COST EMF - MED (Action BM1309):
European network for innovative uses of EMFs in biomedical applications

STSM Report:
Dielectric Measurements of Tissue

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Host Institution: National University of Ireland, Galway). Contact: Martin O'Halloran.
STSM Reference: ECOST-STSM-BM1309-33049
STSM dates: FROM 3rd April 2016 TO 30th April 2016

Abstract:
The measurement of dielectric properties of human tissue was the subject of study of this Short Term Scientific Mission. Samples of mostly fatty human tissue extracted during breast cancer surgeries were analysed and initial *ex vivo* measurements were compared with data available in the literature, in a frequency range between 500MHZ and 8.5GHz. An Agilent measuring system (Vector Network Analyser combined with a slim probe) was used.

A. Purpose of the STSM
The purpose of this STSM was to learn and familiarise myself with the measurement of dielectric properties of biological tissues. I have a particular interest in the dielectric properties of axillary and cervical lymph nodes, which are commonly affected in patients with breast and head & neck cancers, respectively. Currently, I am waiting for the evaluation of one individual funding scheme (Portuguese FCT Investigator Starting Grant) on the topic of axillary lymph node diagnosis, and I am preparing further grant proposal in the area of cervical lymph nodes, and this STSM allowed me to establish valuable collaboration with the National University of Ireland Galway to be further extended to future projects. The work in this STSM is aligned with the objectives of WG1 (Cancer EMF interactions and applications) and WG3 (EMF dosimetry - in silico tools & measurements).

B. Work Description
I visited Dr Martin O'Halloran at the Translational Research Facility in the National University of Ireland in Galway who recently started a 5-year ERC Starting Grant dedicated to the measurement of dielectric properties of biological tissue, called "BioElecPro".

During this STSM, I learnt to complete the following:
1) Learn about high-accuracy calibration of a Network Analyser for dielectric property measurement of biological tissues
2) Learn about the verification of the above calibration
3) Addressing the estimation of measurement uncertainty
4) Learn about controlling clinical confounders when measuring dielectric properties of tissues (e.g. electronic noise, cable movement)
5) Laboratory measurement of dielectric properties of a number of biological tissues (fat tissue removed from the breast during surgeries for cancer removal) – other properties will also be measured, for example, temperature and pressure
6) Full analysis of measured tissues (still ongoing)
7) Results will be published and also used as proof-of-concept to support new grant proposals towards the development of new medical devices – please note that due to the urgency of delivering the STSM report, not all results are exploited in this document.

C. Results

Firstly, the system was calibrated. The calibration type which was performed was the air/short/water. First the slim-probe was calibrated in air (open-circuit). It was then calibrated with a shorting block with the help of a metal shorting pad (short-circuit). Finally the system was calibrated with deionised water at room temperature. Validation measurements of deionised water were completed before and after measurements to assure that these measurements matched well, and so the system was performing correctly during the measurement of biological tissues. Figures 1 and 2 show the validation measurement before and after measurements, respectively. It was observed that it is essential to have the probe at the same depth between measurements as this can affect validation measurements greatly. Figure 3 shows a validation measurement in which the probe was immerged at a different depth to that during calibration.

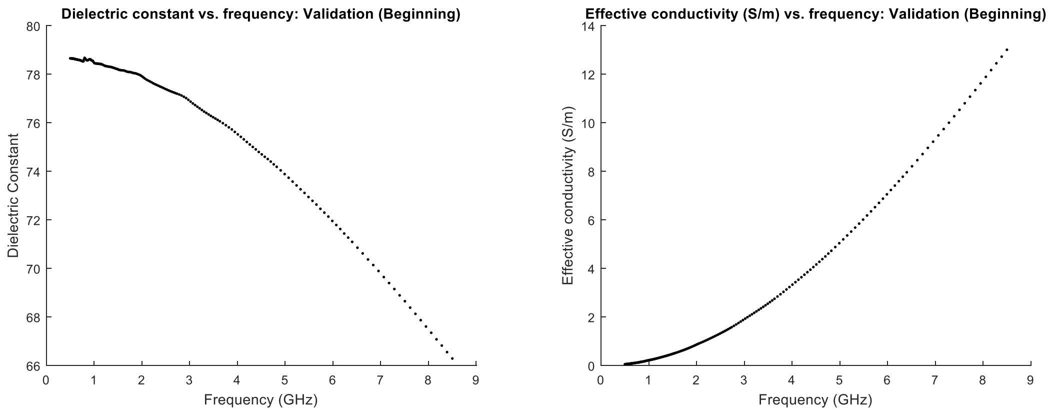

Figure 1. Dielectric constant and effective conductivity of deionised water ahead of measurement of biological tissue.

