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The 52nd European Microwave Conference

Millifluidic sensor designed to perform the microwave dielectric spectroscopy of biological liquids

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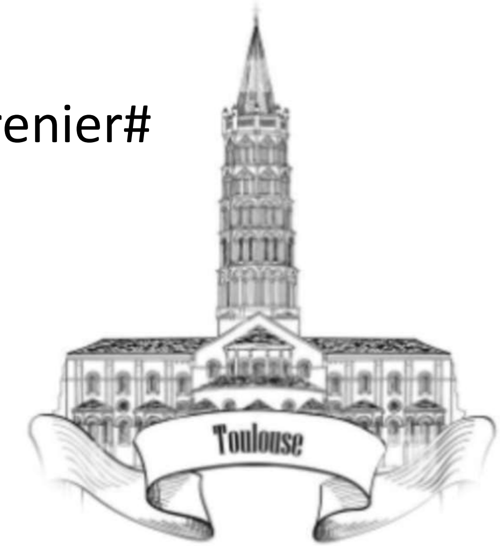
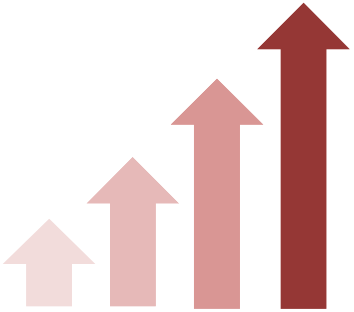


Context and actuality



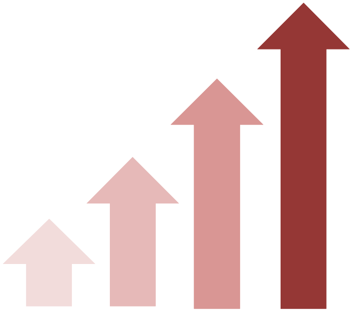
Problem of a quality control

Need of the analysis technique

- Quick
- Cheap
- Safe
- Transportable

Context and actuality

Consummation



Problem of a quality control

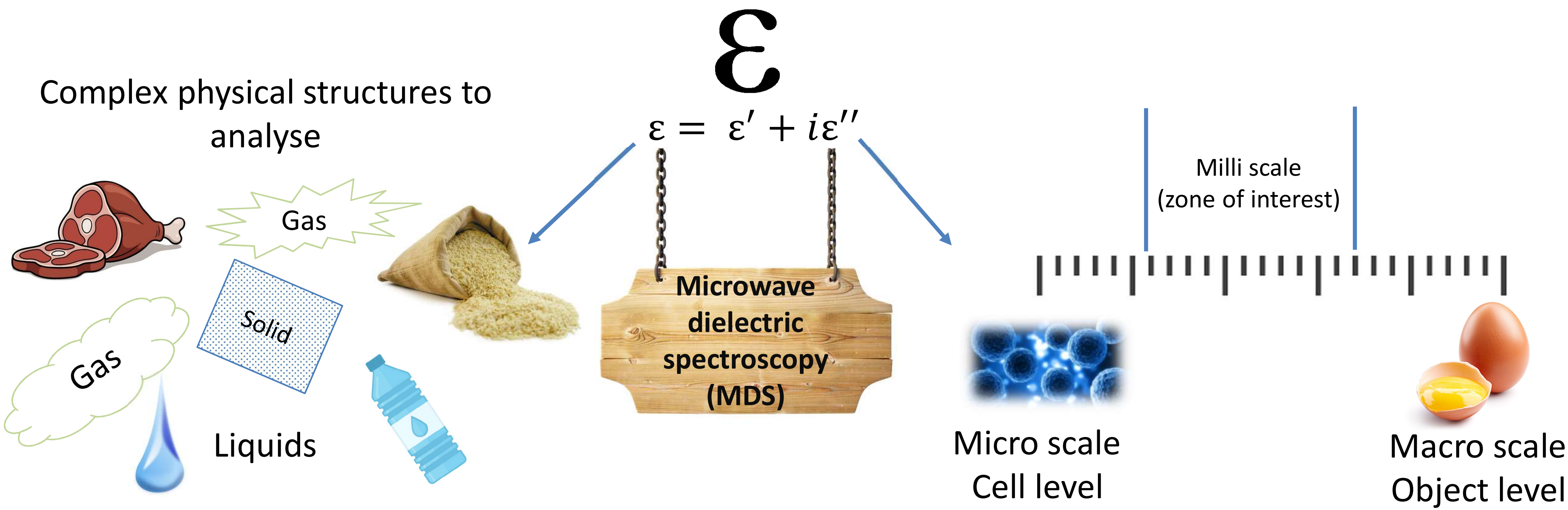
Need of the analysis technique

- Quick
- Cheap
- Safe
- Transportable

For huge egg market need to control:

- Freshness
- Quality
- Identity
- Shell integrity

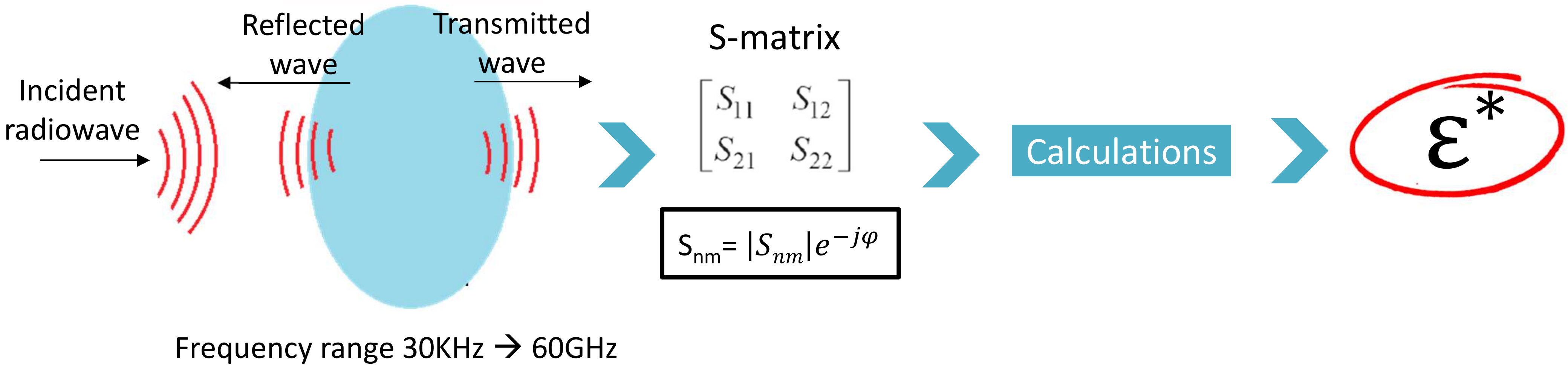
Context and actuality



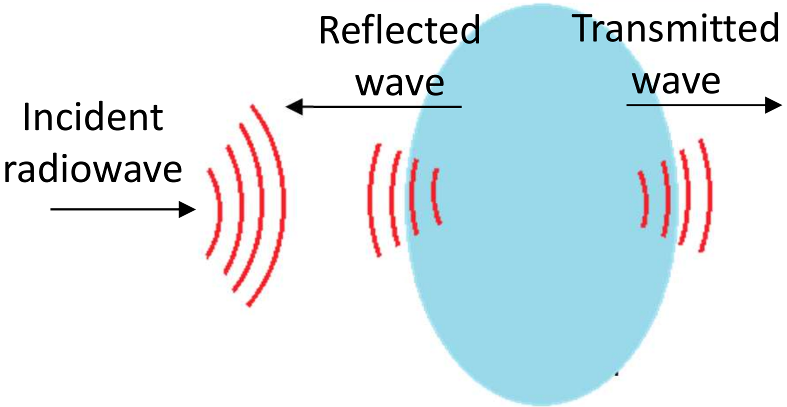
Possible fields of application

- Science
- Medicine
- Civil engineering
- Agriculture
- Alimentation production
- Etc.

