges from 3.5 dB at the finger to 7 dB at the hand. The outcomes of this study indicate the feasibility of stress detection through skin reflectance measurement and serve as a suggestion for deeper exploration of higher frequency bands.**

I. INTRODUCTION

Various sources in literature have reported the possibility to detect stress based on changes in the Galvanic Skin Response (GSR) [1], [2]. It has also been shown that the GSR is correlated with the reflection coefficient of the skin and that it is possible to measure it via changes in the skin's reflectance at frequencies in the mm-wave / sub-THz band.

Feldman et al. [3] first provided experimental evidence that the skin spectral response can be associated with physiological processes that excite the perspiration system. One striking example of such process is stress. More specifically, it has been proposed that the sweat ducts exhibit electromagnetic behavior due to the resemblance of their shape to helical antennas. The skin reflectance has been used to detect stress due to physical activity and was further correlated to heart rate and blood pressure. The same group has conducted a number of studies including both experimental and simulation work towards modeling the skin sweat ducts and investigating their spectral properties in a frequency range from 75 to 450 GHz [4], [5]. Moreover, the association of skin reflectance to mental stress has been demonstrated in the frequency bands of 75-110 GHz and 110-170 GHz [6]. Recently, the reflection of the human palm has been recorded using TH-imaging at 100 GHz and correlated to the distribution of sweat pores in the respective region under different stress levels [7]. In a different study [8], the morphological and dielectric features of human sweat ducts have been investigated and the resonance frequency was identified based on time-domain spectroscopy data and theoretical models in the range of 332-590 GHz.

Currently, the aforementioned frequency bands are reachable with CMOS technology (detectors and sources) which is capable of operation up to about 500GHz. This fact opens the door to miniature, low power, safe and low cost solutions for potential applications in the domains of health (e.g. contactless scanner for stress sensing) and security (e.g. remote lie detector). Additionally, it has been reported that changes in the GSR may also be an indicator of medical conditions such as diabetes [9].

The combination of the reflectance spatial and temporal response (Fig.1) has the potential to lead to the creation of a generic method for remote sensing of physical and emotional state of human beings.

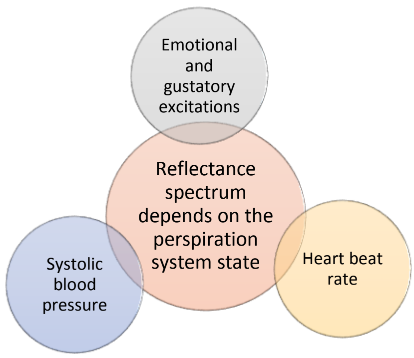


Figure 1: Skin reflectance potential diagram.

In the present study, the detection of physical and mental stress is investigated through measurement of the skin reflectance. Two frequency bands proposed in the literature, namely 75-110 GHz and 350-480 GHz have been investigated. To the authors' knowledge this is the first study that reports stress detection in the 350-480 GHz frequency band. The combination of the reflectance spatial and temporal response has the potential to lead to the creation of a generic method for remote sensing of the physical and emotional state of human beings.

II. METHODS

A. Measurement setup

Two frequency bands were considered, Band-I (75-110 GHz) and Band-II (325-500 GHz). To support both bands, commercially available transmitters/receivers have been used

* The research leading to these results has received funding from the EU Framework program Horizon H2020 under grant agreement no. 644039 and was carried out in the frame of M3TERA project (Micromachined terahertz systems - a new heterogeneous integration platform enabling the commercialization of the THz frequency spectrum). A. Vorobyov, E. Daskalaki, C. Hennemann and J.-D. Decotignie are with Centre Suisse d' Electronique and de Microtechnique SA (CSEM), Neuchatel 2000, Switzerland (corresponding author: A. Vorobyov; phone: +41 32 7205587; e-mail: alexander.vorobyov@csem.ch).

Preprint submitted to 38th Annual International Conference of the IEEE Engineering in Medicine and Biology Society. Received March 14, 2016.

in the measurement setup [10]. Each transmitter and receiver set is equipped with a matched standard horn antenna operated at the selected frequency band.

