Towards mm-wave camera assisted human stress gauging

Evgeny Shumaker[1], Dan Corcos[1], Paul Ben Ishai[2], Ilya Gutman [2], Yuri Feldman[2], Alexander Puzenko[3] and Danny Elad[1]

[1]IBM Research – Haifa, Haifa University Campus, Haifa 31905, Israel

[2]Hebrew University of Jerusalem, Department of Applied Physics, Givat Ram, Jerusalem 91904, Israel

[3]Neteera Ltd, Givat Ram, Jerusalem 91904.

***Abstract*—Recent publications show strong correlation between the sub-THz reflection coefficient of a human skin and various stress related ECG parameters. The main hypothesis explaining the phenomenon is based on the coiled nature of human sweat ducts. The way to the development of disruptive commercial applications exploiting this phenomena, traverses through multi-pixel imaging of the human skin tissue (in the sub-THz range). Towards that goal, a fully integrated and packaged SiGe based total-power single pixel receiver (operating in the W-band) has been employed for human stress gauging in both reflectometric and radiometric modes. Initial (and quite encouraging) results are brought forth in this article.**

I. INTRODUCTION

ADVANCES in the state-of-the-art silicon based processes (such as deep sub-micron CMOS and SiGe BiCMOS) are paving way for disruptive systems operating at the very doorstep of the THz range. One such system is a Focal Plane Array (FPA) millimeter-wave imager, designed to provide high-resolution combined with large instantaneous field-of-view. Featuring physical pixel plurality and integrated interfaces, it is envisioned to capture live imagery that is currently out of reach of scanned systems, even those based on high performance III-V electronics.

A prominent example for an application that could benefit from such camera is the human skin imaging that promises new and exciting methods for remote stress gauging in humans [1]. Researchers have previously shown that very high correlations exist between the reflection coefficient of a human skin in an area populated by sweat ducts and various physiological parameters (generally acknowledged as stress markers). The current hypothesis stipulates that this correlation stems from the fact that sweat ducts in high primates feature a helical structure, resembling that of a helical antenna. When filled with a conductive fluid (which sweat is known to be), those antennae display significant axial mode responses in the 300-400 GHz range. Normal mode responses and layer interference effects are evident in the W-band, both being heavily influenced by the ac conductivity of the sweat ducts [2].

An amplified receiver (Fig. 1) complemented by a flip-chip style system-in-package solution (Fig. 2) have been previously developed within IBM HRL, as to act as building blocks of future mm-wave FPA cameras. The receiver and its wafer-level characterization have been already reported on in [3]. The sensitivity of the packaged receiver averages at about 50 fW/srHz within the 86-102 GHz frequency range. This packaged pixel is employed in both reflectometric (-50 dBm illumination power) and radiometric style stress-tests experiments. Optical setup and experiment protocol employed are described in Fig. 3. The spot size of both the illuminating and the receiving antennae was calculated (given the range and the antennae gain) to about 9 cm in diameter, hence covering almost the entire hand-palm. The test was reiterated with 4 different test subject in reflectometric mode, and one subject in radiometric (without any external illumination) mode.

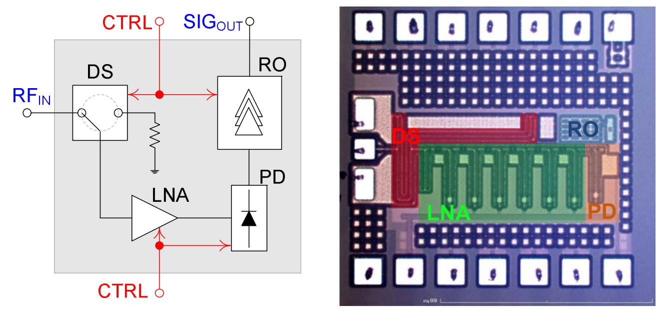

Fig. 1. (Left) Schematic diagram of the Dicke-radiometer implementation. (DS - Dicke switch, LNA - Low noise amplifier, PD - power detector, RO – Read-out). (Right) Pixel die micrograph.