Microwave dielectric spectroscopy



Microwave dielectric spectroscopy



Frequency range 30KHz → 60GHz

S-matrix

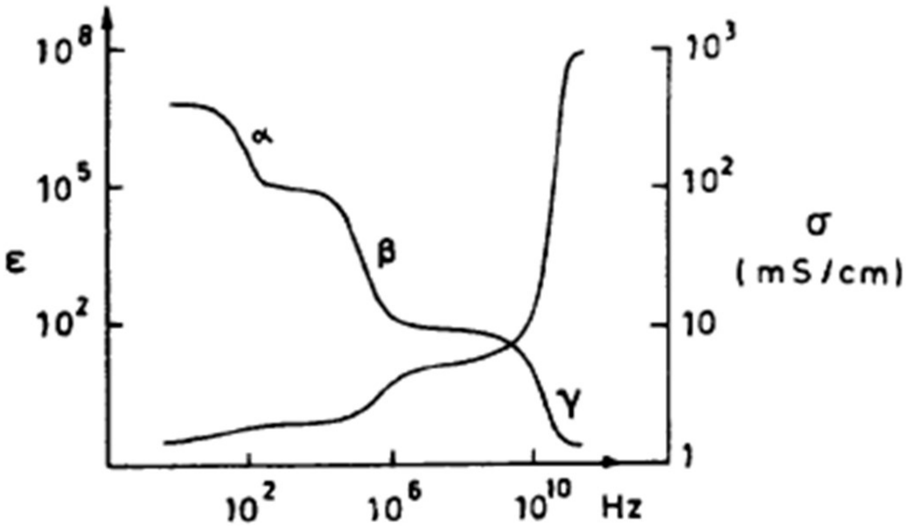
$$\begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix}$$

$S_{nm} = |S_{nm}|e^{-j\varphi}$

Calculations

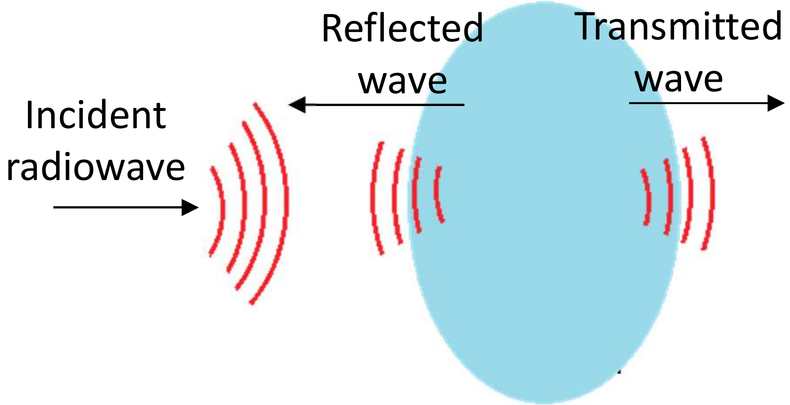
ε^*

Frequency-dependent
for biological tissues



*H. P. Schwan et all, IEEE 1994

Microwave dielectric spectroscopy



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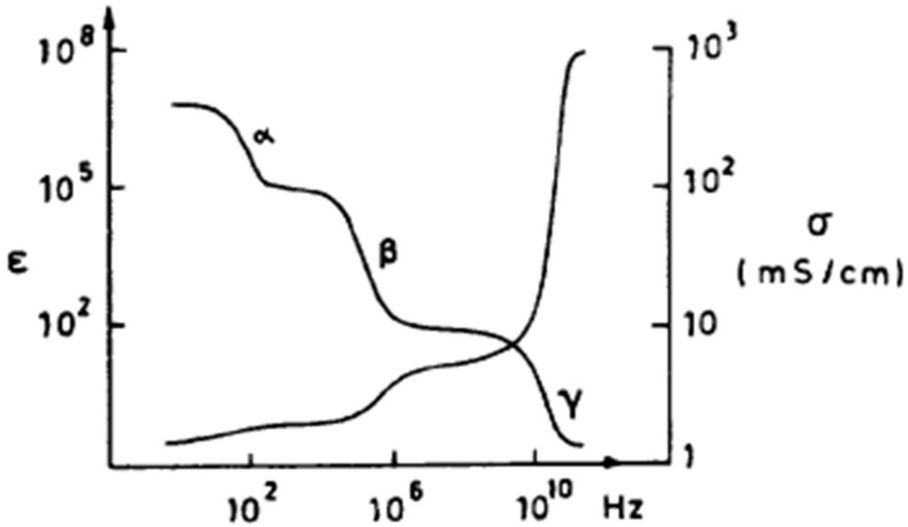


*H. P. Schwan et all, IEEE 1994

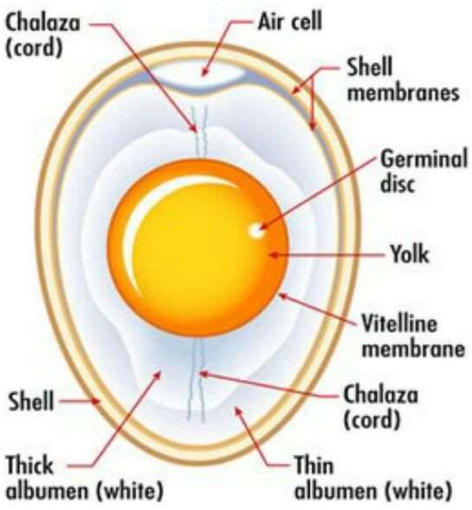
Advantages:

- Easy
- Fast
- Low cost of equipment
- Possible for biological products

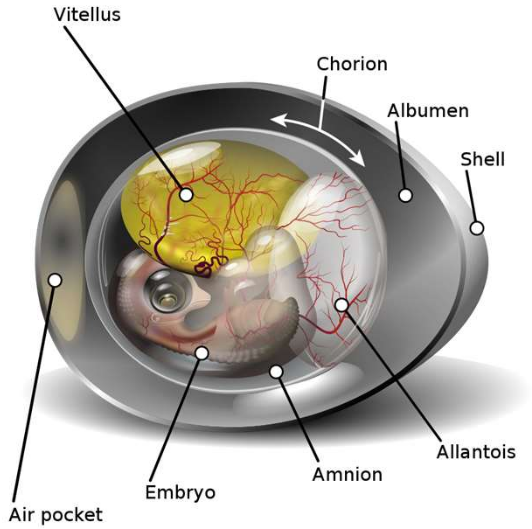
Application to egg constituents analysis

Microwave dielectric spectroscopy applied to eggs

Non-fertilized egg



Fertilized egg



Why MDS for egg production control?

Need of technique, which is:

- fast, precise and cheap quality control technique
- non-invasive technique
- technique non-dependent on eggs' size and shape
- safe control technique

Problems

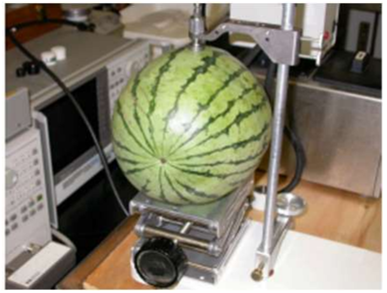
- complex object
- viscosity of liquids ↑ , very sticky
- big diversity (shape, production and storage conditions, etc.)
- fragility
- short consumption period

Which information to look at?