The transmitter and receiver used during the test are active mixers. To operate each active module a local oscillator (LO) is required. The PXA and the Agilent generators are used as LO for transmitter (TX) and receiver (RX) accordingly (Fig. 2). The output signal from the receiver (RX) is gathered by a spectrum analyzer and then post-processed. The entire lab bench is connected through GPIB and both LO generators are synchronized (10MHz).

The measured reflected signal amplitude is recorded and post-processed on a personal computer. The specifications and block-diagram of the measurement setup are summarized in Table 1 and Fig. 2 respectively.

TABLE I. MEASUREMENT SETUP SPECIFICATIONS

Setup Band-I		
Active frequency multiplier TX / TXR 110		
	Frequency band	75-110 GHz
	Output power	~16 mW
	LO multiplication factor	6
	LO freq. range	12.5 - 18.4 [MHz]
Standard Gain Horn Antenna		
	Antenna gain	20-23 dBi
	Beamwidth	15˚
Area of the arm Illuminated during test		13.5×13.5 mm^2
Distance between arm and horn		~ 24.5 mm
Setup Band-II		
Active frequency multiplier TX / TXR 500		
	Frequency band	325-500 GHz
	Output power	0.02-0.03 mW
	LO multiplication factor	24
	LO freq. range	13.5 – 20.9[MHz]
Standard Gain Horn Antenna		
	Antenna gain	25-27 dBi
	Beamwidth	~8˚
Area of the arm Illuminated during test		7×7 mm^2
Distance between arm and horn		~ 24.5 mm

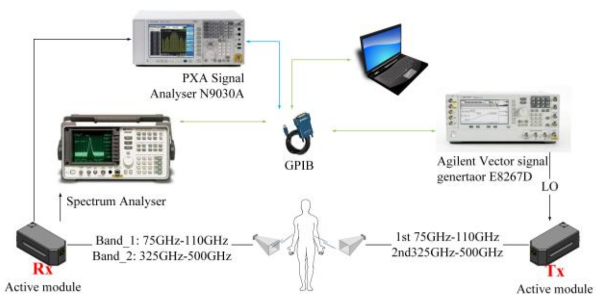


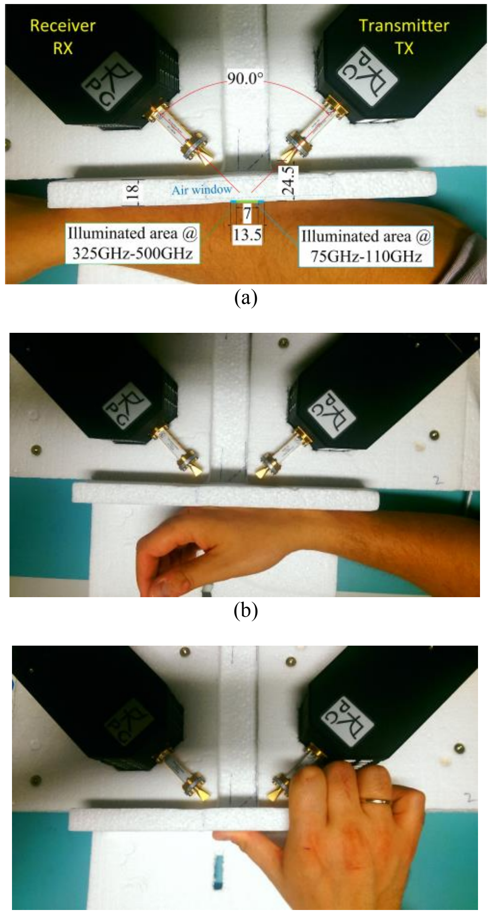
Figure 2: Skin reflectance measurement setup.

Both active modules on receive (RX) and on transmit (TX) sides are fixed on a plastic foam support to prevent any movement during the tests. They are angled at 90 degrees to each other as presented in Fig. 3a. The signal from the transmitter is passing through an air window in the plastic form wall. Thus, no additional signal losses are introduced.

The system setup is managed by in-house software that drives skin reflectance measurements over the specified frequency bands.