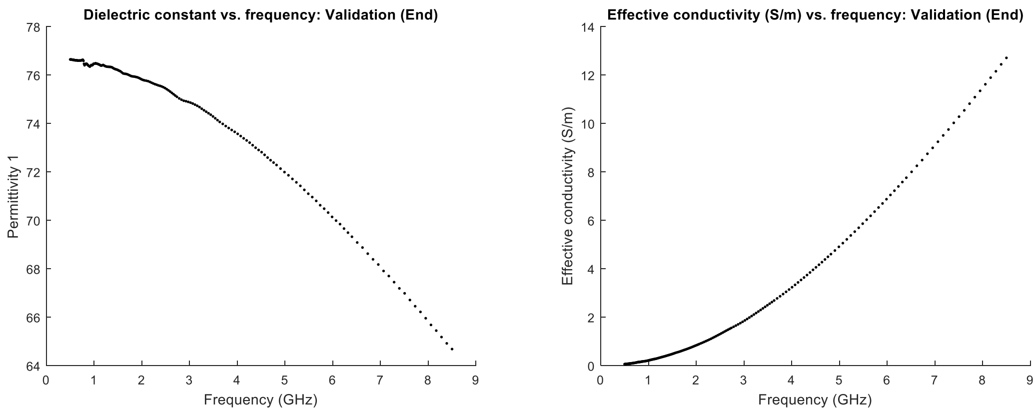

Figure 2. Dielectric constant and effective conductivity of deionised water after the measurement of biological tissue.

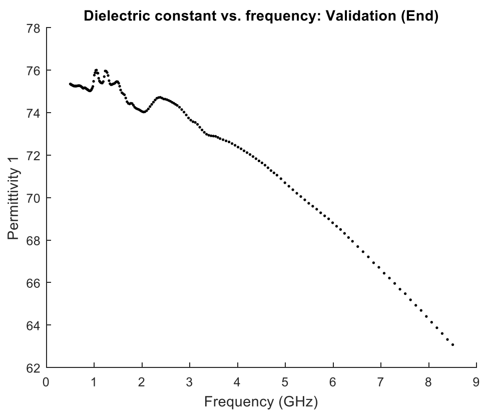

Figure 3. Dielectric constant and effective conductivity of deionised water after the measurement of biological tissue, when the slim probe is placed at a different depth compared to the depth used during calibration.

Figure 4. Measurement setup at the TRF facilities, National University of Ireland Galway.

State-of-the-art dielectric properties of excised tissues from breast mastectomies (for cancer removal) were measured. A publication with these initial results, together with further work at the host institution, is expected. Unfortunately, the dielectric properties of Axillary Lymph Nodes and Cervical Lymph Nodes were not measured – these tissues are not often made available to pathologists, and a longer period at the host institution would have been needed to come across such tissues. Instead, together with the host institution, we have prepared an initial protocol to be followed in future measurements for such tissues can be measured when they become available. These particular future measurements will be directly introduced in numerical phantoms of the breast and head & neck regions that I will be developing in future projects.

During this STSM, I was able to measure 3 samples of human fat tissue. In this report I will show partial results of the third tissue sample which was analysed: a large fat sample excised during the surgical removal of invasive ductal carcinoma.
The measuring system comprises a Vector Network Analyser from Agilent (E5063A, Keysight) combined with a measuring slim probe (85070E kit, Agilent) – Figure 4. Dielectric properties of tissue were measured in a range between 500MHz and 8.5GHz

Several locations of the sample were assessed, in this report we show successive measurements related to a fat region (the slim probe is in contact with this region in Figure 5) and to a vascularised region, with blood accumulation (the slim probe is in contact with this region in Figure 6).