- quality
- freshness
- fertilisation detection
- male or female
- incubation day (fertilized egg)
- shell integrity

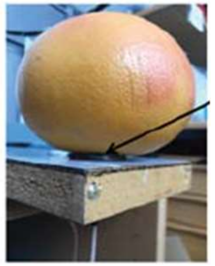
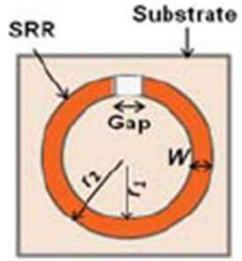
What do we have nowadays?

Open-ended coaxial-line probe **10 MHz – 1.8 GHz**



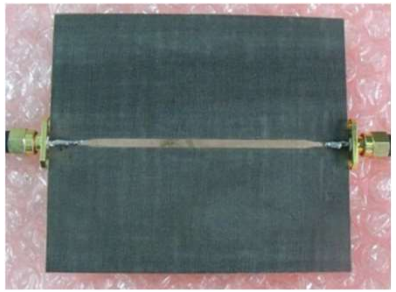

S. O. Nelson et al. IEEE 2007

Split ring resonator (SRR) **1 – 10 GHz**

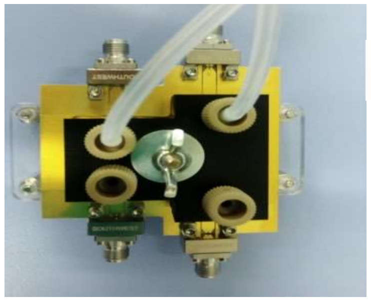
S. Redzwan et al. IEEE 2018

Microstrip antenna **1,5 – 4,5 GHz**




Gang Ji et al. IEEE 2010

Coplanar line **1 MHz – 4 GHz**



2 channels

P. Jaque Gonzalez et al. IEEE EuMC 2019

Disadvantages

- “Dead angles”
- Calculation difficulty
- Required liquid volume (1,3 ml)
- Long measurement (30 sec)

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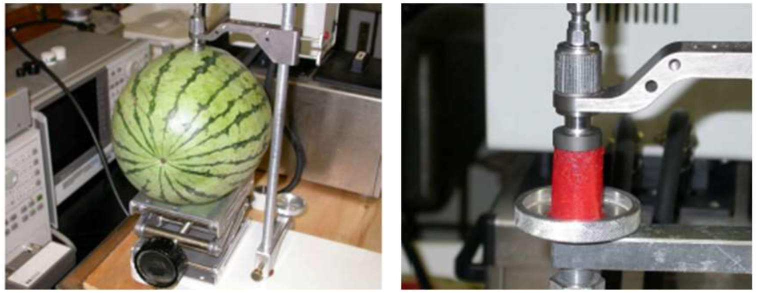

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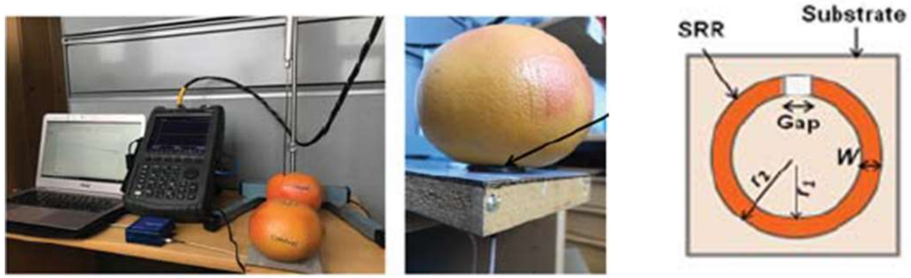

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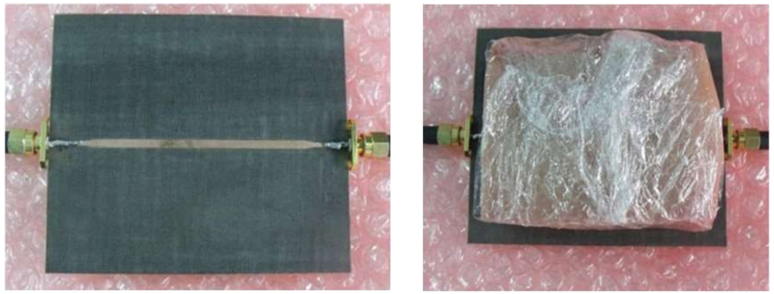

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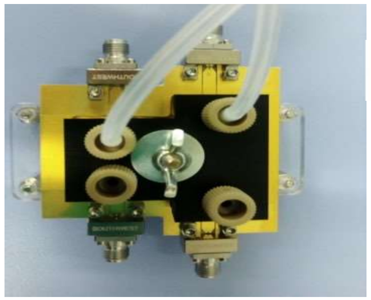

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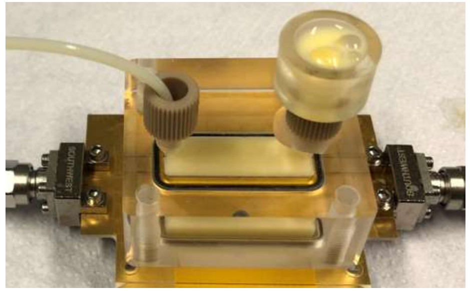
THIS WORK

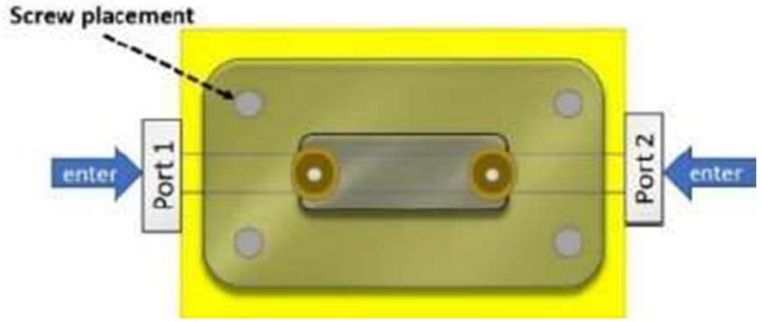


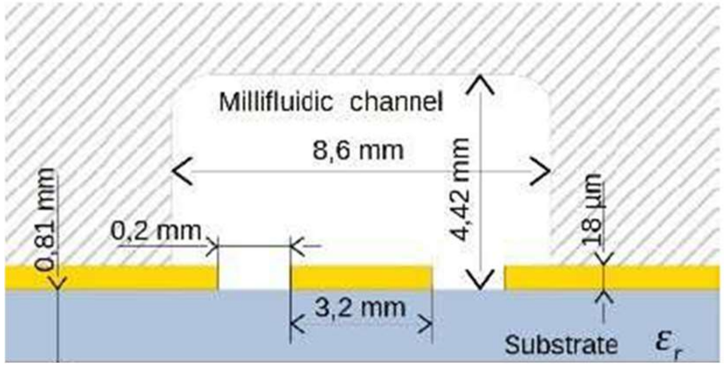
1 channel

Device with one millifluidic channel

- ❑ **Coplanar waveguide configuration**
- ❑ **Broadband fonctionality: 1 MHz → 4 GHz**
- ❑ **Millifluidic channel** (0.8 ml) made of plexiglass
- ❑ **Changing** in form and additional expanded plastic tip made 3-D printing
- ❑ **Rigid and secure** fixation by plastic srews (level of undesired involved interaction ⇩)
- ❑ **Ease** of assembly and disassembly (ease of cleaning ⇧)

