



**HAL**  
open science

## **RF characterization of intracellular microalgae lipids**

Abdelhatif El Fellahi, Thierry Bore, Pierre Bodénès, Sakina Bensalem, Bruno Le Pioufle, Filipa Lopes, E Martinsic, Olivier Français

► **To cite this version:**

Abdelhatif El Fellahi, Thierry Bore, Pierre Bodénès, Sakina Bensalem, Bruno Le Pioufle, et al.. RF characterization of intracellular microalgae lipids. 30th anniversary Eurosensors Conference, Sep 2016, Budapest, Hungary. pp.1287-1290, 10.1016/j.proeng.2016.11.449 . hal-01368312

**HAL Id: hal-01368312**

**<https://hal.science/hal-01368312>**

Submitted on 26 Jun 2023

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution - NonCommercial - NoDerivatives 4.0 International License



30th Eurosensors Conference, EUROSENSORS 2016

## RF Characterization of intracellular microalgae lipids

A. El Fellahi<sup>a</sup>, T. Bore<sup>a,d</sup>, P. Bodenes<sup>a,b</sup>, S. Bensalem<sup>a,b</sup>, B. Le Pioufle<sup>a</sup>, F. Lopes<sup>b</sup>, E. Martincic<sup>c</sup>,  
O. Français<sup>a\*</sup>

<sup>a</sup> SATIE, UMR CNRS 8029, ENS Cachan, Univ. Paris-Saclay, Cachan, France

<sup>b</sup> LGPM, EA 4038, CentraleSupélec, Univ. Paris-Saclay, Chatenay-Malabry, France

<sup>c</sup> Centre de Nanosciences et de Nanotechnologies, UMR CNRS 9001, Univ. Paris-Sud, Université Paris-Saclay – Orsay, 91405 Orsay, France

<sup>d</sup> School of Civil Engineering, University of Queensland, St Lucia, Australia

### Abstract

This work presents an original approach to sense the lipid intracellular content of microalgae, by the Radio Frequency (RF) dielectric spectral characterization of these unicellular organisms. To do so, a “homemade” open-ended coaxial sensor was associated to a Vector Network Analyzer (VNA), which allowed a broadband characterization in the frequency range from 30 MHz to 3 GHz. The sensor combines a coaxial line with a modified SMA connector. This study shows that the lipid quantification can be determined with the complex dielectric spectra properties extracted from the reflection coefficient ( $\underline{S}_{11}$ ) measurement. A calibration of the open-ended coaxial probe is performed by using three different conditions (vacuum, water, methanol) from which the complex dielectric behavior is mastered. A model inversion is finally achieved to estimate the complex permittivity spectrum of the biological samples in a large frequency range, which is related to the microalgae lipid content.

© 2016 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

Peer-review under responsibility of the organizing committee of the 30th Eurosensors Conference

**Keywords:** RF characterization; Broadband; RF sensors; Intracellular; Microalgae; lipid accumulation;

### 1. Introduction

Electric characterization of biological species is classically used as a non invasive way to extract physiological parameters (cell diameter, cell membrane properties...) but the main available techniques are based on low frequency ( $f < 10\text{MHz}$ ) measurements using direct impedance measurement [1] or electrorotation experiments [2]. By

\* Corresponding author. Tel.: + 33 1 47 40 77 36; fax: +33 1 47 40 21 99.  
E-mail address: [olivier.francais@satie.ens-cachan.fr](mailto:olivier.francais@satie.ens-cachan.fr)

using dielectric spectroscopy based on Frequency Domain Reflectometry (FDR), cell intracellular characterization is possible by the penetration of the RF waves within the cell. Results depend strongly on cell composition [3]. Dielectric measurements at Radio Frequency allow intracellular and noninvasive characterization without the need of any sample treatment. In 2014, M. Al Ahmad *et al.* have presented a RF characterization of microalgal lipid content [4]. However, the method is based on a resonant technique which does not retrieve the dielectric spectrum over a wide frequency band. Here, the application of the RF spectroscopy to monitor *in situ* and in real time the lipid content of the microalgae “*Chlamydomonas reinhardtii*” in a bioreactor for algal biofuel production [5] is presented [6]. The set up description is given in section 2. RF measurements and an inversion model applied to estimate the complex permittivity spectrum of the microalgae are presented in section 3.

## 2. Set-up description

To address the increasing need in characterization of biological cells, innovative measurement techniques must be developed. Dielectric measurements at Radio Frequency can meet this challenge, and provide solutions to the limitations of some monitoring methods. Indeed, RF waves allow intracellular and noninvasive characterization without any sample treatment.

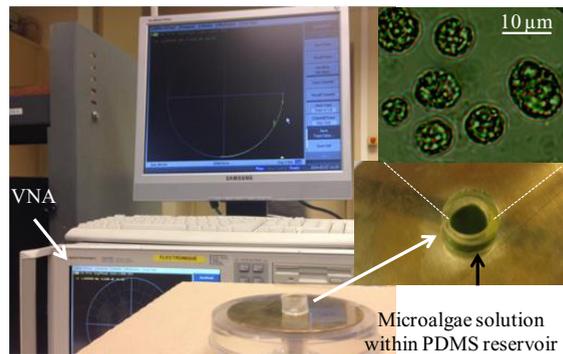


Fig. 1. Photography of the test bench. The inset is optical microscope photography of suspended microalgae solution. (1 ml – number of cells  $\sim 7 \times 10^7$ ).