B. Test Description

The skin reflectance was measured during rest and after mental and physical stress. Physical stress was provoked using a dynamometer under 15 N of force for 5 minutes. Provocation of mental stress was achieved with the use of the Stroop Test [11] for 15 minutes. A stress measurement was always preceded by a resting period of at least 15 minutes. Three hand locations have been considered, (a) arm, (b) hand and (c) finger as shown in Fig. 3.



(a)

(b)

(c)

Figure 3: Measurement hand locations

III. RESULTS

Measurement repeatability was first investigated prior to any stress tests. The test was performed by repeating the same measurement at least five times under resting conditions with release and repositioning of the hand between the measurements. Sample results, shown in Fig. 4 and 5 demonstrate high measurement repeatability both in Band-I and Band-II.

The position of the hand was found to be important in the repeatability of the measurements. Displacement of the hand leads the measured signal amplitude attenuation. To this end,

Preprint submitted to 38th Annual International Conference of the IEEE
Engineering in Medicine and Biology Society. Received March 14, 2016.

the exact position of the hand was noted in order to avoid changes after removal and relocation.

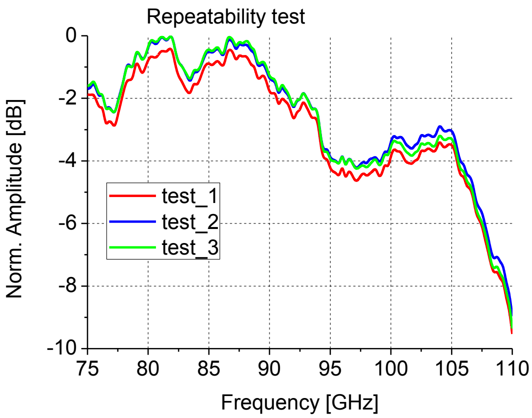


Figure 4: Repeatability test in Band-I

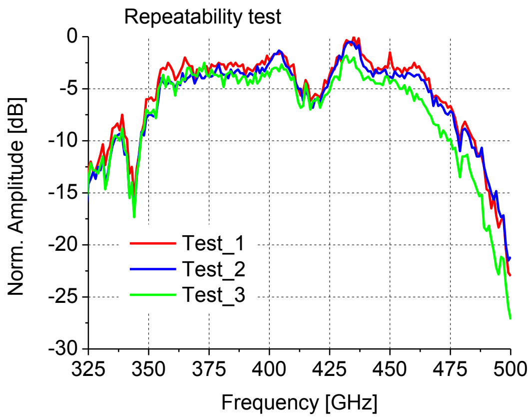


Figure 5: Repeatability test in Band-II

A. Arm

The measurements performed in the arm were also conducted in both frequency bands. Fig. 6 and Fig.7 present the skin reflectance measurements under rest and mental stress for one person. The figures show the portion of the respective band where the difference between the two states is more clearly observed.

In both cases, a shift in the reflectance is observed when the person undergoes mental stress. This shift is much more pronounced in Band-II where a decrease of approximately 4 dB is measured when the person is found under mental stress. It is important to note that, in both cases, the shape of the spectrum remains the same between rest and stress conditions. The results suggest that discrimination of stressing states can be achieved through measurement of skin reflectance in the arm in the frequency band of 440-480 GHz. Given the considerably better results obtained in this frequency range, only Band-II was considered for the rest of the measurements. Detection of physical stress has been also performed in this setup and the results are shown in Fig. 8.

