# Introduction

The project is carried out at the CommSensLab, at the TSC department.

There is a growing need to interact with the living world and mostly of the time this is performed using some king of physical (i.e electrodes) contacts. This kind of connection while well-known and quite robust, mostly of the time are intrusive and discomforting. In this respect the possibility of having wireless contacts or sensing will certainly easy this kind of interactions.

In this work the general idea is to study the potentiality of a wireless sensing of some functional parameter of a living organism either vegetal or animal. **More specifically the idea is to analyse the measurable interaction among the well-known radiofrequency and microwave frequencies and some sample of those living organisms.**

More specifically the aim of this TFG is the numerical modelling and the experimental validation of a representative sample of basic living microorganisms.

The project main goals are:

1. Numerical modelling of the basic electrical parameters: real and imaginary parts of the complex permittivity.
2. The spectral experimental validation of a representative sample of basic living microorganisms.

Extract from TEM Cell design for Material Characterization:

Material characterization is a complex and interesting science and the determination of the material properties at microwave-frequencies is challenging. Information about the permittivity and permeability is of interest in a variety of applications, for example in the communication, military industry and also in medical field.

By applying an external electromagnetic field on a material sample, material properties can be investigated.

To determine how much impact a material has on an electromagnetic

field, one needs to determine the constitutive relations of the material. The permittivity

*e* and the permeability *m* are associated with the electric and magnetic

fields, respectively. Behind the two parameters there are physical explanations

which are treated in the following chapters.

The basic principle for determining the permittivity and the permeability is to

measure the reflected and transmitted electromagnetic fields when a material

sample is illuminated with an incident electromagnetic field, as shown in Fig.1.2. This can be done using a free space measurement setup with antennas or by

using guided waves in a waveguide [9].



# Project background

The capability to wirelessly interact with the electrical signal system of the living microorganisms may open new possibilities in the field of the biotechnology. Among the different spectral ranges, the low intensity microwave signals are able to propagate into a harmless way through the living beings, and to extract basic physiological functions from the observation of their electrical parameters, meaningful morphological or functional information.

Based on this initial concept the research lab has been studying the physiological and electrical parameters of a vegetal organism (mimosa pudica). From this initial studies it has been found that the electrical changes produces by the physiological functions are very small in both physical sizes and permittivity changes. In order to design a proper experimental setup to measure the electrical changes a numerical study needs to be perform. The numerical results will be contrasted with the analytical model proposed by Bai[[1]](#footnote-1).

Based on the previous results a broad bad coaxial-based experimental setup will be design and build at the research lab. Electromagnetic absolute and differential measurements will be performed for different living microorganisms.

# Project requirements and specifications

Project requirements:

* For the numerical model the simulator has to be able to obtain basic electrical parameters from realistic models of microorganisms modeled with HFSS and to upload these results into a Matlab code able to post-process these results and to obtain the permittivity vales of the sample and the differential changes as a function of frequency when some functional activity (i.e. action potential) has occurred.
* For the experimental setup it has to be adequate to hold a sample of the biological object and to obtain values of their electrical parameters based on a previous calibration to correct for the measurement errors.

Project specifications:

* To obtain consistent values of the complex (real and imaginary) permittivity of a representative model of the living microorganism between the numerical results and those existing into the literature for frequencies covering from 1 MHz until 10 GHz
* An experimental coaxial setup to measure the S11 and S12 parameters from 1MHz to 10 GHz with S11<-10 dB and S12 < 1 dB
* To obtain experimental results for two samples of living microorganism consistent with the numerically predicted values and representative of the functional activity

# Material Characterization

# Waveguide Theory

# Simulation and measuring tools

## HFSS

## MATLAB

# Design

# Validation and verification

# Verificacion de los resultados: proceso que se ha seguido\_

Verificació de resultats

El procediment que he seguit ha sigut el següent:

* Per les 3 freqüències (1MHz, 100Mhz, 1GHz) diferents paràmetres:
  + Per P = 0:
    - **Eps\_cmp** (extreta de l'script de matlab basat en Bai, l'Spheroidal)
    - **Eps\_real** (extreta de l'script de matlab basat en Bai, l'Spheroidal)
    - **sigma** (extreta de l'script de matlab basat en Bai, l'Spheroidal)
    - **alpha analyt:** analiticament amb la fórmula dels teus apunts, a l'excel pots veure la fòrmula que he fet servir
    - **beta analyt**: analiticament amb la fórmula dels teus apunts, a l'excel pots veure la fòrmula que he fet servir
    - **alpha MATLAB** : del meu script de MATLAB amb el que calculo el S21, per veure si coincidien , i efectivament coincideixen, per tant fins aquí l'script funciona correctament.
    - **beta MATLAB**: del meu script de MATLAB amb el que calculo el S21, per veure si coincidien , i efectivament coincideixen, per tant fins aquí l'script funciona correctament.
    - **S21 analytic d =3mm**
    - **S21 MATLAB d= 3mm**
    - **S21 HFSS d = 3mm**
    - **S21 analytic d =10mm**
    - **S21 MATLAB d= 10mm**
    - **S21 HFSS d = 10mm**
  + P=0.1:
    - **Eps\_cmp** (extreta de l'script de matlab basat en Bai, l'Spheroidal)
    - **Eps\_real** (extreta de l'script de matlab basat en Bai, l'Spheroidal)
    - **sigma** (extreta de l'script de matlab basat en Bai, l'Spheroidal)
    - **alpha analyt:** analiticament amb la fórmula dels teus apunts, a l'excel pots veure la fòrmula que he fet servir
    - **beta analyt**: analiticament amb la fórmula dels teus apunts, a l'excel pots veure la fòrmula que he fet servir
    - **alpha MATLAB** : del meu script de MATLAB amb el que calculo el S21, per veure si coincidien , i efectivament coincideixen, per tant fins aquí l'script funciona correctament.
    - **beta MATLAB**: del meu script de MATLAB amb el que calculo el S21, per veure si coincidien , i efectivament coincideixen, per tant fins aquí l'script funciona correctament.
    - **S21 analytic d =3mm**
    - **S21 MATLAB d= 3mm**
    - **S21 HFSS d = 3mm**
    - **S21 analytic d =10mm**
    - **S21 MATLAB d= 10mm**
    - **S21 HFSS d = 10mm**