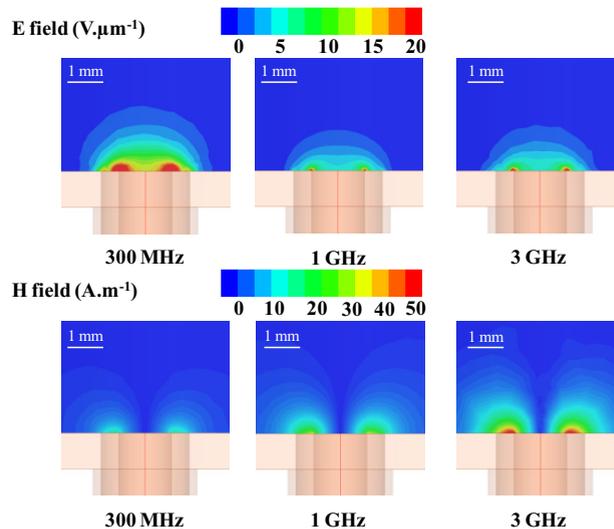


Figure 2: Magnitude of the electrical and magnetic field distributions at the test frequencies 0.3, 1 and 3 GHz in cross-section (on conductive medium;  $0.1 \text{ S.m}^{-1}$ ).

The method presented in this paper is based on an adapted open-ended coaxial probe that is classically used to characterize porous material [4] and enables here a broadband measurement of RF scattering parameters  $\underline{S}_{11}$  of

microalgae suspensions. The Fig.1 shows the photography of the test bench using a VNA (E5061B) with the “homemade” probe. The microalgae suspension is inserted inside PDMS reservoir with 10 mm diameter above the probe.

The probe is a coaxial line and a modified SMA connector. The diameter of the inner conductor is equal to 1.5 mm, while the inner diameter of the outer conductor is equal to 4.2 mm. The distribution of the electrical and magnetic fields in the vicinity of the probe is investigated by means of electromagnetic simulations (@Ansys/HFSS) in the frequency range of 0.03 - 3 GHz. Fig. 2 presents the magnitude of the electrical and magnetic field distributions (on conductive medium;  $0.1 \text{ S.m}^{-1}$ ) at the test frequencies of 0.3, 1 and 3 GHz. We can note that the fields are well confined at the end of the probe and the depth resolution depends directly on the probe geometry and size.

### 3. RF measurements

The complex relative permittivity  $\epsilon_r^* = \epsilon_r' - j\epsilon_r''$  can be expressed through the reflection coefficient  $\underline{S}_{11}$  in the following form:

$$\epsilon_r^* = \frac{c_1 \underline{S}_{11} - c_2}{c_3 - \underline{S}_{11}} \quad (1)$$

$c_1$ ,  $c_2$  and  $c_3$  are three complex calibration constants which are determined using three measurements of perfectly known dielectric liquids [7]. An Open-Water-Liquid (OWL) calibration procedure is conducted and (1) can be rewritten as:

$$\begin{aligned} S_{11}^O c_1 - c_2 - \epsilon_{r,O} c_3 &= -\epsilon_{r,O} S_{11}^O \\ S_{11}^W c_1 - c_2 - \epsilon_{r,W} c_3 &= -\epsilon_{r,W} S_{11}^W \\ S_{11}^L c_1 - c_2 - \epsilon_{r,L} c_3 &= -\epsilon_{r,L} S_{11}^L \end{aligned} \quad (2)$$

Suspensions of *Chlamydomonas reinhardtii* of  $7 \times 10^7$  cells/ml with cells presenting two levels of lipid content (30%, 70%) were tested. Cells with different lipid contents observed by Confocal Laser Scanning Microscopy (CLSM) are shown in Fig 3. Lipid droplets emitting a green fluorescence were stained with Bodipy 505/515 [7].

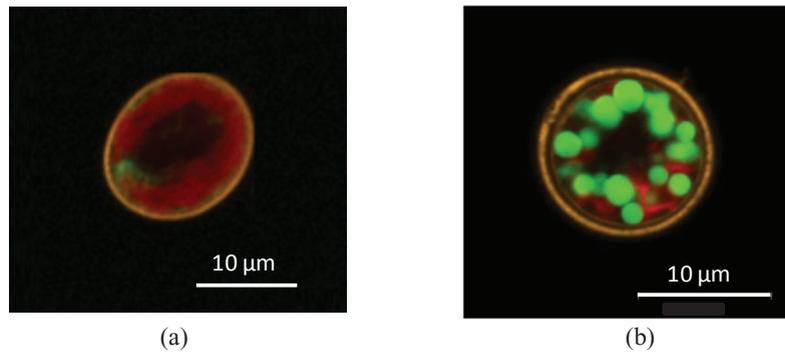


Fig. 3. Confocal Laser Scanning Microscopy of *Chlamydomonas reinhardtii* cells with different lipid content. (a) no lipid droplets, (b) high lipid content. (Green fluorescence: lipid droplets stained with Bodipy, red fluorescence: chlorophyll autofluorescence, yellow fluorescence: cell wall stained with concanavalin A).