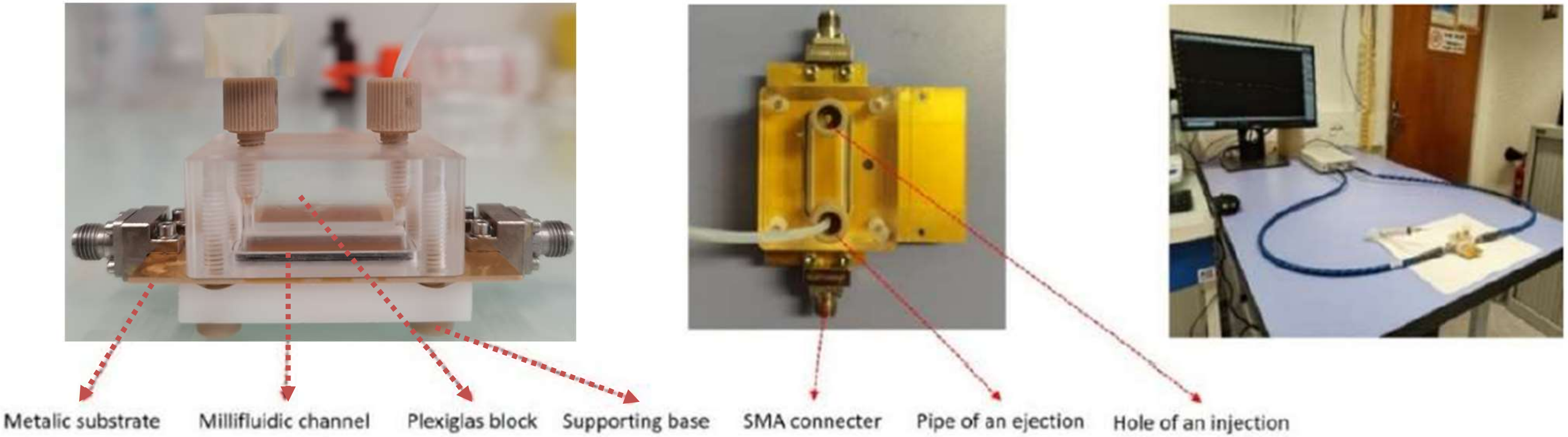
Device dimensions





Device with one millifluidic channel

Device and measuring setup photos

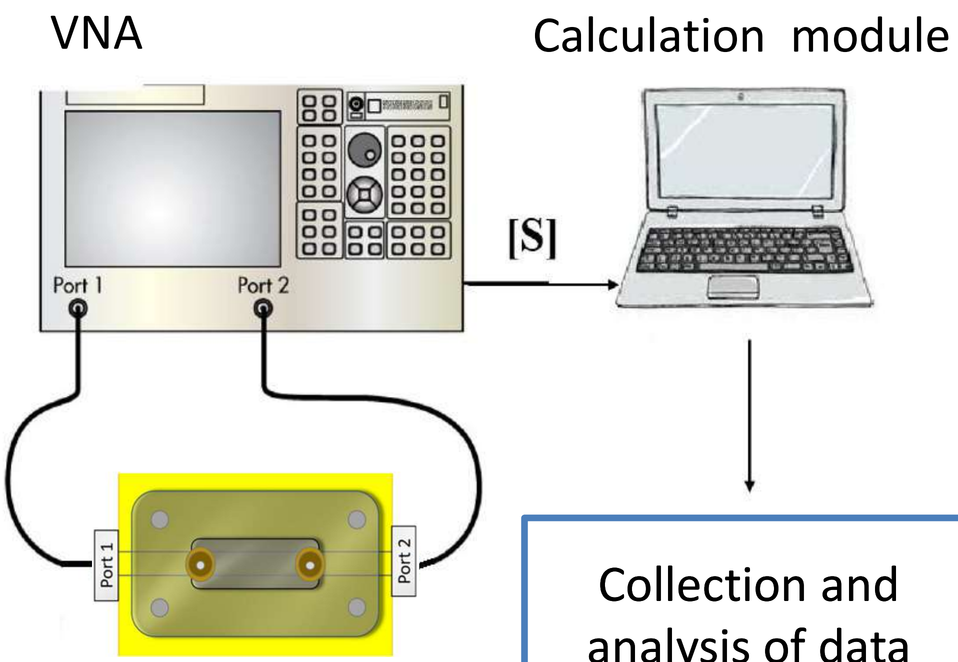


Advantages

- Required liquid volume ↓ (0.8 ml)
- Ease of operation ↑
- Better form and material (plexiglass,no « dead angles»)
- Measuring time ↓ (3 – 5 sec)
- Easier calculation

Approach. Test setup

Test setup



Developed device with a millifluidic channel

Collection and analysis of data due to created program block

1. **RF device with a millifluidic channel:** dedicated to the analysis of liquids in millifluidic volume
2. **Simplicity and convenience of work:** small and transportable
3. **Fast measurement:** in the order of 3-5 seconds
4. **Sensitivity:** differentiation of liquids with different consistences
5. **Adaptation of measurements:** specific liquid dependent protocols of measurements

First evaluation with BSA solutions

4 concentrations of BSA solutions:

- *Reference : DI water*
- **5 mg/ml** ✕ 5 measurements
- *Reference*
- **10 mg/ml** ✕ 5 measurements
- *Reference*
- **50 mg/ml** ✕ 5 measurements
- *Reference*
- **100 mg/ml** ✕ 5 measurements

Referenced measurements

$$\Delta|S_{21}| = |S_{21}|_{liquid} - |S_{21}|_{water}$$

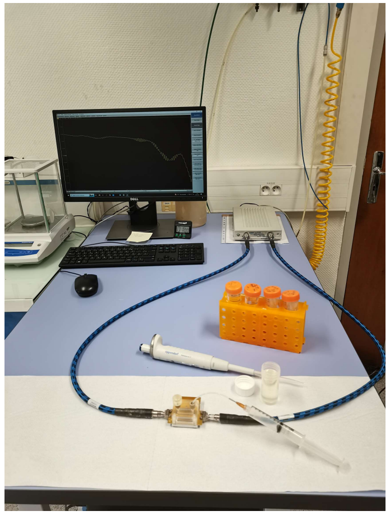
$$\Delta\varphi_{S_{21}} = \varphi_{S_{21}liquid} - \varphi_{S_{21}water}.$$