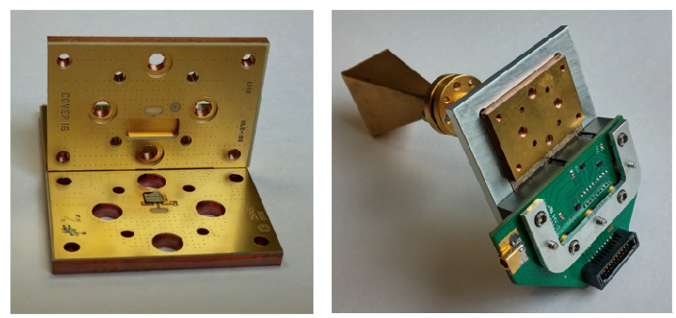

Fig. 2. (Left) Pixel die flip-chiped on an organic substrate with WR-10 transition, (right) Assembled pixel with horn antenna used for the study.

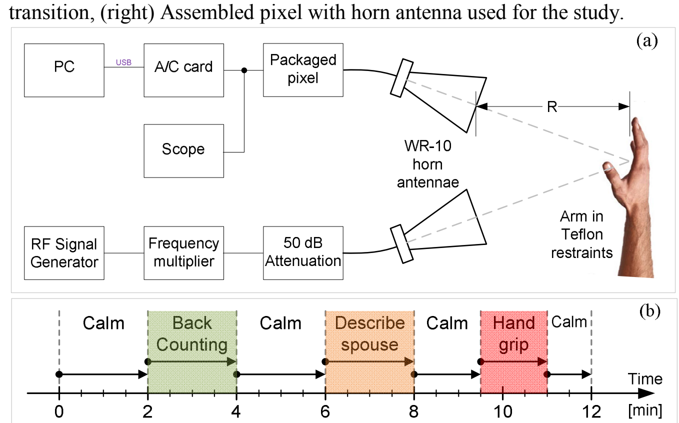

Fig. 3. (a) Optical setup (similar to [1]) employed for both reflectometric and radiometric (the RF generator is switched off) tests (b) 12- minute experiment protocol combining mental (back counting, spouse's morning gown description) and physical stress (hand grip) interleaved with periods of rest.

II. RESULTS

Fig. 4 shows normalized reflection coefficient (left axis) juxtaposed to the heart rate monitor readings (right axis), as recorded during the test protocol described in Fig. 3 for four