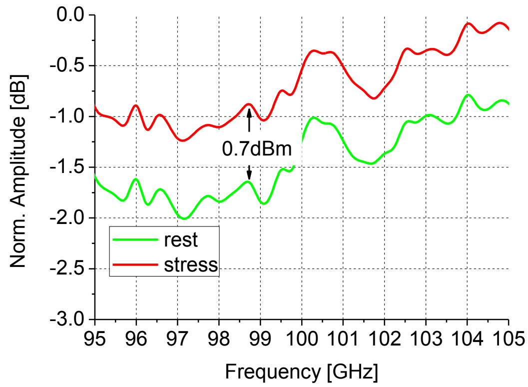


Figure 6: Skin reflectance under rest and mental stress in Band-I

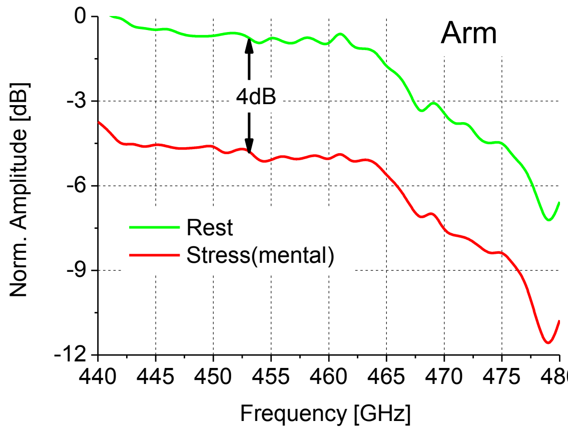


Figure 7: Skin reflectance under rest and mental stress in Band-II

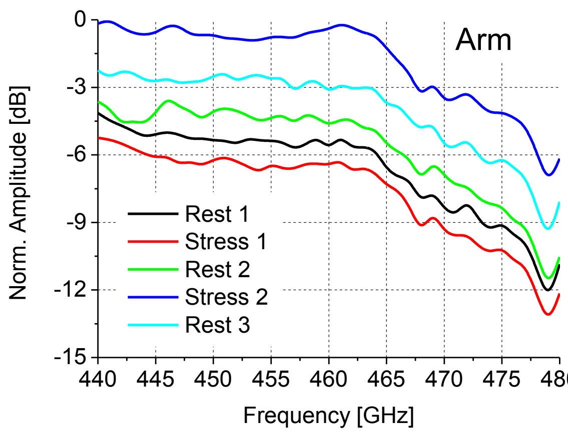


Figure 8: Skin reflectance under rest and physical stress in Band-II

The difference in this case is smaller as the physical load undertaken was relatively low. It has been observed that significant differences in the reflectance spectrum require heavier physical exercise. Again, the shape of the spectrum is the same as in the cases of rest and mental stress.

Preprint submitted to 38th Annual International Conference of the IEEE Engineering in Medicine and Biology Society. Received March 14, 2016.

B. Hand

In this testing setup, the skin reflectance was measured at the dorsal side of the hand. The results, shown in Fig. 9, demonstrate a difference of 7 dB between rest and mental stress states.

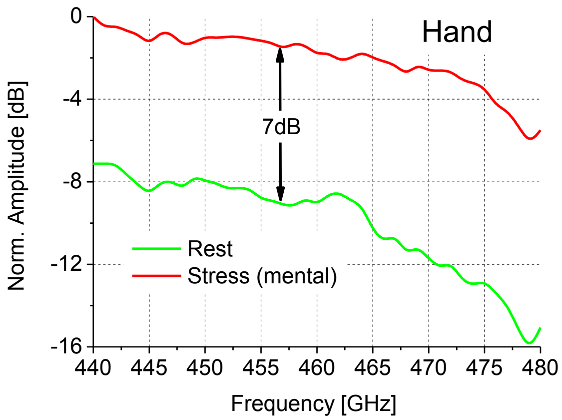


Figure 9: Skin reflectance in hand under rest and mental stress in Band-II

C. Finger

Similarly to the previous setups, the skin reflectance was measured at the tip of the thumb and the results are shown in Fig. 10.

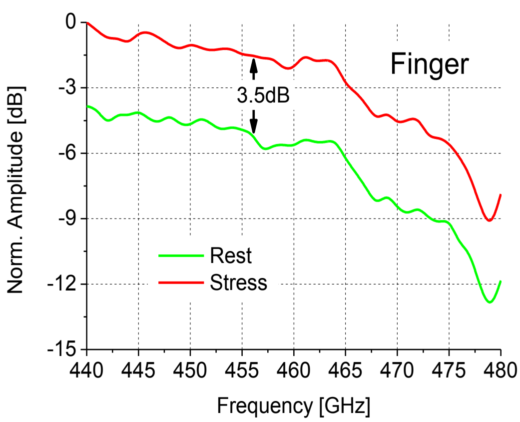


Figure 10: Skin reflectance in hand under rest and mental stress in Band-II

Once again, a clear difference is observed between rest and stress states. In contrast to the respective results of the arm, an increase in reflectance under stress is observed for the hand and the finger. A possible explanation may lay in the differences of the sweat ducts distribution between the arm and the hand. This observed difference has been remarked and remains to be extensively studied in our future work.