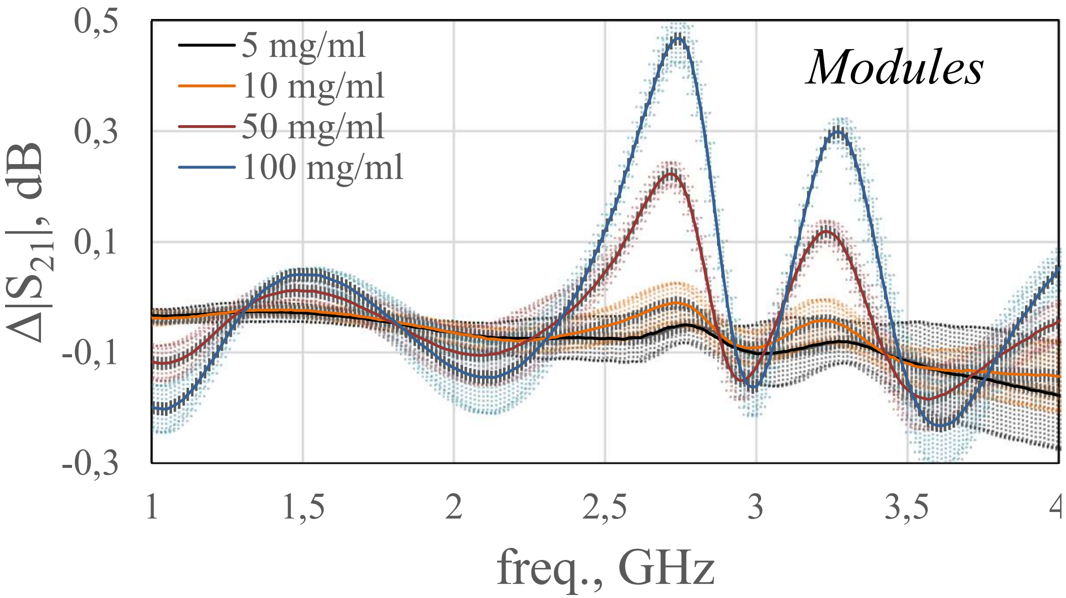
⇩

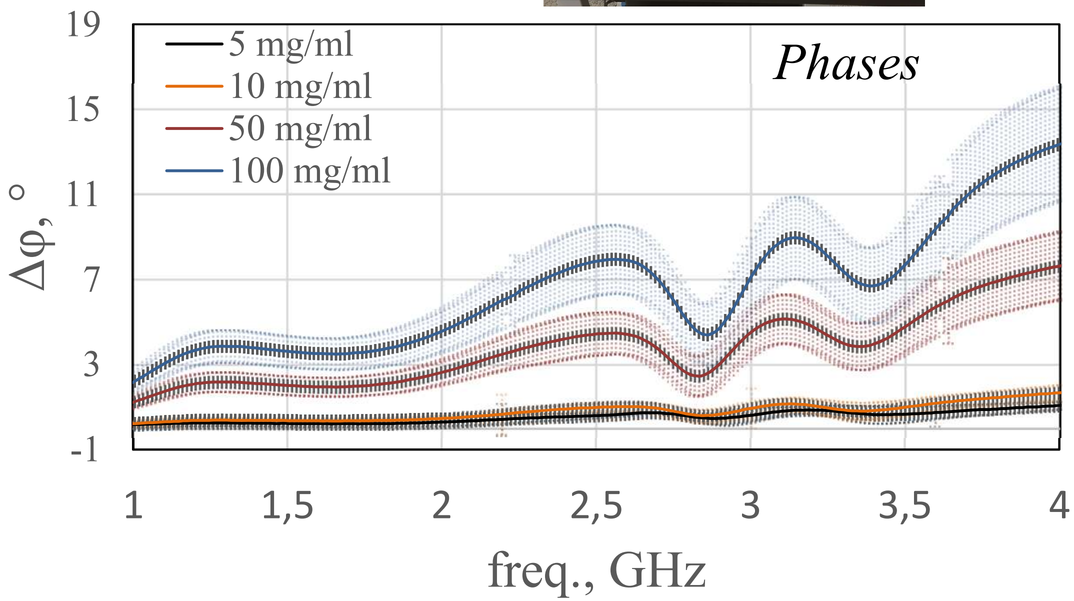
Common reference

⇩

Error minimisation







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- *Reference*
- **100 mg/ml** × 5 measurements

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Common reference

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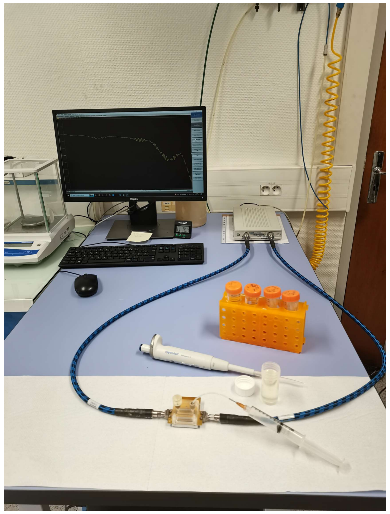
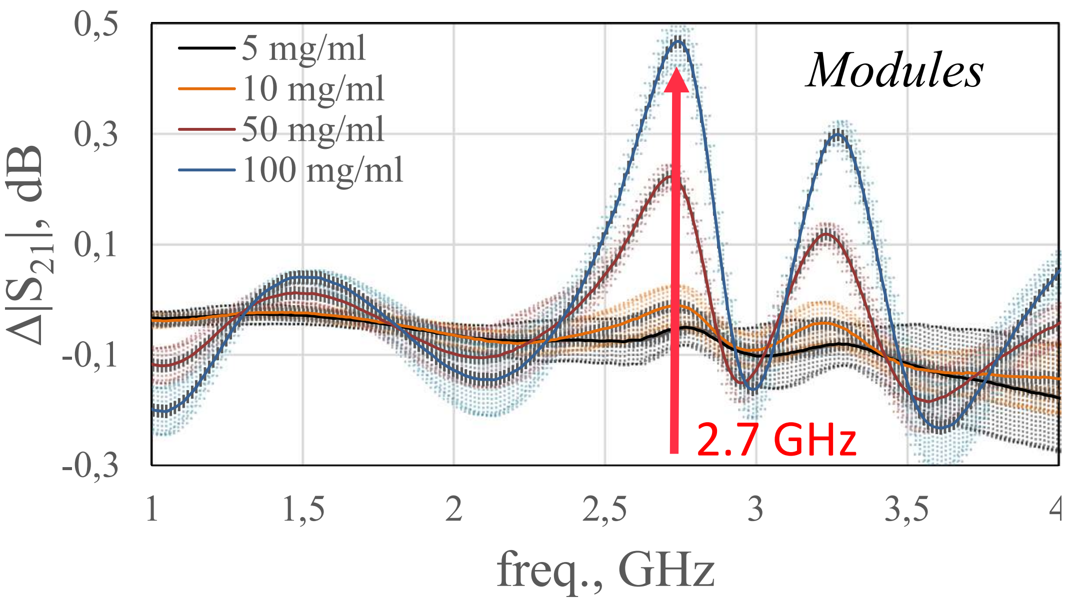
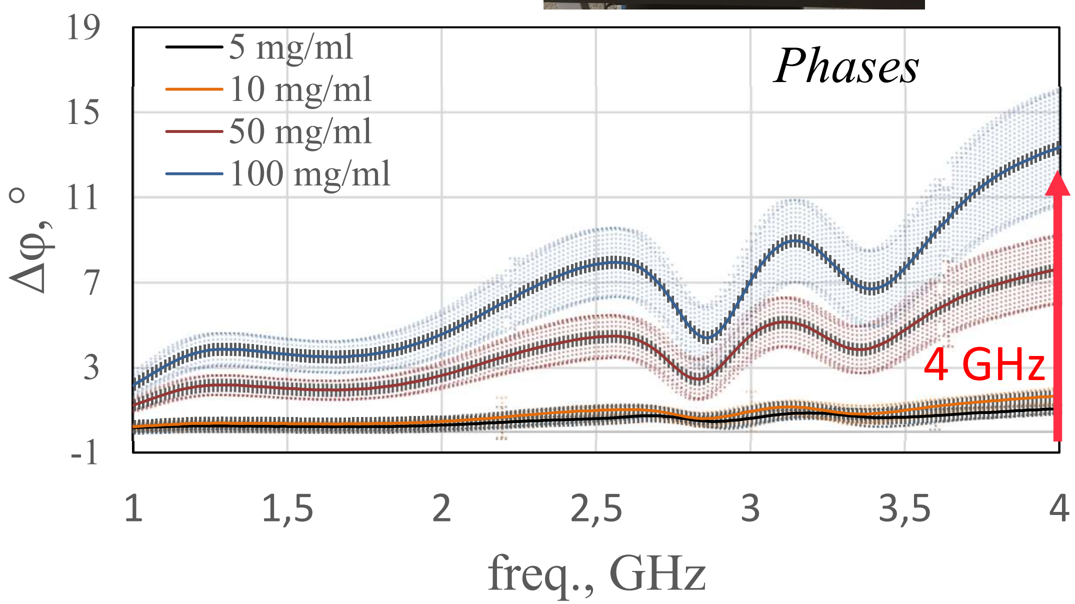
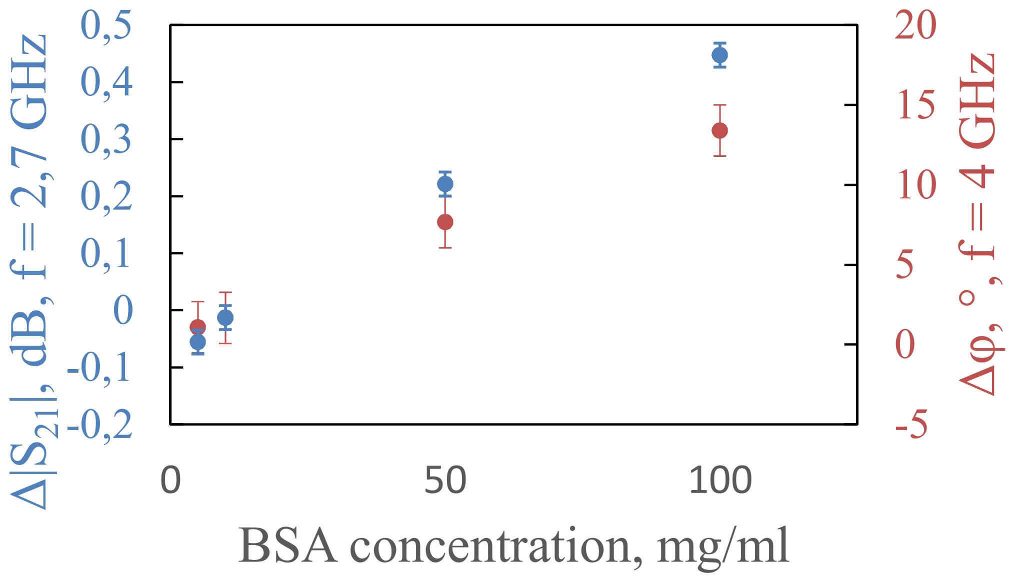
Error minimisation