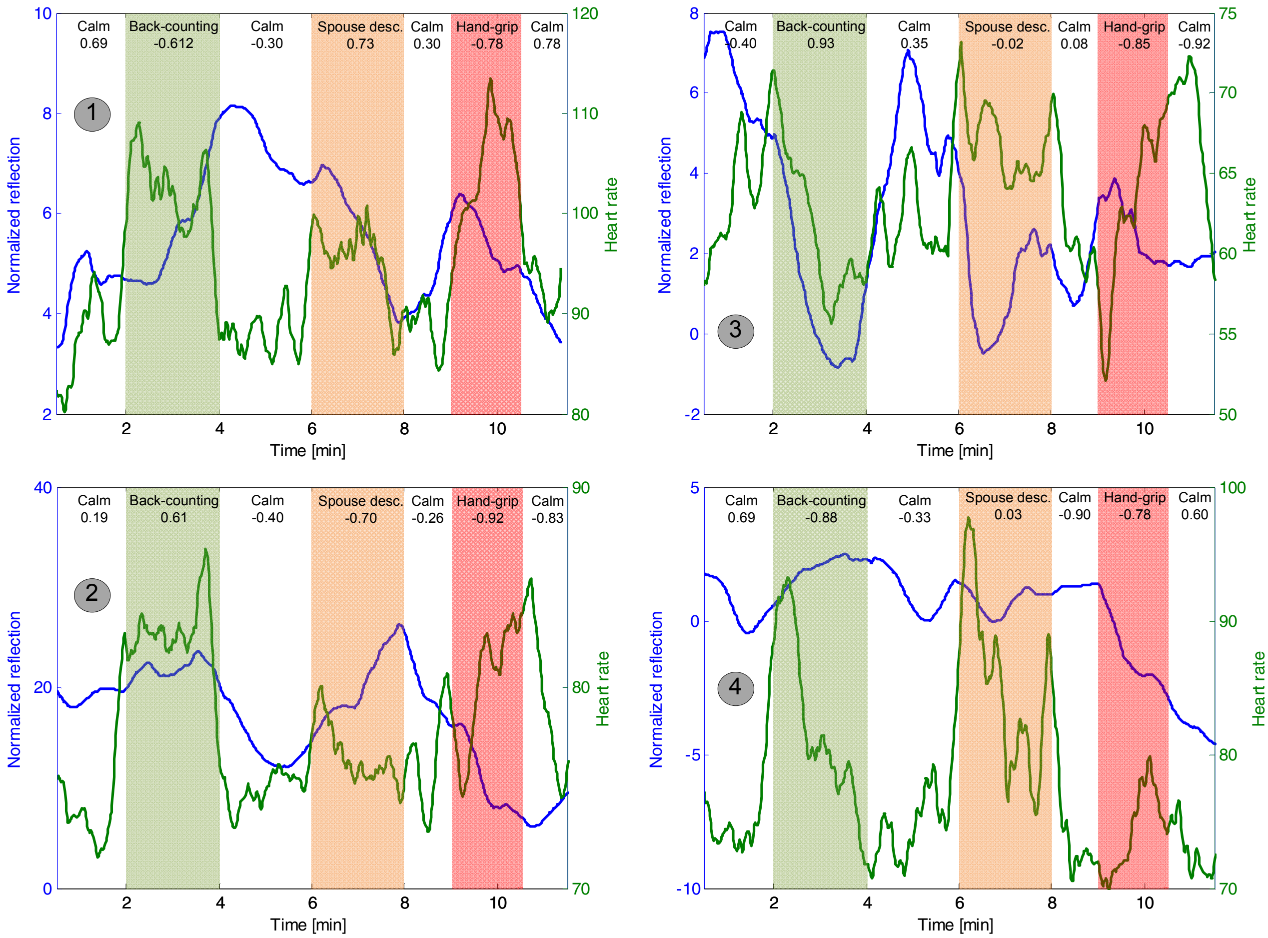

Fig. 4. Normalized reflection coefficient and heart rate vs. time for 4 test subjects. Correlations, computed per activity, are marked above.

test subjects. Initial analysis reveals very strong and similar anti-correlation in case of the hand grip exercise (physiological stress). Similar results are obtained for the radiometric measurement, shown in Fig. 5, with the strongest correlation (also negative) occurring for the hand grip test.

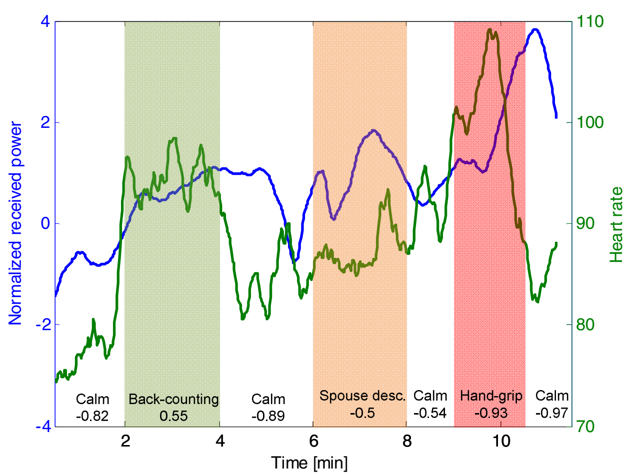

Fig. 5. Normalized detected power and heart rate vs. time for radiometric measurement. Correlations are computed per activity (denoted below).

It is relatively safe to say that further analysis and increased sample size are needed to establish the reasons for large correlation or a complete lack of it as is evident in other parts of the stress protocol. However, there is also some evidence to suggest that W-band reflectometry and radiometry measurements can be used for physical stress estimation as stems from the large anti-correlation of heart rate with the (normalized) reflection and received power.

REFERENCES

[1]. E. Safrai, P. Ben 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, July 2012.

[2]. I. Hayut, A. Puzenko, P. Ben Ishai, A. J. Agranat, Y. Feldman, "The Helical Structure of Sweat Ducts: Their Influence on the Electromagnetic Reflection Spectrum of the Skin," *IEEE Transactions on Terahertz Science and Technology*, vol.3, no.2, pp.207-215, March 2013.

[3]. E. Shumaker, D. Elad, "Analog read-out integrated W-band Dicke-radiometer in 0.13um SiGe design and characterization of W-band radiometer RFIC intended for FPA imager," *2014 European Microwave Conference (EuMC)*, pp.1130-1133, Oct. 2014.