All measurements were obtained at room temperature from 30 MHz to 3 GHz (Fig. 4). Each calibration standard is measured using the average of 50 runs and input source is set to 0 dBm. The temperature of the liquids was also checked. The two different evolutions of the measured reflection coefficient  $\underline{S}_{11}$  are associated to cell lipid content and thus the intrinsic physical properties of the microalgae.

Thanks to the model given in Eqs. (1)–(2), the complex permittivity of the microalgae suspensions with different lipid contents can be easily determined. Three calibration measurements were carried out: open, deionized water ( $\epsilon_{r,\text{water}}=78$ ) and methanol.

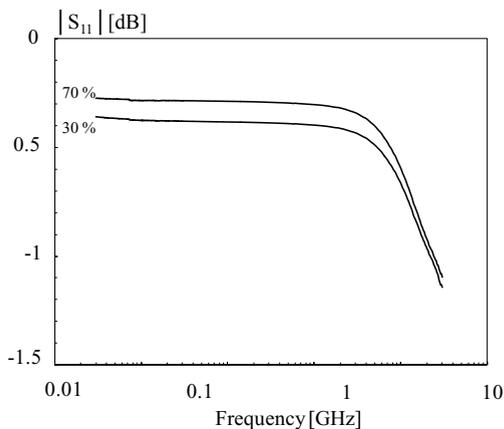


Fig. 4. Measured reflection coefficient  $S_{11}$  for suspensions of microalgae with different lipid contents.

After obtaining these three complex parameters, the unknown relative complex permittivity can be found from the measured reflection coefficient  $S_{11}$  at each frequency. Table 1 summarizes the resulting complex permittivity at 0.3, 1 and 3 GHz for the different suspensions of microalgae. We can note that the complex dielectric permittivity of microalgae suspension decreases when the lipid content concentration ( $\epsilon_{r, \text{lipid}}=2.5$ ) increases. Results demonstrate that the lipid content of *Chlamydomonas reinhardtii* can be evaluated by the developed method.

Table 1. Complex dielectric permittivity  $\epsilon_r^*$  determined.

Lipid content	$\epsilon'$			$\epsilon''$		
	0.3 GHz	1 GHz	3 GHz	0.3 GHz	1 GHz	3 GHz
30%	77.18	76.62	73.97	9.6	6.4	12.03
70%	75.23	74.59	71.86	9.32	6.35	11.99

**4. Conclusion**

In this work, an open-ended coaxial line probe is used to obtain dielectric spectra of microalgae suspensions with different lipid contents in a large frequency range (0.03 – 3 GHz). The frequency dependent complex permittivity was deduced from the measured complex reflection coefficient  $S_{11}$  after a calibration procedure using three standards: air and two well-known liquids. Results demonstrate that biological cells can be non-invasively characterized by the developed RF method in a broadband range of frequencies. New applications in a wide range of different fields such as medicine, biology, chemistry and food industry can therefore be envisaged.

**Acknowledgements**

The authors acknowledge the Labex LaSIPS (ANR-10-LABX-0040-Lasips), the “Ecole Doctorale EOBE” of Université Paris-Saclay, the “Institut d’Alembert” and the “CNRS” for project foundings.

**References**

[1] Peter S et al. (2016). Dielectrophoresis: Label-free whole blood cell differentiation based on multiple frequency AC impedance and light scattering analysis in a micro flow cytometer. *The Royal Society of Chemistry*. 16, 2326-2338.

[2] Trainito C.I., et al. (2015). Monitoring the permeabilization of a single cell in a microfluidic device, through the estimation of its dielectric properties based on combined dielectrophoresis and electrorotation in situ experiments. *Electrophoresis*, 36, (9-10), 1115-1122.

[3] Pethig, R. (2013). Dielectrophoresis: An assessment of its potential to aid the research and practice of drug discovery and delivery. *Adv. Drug Deliv. Rev.* 65, 1589-1599.

[4] M. Al Ahmad et al. (2014) : RF Microalgal lipid content characterization. *Scientific reports* 4, 5108.

[5] Chisti, Y. (2007). Biodiesel from microalgae. *J. Biotech. Adv.* 25, 294–306.

[6] Bodenes, P. et al. (2016). Microdevice for studying the in situ permeabilization and characterization of *Chlamydomonas reinhardtii* in lipid accumulation phase. *Algal Research*, 16, 357-367.

[7] N. Wagner et al. (2013). Numerical 3D FEM and experimental analysis of the open-ended coaxial line technique for microwave dielectric spectroscopy on soil. *IEEE Trans.on Geosci. and Remo. Sen.* 52, 880-893.