First evaluation with BSA solutions

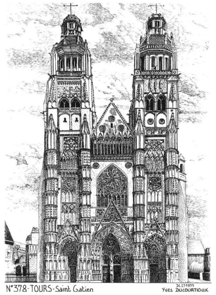


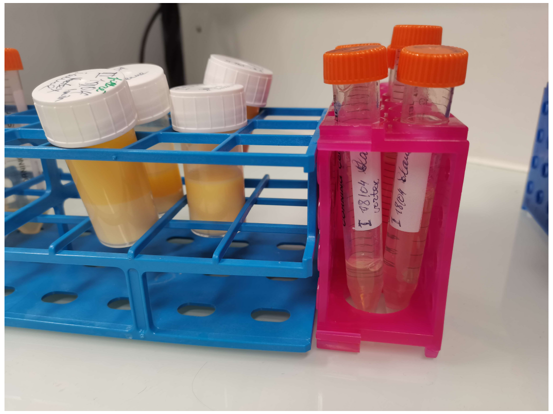
BSA Concentration	Mean $\Delta\|S_{21}\|$, dB f = 2,7 GHz	σ $\Delta\|S_{21}\|$	Mean Δϕ, ° f = 4 GHz	σ Δϕ
5 mg/ml	-0,06	0,04	1,08	0,18
10 mg/ml	-0,01	0,04	1,67	0,37
50 mg/ml	0,22	0,02	7,66	1,6
100 mg/ml	0,45	0,04	13,4	2,7

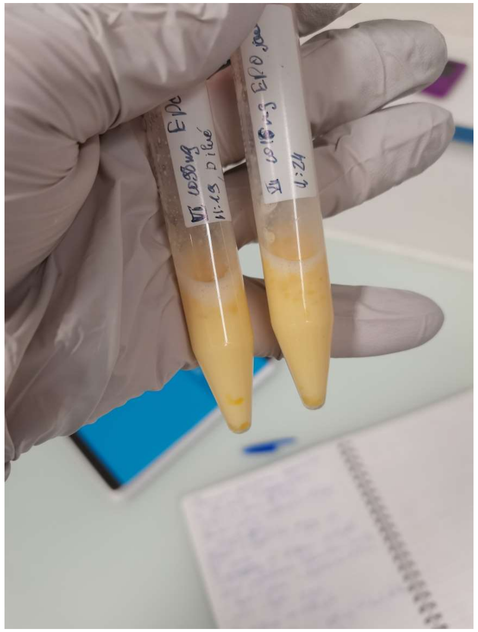
- Visible difference of data
- Distinguishing a base liquid with different concentration

Next step : application to liquids from eggs

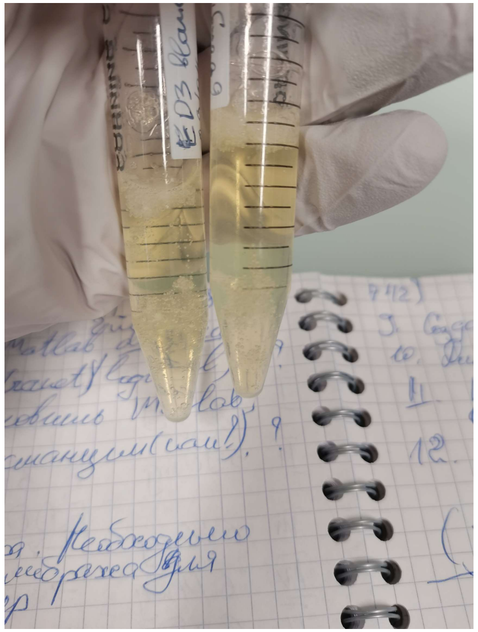
Freeze-dried egg samples





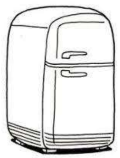


Prepared yolk



Prepared albumen

Why freeze-dried samples?



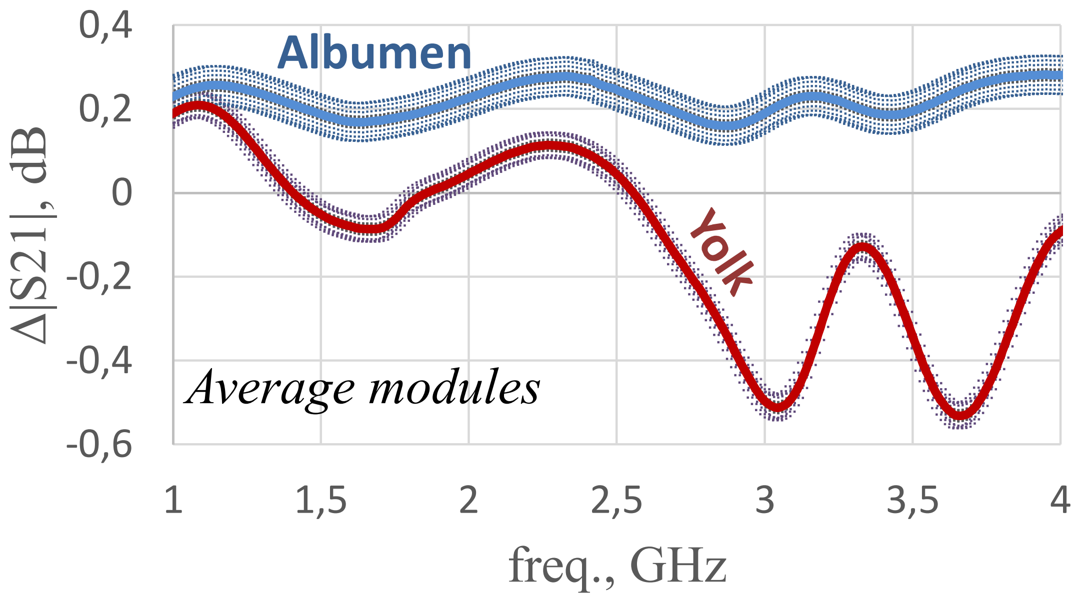
- Long time of storage
- Easy to transport
- Good level of a samples homogeneity