# Conclusions

* Alpha i Beta coincideixen MATLAB i analiticament.
* S21 coincideixen MATLAB i analiticament
* Amb l’HFSS no coincideixen els valors del S21.
* No tinc clar, que tingui sentit que per la porporció P=0 la sigma i la permitivitat siguin constants per a totes les freqüències, tot i que són els resultats obtinguts amb les fòrmules de l’article de Bai.

# Analitical results: Coaxial setup with differents materials (13/11)

# **Introduction**

In order to analyze the variation of the permittivity of a coaxial cell culture inside when applied to a microwave beam must first determine if our network analyzer have sufficient sensitivity.  
To obtain the sensitivity to be measured, the S parameters of the coaxial have been analyzed when the interior has different medium. The mediums that will be analyzed are the following:

• Vacuum  
• Distilled water  
• Sea water  
• Cultivation water  
• Cell culture (P = 0.1)

# **Experiment**

//Cal definir els parametres de matlab

# **Expressions**

Expressions only valid for

In general



# **Results**

## Scattering parameters for differents mediums in Matlab

**S21 Vacuum **

**S21 Distilled Water**

****

**S21 Sea Water**

****

**S21 Culture Medium without Cells**

**S21 Culture Medium with 0.1% Cells**

****

**S21 Culture Medium with 0.05 of cells**

****

**S21 Culture Medium with 0.025 of cells**

**S21 Culture Medium with 0.0125 of cells**

****

In order to define the culture medium (for different concentrations of cells) in HFSS we will use the **Debye model:**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **P** | **Frequency** | | **Relative Permittivity (Real)** | | **Loss tangent** | | **Conductivity (at DC)** |
| **L** | **U** | **L** | **U** | **L** | **U** |
| **0.1** | **1x104** | **3x109** | **335.2686** | **80.5064** | **1.5018e3** | **0.0254** | **0.2968** |
| **0.05** | **1x104** | **3x109** | **225.5160** | **80.7530** | **2.5724e3** | **0.0256** | **0.3227** |
| **0.025** | **1x104** | **3x109** | **115.2145** | **80.8764** | **3.8933e3** | **0.0258** | **0.3362** |
| **0.0125** | **1x104** | **3x109** | **118.6111** | **80.9382** | **5.1988e3** | **0.0258** | **0.3430** |

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **MATLAB** | | | | **HFSS** | | | |
| P | **(f= 0.1GHx)** | **(f= 0.3GHx)** | **F = 1GHz** | **f = 3 GHz** | **(f= 0.1GHx)** | **f = 0.3GHz** | **f = 1 GHz** | **F = 3 GHz** |
| 0 |  |  |  |  |  |  |  |  |
| 0.1 |  |  |  |  |  |  | **0.975612**  -0.107228dB |  |
| 0.05 |  |  |  |  |  |  | **0.975185**  -0.109129dB |  |
| 0.025 |  |  |  |  |  |  | **0.975811**  -0.106342dB |  |
| 0.0125 |  |  |  |  |  |  | **0.975817**  -0.106316dB |  |

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Material **(1GHz, Δz=3mm)** |  | σ |  | α | β |  |  |  |
| **Distilled Water** | 81 | 0.0002 | 0.023 | 0.0042 | 188.5 | **0.99998740**  -0.00011 dB | -32.401 | 2.8395x10-4 |
| **Fresh Water** | 81 | 0.0325 | 3.671 | 0.6807 | 188.5 | **0.99795998**  -0.0177 | -32.401 | 0.0453209 |
| **Sea Water** | 81 | 4.0 | 451.77 | 83.78  (287.9218 exact) | 188.5 | **0.77775789**  -2.1831 dB  -7.5025 dB | -32.401 | 5.577407407 |
| **Culture Liquid** | 81 | 0.35 | 39.53 | 7.33 | 188.5 | **0.97825002**  -0.1910 dB | -32.401 | 0.4880246 |

## 

## 

## Simulation results in HFSS





****

****

****

****

****

# **Conclusions**

# Sensibilitats dos opcions (05/12)

Case 1

Gràfiques de la sensibilitat per el canvi de medi de **aire – cultiu - aire.**









Case 2

Gràfiques de la sensibilitat per el canvi de medi de **cultiu sense celules – cultiu – cultiu sense celules.**













 

**Nota: S’observa uns pics que no identifico a qué es deuen, al llarg del dia d’avui ho miraré.**

**Resultados MATLAB después de la extracción del HFSS**

****

****

1. *(Dielectric properties of E. coli cell as simulated by the tree-shell spheroidal model)*. [↑](#footnote-ref-1)