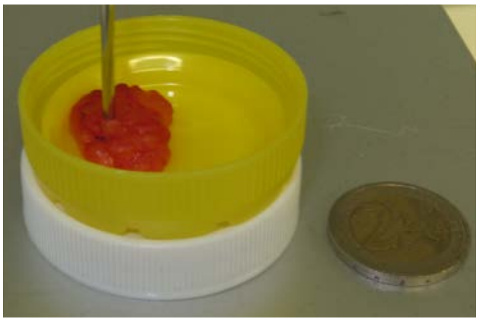

Figure 5. Measurement location of fat tissue in sample 3.

Figure 6. Measurement location of vascularised region in sample 3.

Table 1. Measurement location of fat tissue in sample 3.

Time order	Measurment time (hours:minutes)	Temp (ºC)	Colour
1	19:02	21.8	Blue
2	19:03	21.8	Black
3	19:04	*Not measured*	Green
4	19:05	*Not measured*	Red

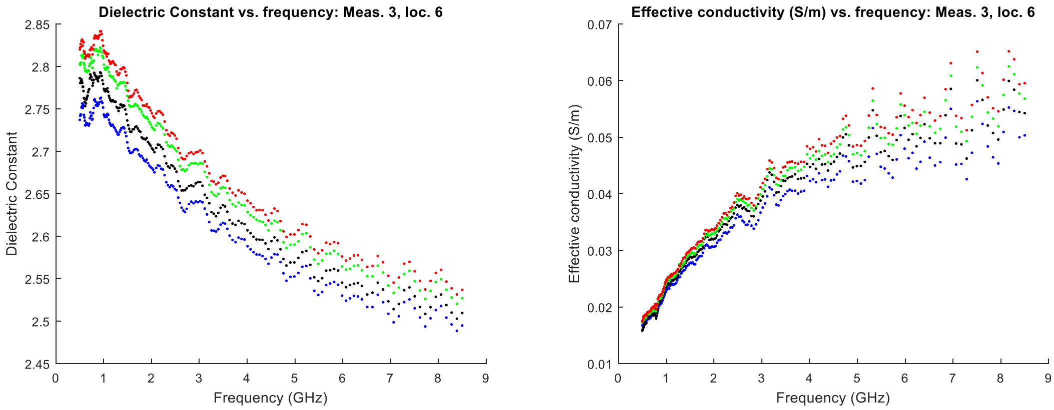

Figure 5. Dielectric constant and effective conductivity of fat tissue in sample 3. Different colours reflect the order of the measurement: blue – 1st measurement, black – 2nd measurement, green – 3rd measurement, red – 4th measurement.

Table 2. Measurement location of vascularised region in sample 3.

Time order	Measurement time (hours:minutes)	Temp (ºC)	Colour
1	18:53	21.8	Blue
2	18:56	Not measured	Black
3	18:57	Not measured	Green
4	18:58	Not measured	Red
5	18:59	Not measured	Cian

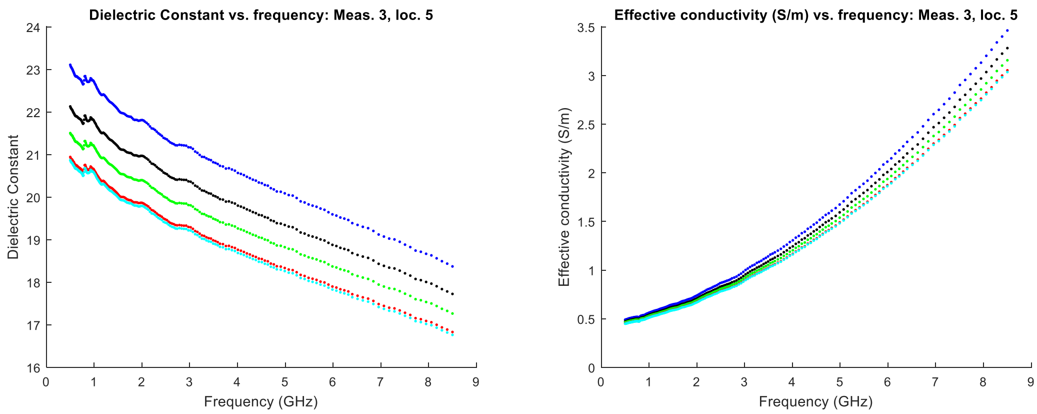

Figure 6. Dielectric constant and effective conductivity of vascularised region in sample 3. Different colours reflect the order of the measurement: blue – 1st measurement, black – 2nd measurement, green – 3rd measurement, red – 4th measurement, cyan – 5th measurement.