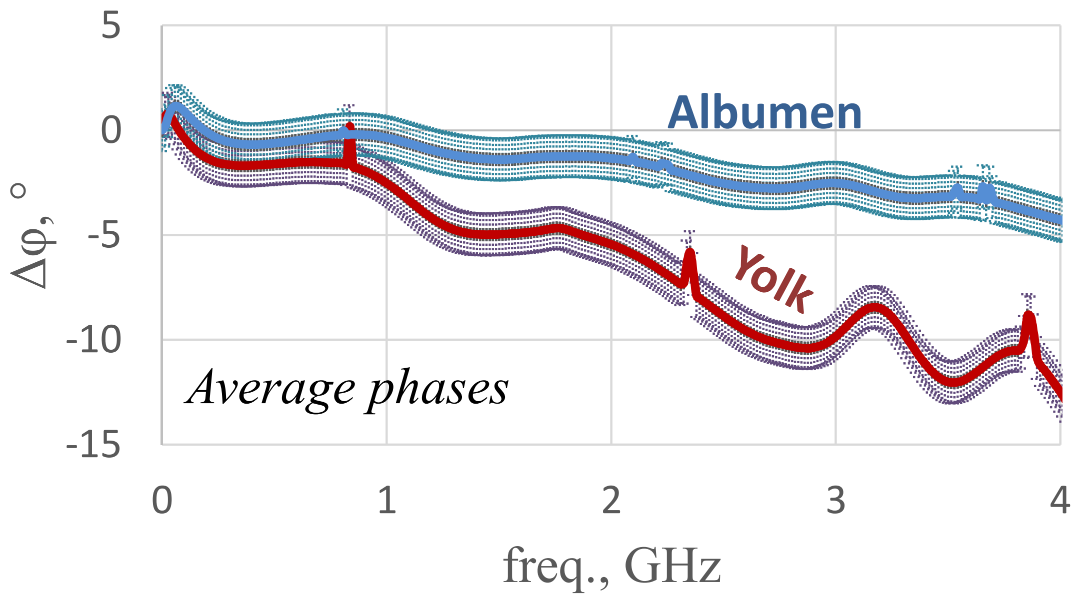
An unique protocol of preparation for each liquid

Dielectric characterization of egg liquids

A) <u>Repeatability</u> Yolk and albumen extracted from one fertilized chicken egg

- Reference for the yolk
- Yolk ✖ 10 measurements
- Reference for the albumen
- Albumen ✖ 10 measurements





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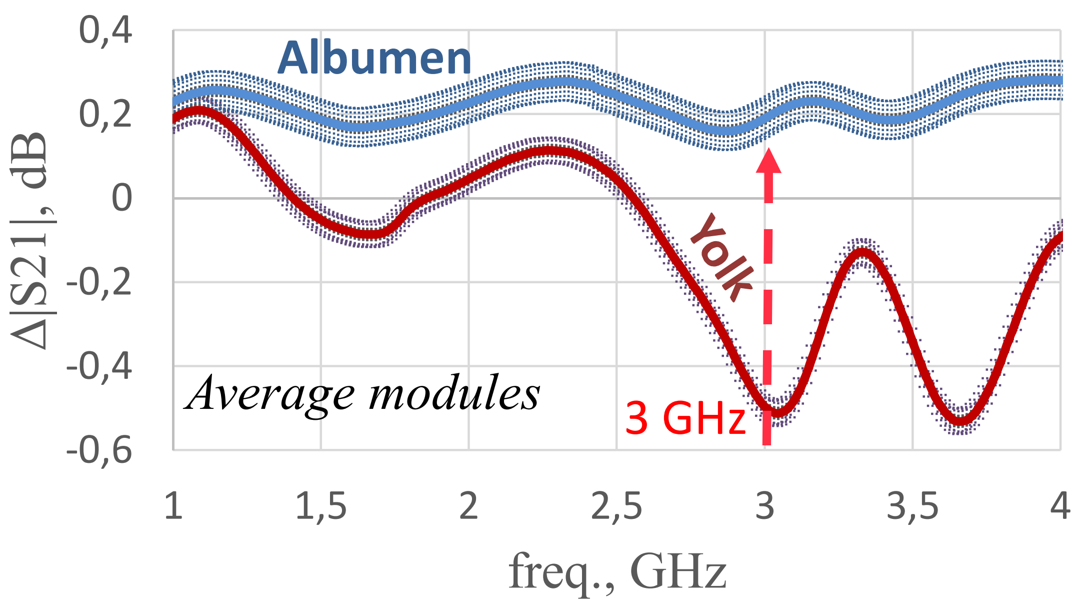
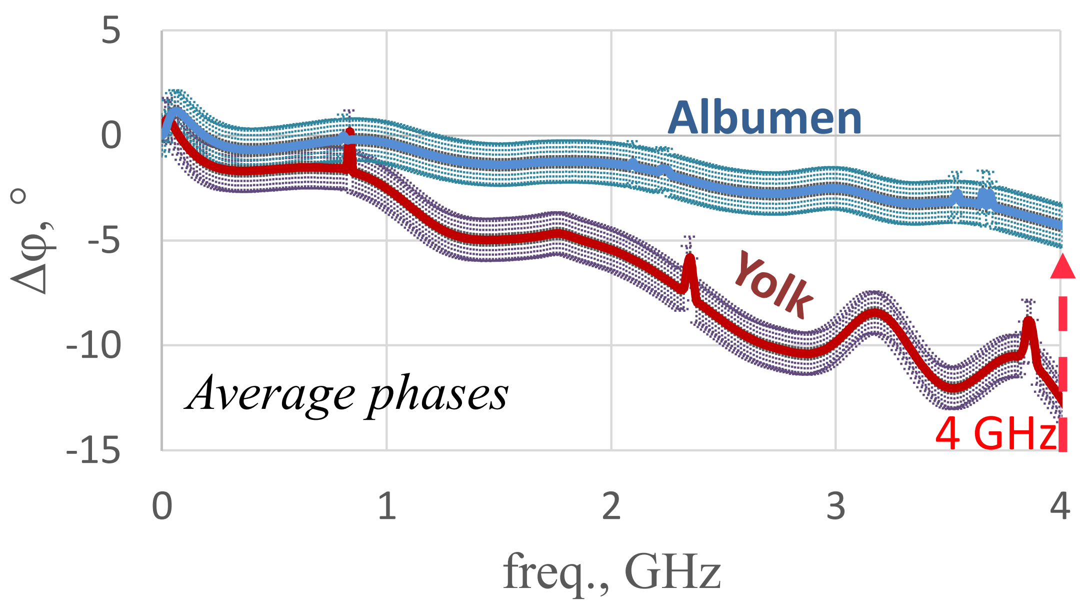
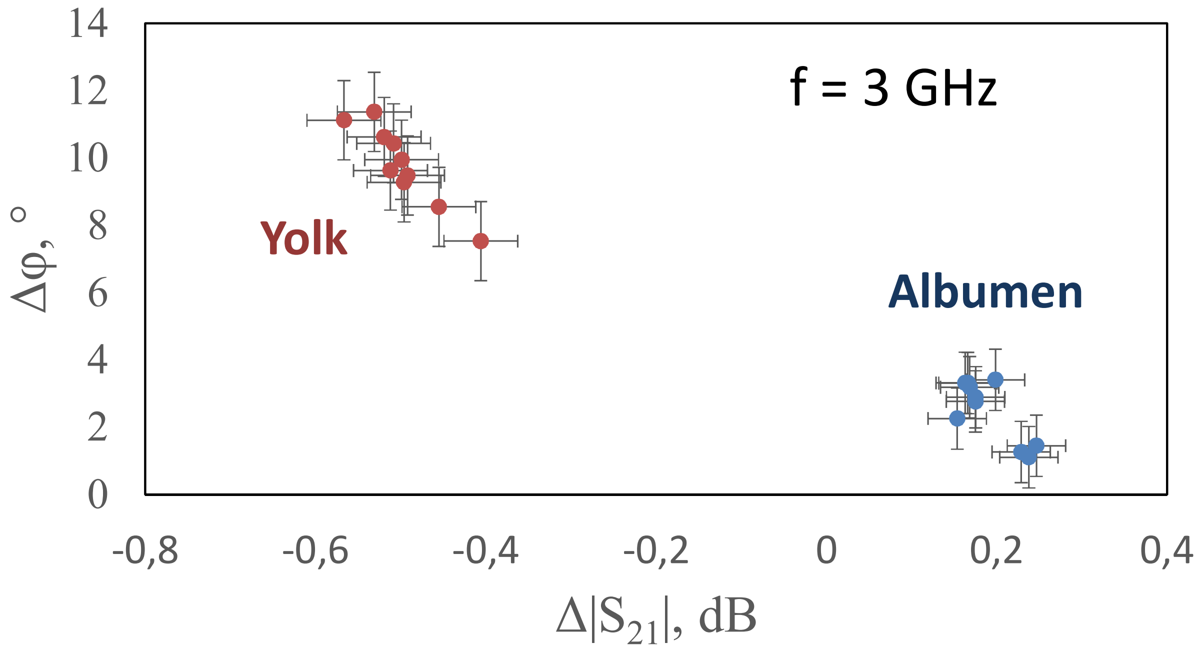