IV. Conclusions

A dedicated setup for the measurement of skin reflectance has been designed and discussed in detail. Measurements have been recorded under rest and during mental and light physical stress in the arm, hand and finger. Two frequency bands, Band-I (75-110 GHz) and Band-II (325-500 GHz) have been considered. The results provide convincing evidence that stress can be detected through the skin reflectance. About 1dB difference between rest and stress is observed at Band-I. Band-II has shown significantly higher (3dB-7dB) differences between the two states, suggesting that this frequency band should be explored in more depth. Future work includes expansion of the study to a high number of subjects, and investigation of different stress levels.

References

[1] M.V. Villarejo, B.G. Zapirain. A.M. Zorrilla, "A stress sensor based on Galvanic Skin Response (GSR) controlled by ZigBee," *Sensors*, vol. 12, no. 5, pp.6075-6101, 2012.

[2] H. Storm, K. Myre, M. Rostrup, O. Stokland, M.D. Lien, J.C. Raeder, "Skin conductance correlates with perioperative stress," *Acta Anaesthesiologica Scandinavica*, vol. 46, no. 7, pp.887-895, 2002.

[3] Y. Feldman, A. Puzenko, P.B. Ishai, A. Caduff, A.J. Agranat, "Human skin as arrays of helical antennas in the millimeter and submillimeter wave range," *Physical review letters*, vol. 100, no. 12, pp.128102, 2008.

[4] Y. Feldman, A. Puzenko, P.B. Ishai, A. Caduff, I. Davidovich, F. Sakran, A.J. Agranat, "The electromagnetic response of human skin in the millimetre and submillimetre wave range," *Physics in medicine and biology,* vol. 54, no. 11, pp.3341, 2009.

[5] I. Hayut, A. Puzenko, P. Ben Ishai, A. Polsman, A.J. Agranat, Y. Feldman, "The helical structure of sweat ducts: Their influence on the electromagnetic reflection spectrum of the skin," *Terahertz Science and Technology, IEEE Transactions on*, vol. 3, no. 2, pp. 207-215, 2013.

[6] E. Safrai, P.B. Ishai, A. Caduff, A. Puzenko, A. Polsman, A.J. Agranat, Y. Feldman, "The remote sensing of mental stress from the electromagnetic reflection coefficient of human skin in the sub-THz range," *Bioelectromagnetics*, vol. 33, no. 5, pp.375-382, 2012.

[7] Y. Feldman, P. Ben Ishai, H. Goldberger, A. Puzenko, I. Gutman, "Can the sub-THz image of skin be the new fingerprint? Visions in Biometrics,*"* in *40th International Conference Infrared, Millimeter, and Terahertz waves (IRMMW-THz),* pp. 1-3, 2015.

[8] S.R. Tripathi, E. Miyata, P.B. Ishai, K. Kawase, "Morphology of human sweat ducts observed by optical coherence tomography and their frequency of resonance in the terahertz frequency region," *Scientific reports*, vol. 5, 2015.

[9] K. Khalfallah, H. Ayoub, J.H. Calvet, X. Neveu, P. Brunswick, S. Griveau, V. Lair, M. Cassir, F. Bedioui, "Noninvasive galvanic skin sensor for early diagnosis of sudomotor dysfunction: application to diabetes," *IEEE Sensors Journal,* vol. 12, no. 3, pp.456-463, 2012.

[10] http://www.radiometer-hysics.de/products/mmwave-and-terahertz-products/spectrum-analyzer-extenders/fs-z-mixers/

[11] F.T. Silva J.R. Leite, "Physiological modifications and increase in state anxiety in volunteers submitted to the Stroop Color-Word Interference Test: A preliminary study," *Physiology & Behavior,* vol. 70 no. 1, pp. 113–118, 2000.

Preprint submitted to 38th Annual International Conference of the IEEE Engineering in Medicine and Biology Society. Received March 14, 2016.