As expected, the fat measurement results shown in Figure 4 match well with those in the literature [1, 2]. Figure 7 is a reproduction of the dielectric properties of breast tissue. It can be visually inspected that our measurements match well with those in the literature regarding group 3.3.

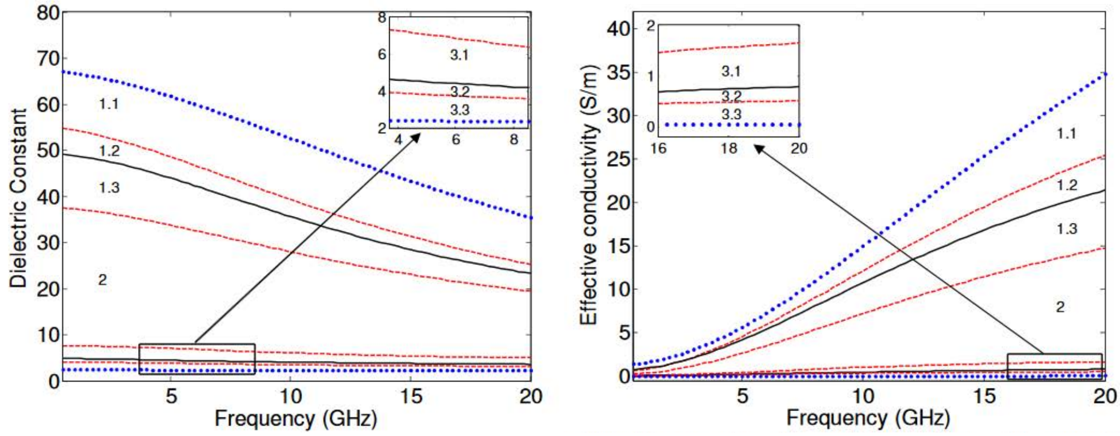

Figure 7. The dielectric properties of normal breast tissue [1] (no copyright infringement intended with the reproduction of this figure). Groups 3.1, 3.2 and 3.3 correspond to fat tissue.

The vascularised region was not compared to blood measurements in the literature as we did not have a ground truth knowledge of the percentage of blood and fat tissue, but as expected we observed an increase of dielectric properties, when compared to fat measurements.

To note that the dielectric constant and effective conductivity properties of fat tissue do not vary significantly with time lapse between measurements – these are within the measurement error –, although a small increase of the dielectric properties can be observed as time goes by. Conversely, the dielectric constant and effective conductivity properties of the vascularised region decreased over time – we hypothesise that the blood in touch with the slim probe dries over time, hence less water content will result in the decrease of the dielectric properties (quite noticeable in Figure 6).

The temperature of the samples did not vary significantly between measurements. The tissue sample was excised significantly long before measurement, so the temperature of the tissue was stable at room temperature. Errors associated with measurements will be calculated later, as well as full measurements of all 3 samples.

D. Future collaboration with host institution

Together with the host institution, we are writing a protocol which will be followed when axillary and/or cervical lymph nodes become available for measurement. I will apply for 1 or 2 grants in collaboration with the National University of Ireland (other collaborations with EMF-MED and MiMed participants is extremely likely) regarding the development of a microwave imaging device of cervical lymph nodes.

E. Expected Publications

We anticipate writing a journal paper with the following tentative title “Clinical confounders in the measurement of dielectric properties of the biological tissue”.

F. Others: References

1. E. Zastrow *et al*, *Database of 3D Grid-Based Numerical Breast Phantoms for Use in Computational Electromagnetics Simulations, in:* http://uwcem.ece.wisc.edu/home.htm

2. M. Lazebnik *et al*, "A Large-Scale Study of the Ultrawideband Microwave Dielectric Properties of Normal, Benign and Malignant Breast Tissues Obtained from Cancer Surgeries", *Phys. Med. Biol.*, 52, 6093–6115, 2007

Confirmation by the host institution of the successful execution of the STSM:

We confirm that Raquel Cruz da Conceição has performed the research work as described above.

Contact Person of Host Institution Martin O’Halloran Signature	Name of researcher Raquel Cruz da Conceição Signature
	Raquel Cruz da Conceição