Dielectric characterisation of 2 egg liquids



- Visible difference between two biological liquids with different consistence
- Relatively low data dispertion for each liquid (σ↓) → level of repetitivity ↑

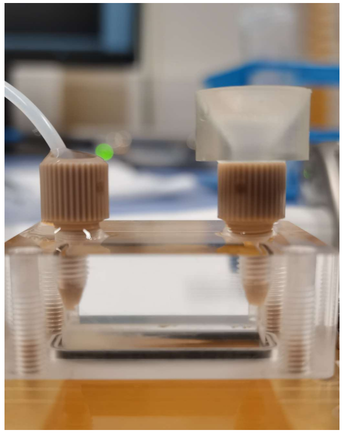
Liquid	Mean $\Delta\|S_{21}\|$, dB f=3 GHz	σ $\Delta\|S_{21}\|$	Mean Δϕ, ° f=4 GHz	σ Δϕ
Yolk	-0,5	0,05	-12,6	1,8
Albumen	0,2	0,03	-4,3	1,5

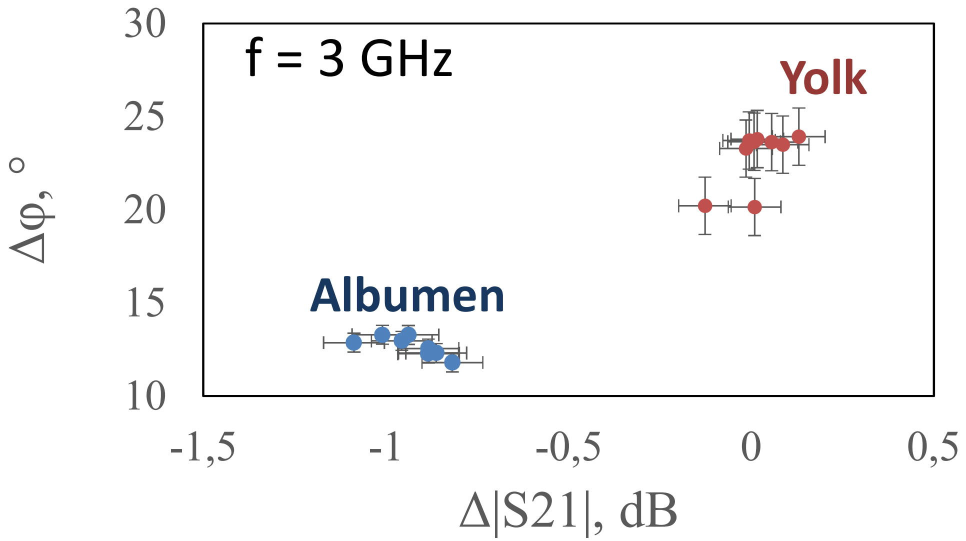
Dielectric characterisation of 9 egg liquids

B) Reproducibility

18 samples extracted from 9 fertilized chicken eggs:

- Reference for yolks
- 9 Yolks → average of 3 measurement for each sample
- Reference for albumens
- 9 Albumens → average of 3 measurement for each sample



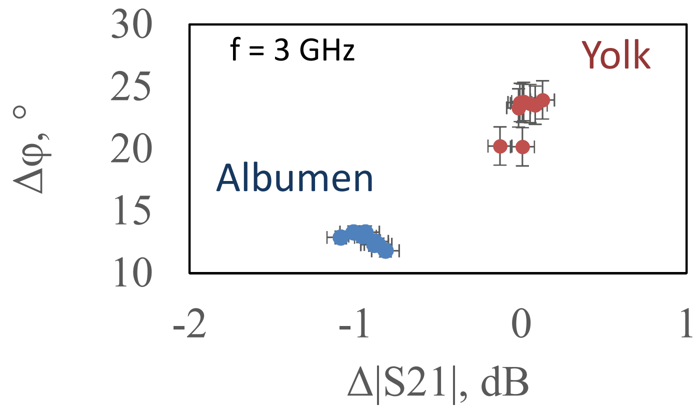


Liquid	Mean $\Delta\lvert S_{21}\rvert$, dB f = 3 GHz	σ $\Delta\lvert S_{21}\rvert$	Mean Δϕ, ° f = 4GHz	σ Δϕ
Yolk	0,02	0,07	41,7	2,7
Albumen	-0,9	0,08	21,7	0,8

- ➢ Visible difference between two types of biological liquids from different eggs
- ➢ Relatively low data dispertion for each liquid (σ↓) → level of reproducibility↑

Conclusions

- Design of a microwave sensor dedicated to the study of liquids in millimetre volume (0.8 ml instead of 1.3 ml)
- Development of a low cost microwave test setup
  - Implementation of the measurement protocols for different liquids using references
  - Development of a program module collecting and analyzing obtained data
  - Mesurement time decreased from 25 to 5 seconds
- Sensitivity evaluation with a model solution - BSA - at different concentrations (5 to 100 mg/ml)
- Sensitivity evaluation using two different types of egg liquids – the yolk and the albumen of fertilized hen eggs.
  - Establishment of a specific protocol for samples preparation
  - Adaptation of the measurement protocol with appropriate references
  - Two measurement approaches: repeatability and reproducibility
- Future investigations in the agro-industrial field for egg sexing during incubation.



Acknowledgements

PPILOW

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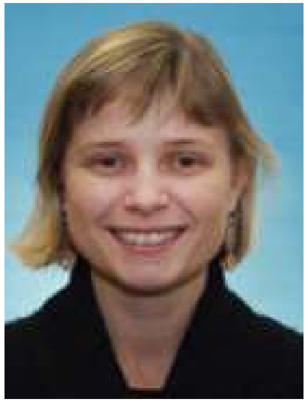
INRAE

Sophie Rehault-Godbert

LAAS CNRS

Katia Grenier



David Dubuc

My dream team

Thank you for your attention