Confounders in tissue dielectric measurements

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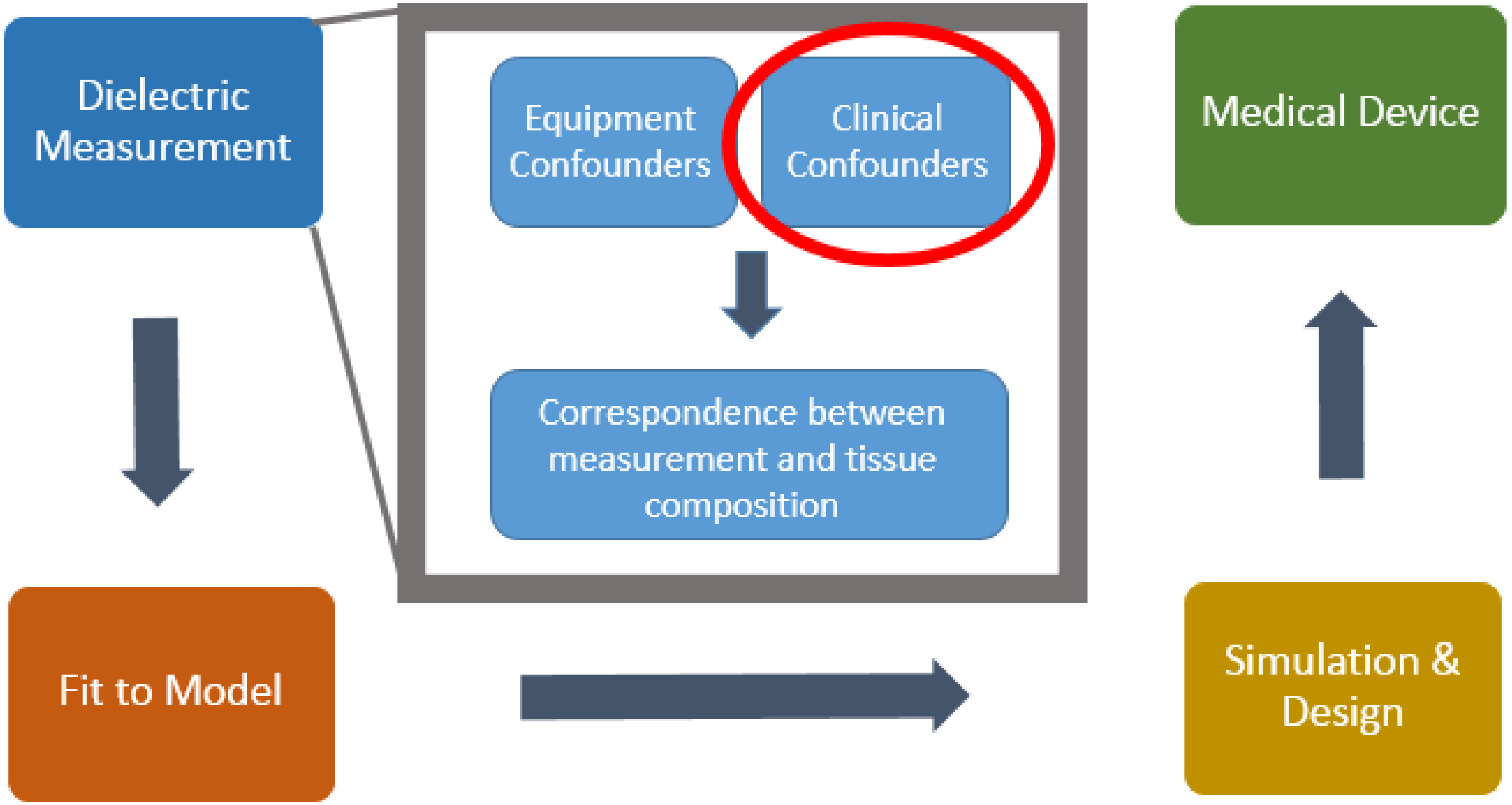
Technology Development Process



Outline

- Motivation
- Main confounders in:
  - Experimental design
  - Calibration
  - Validation
  - Tissue measurements
- Use of sensors in pressure-controlled experiments
- Summary and challenges

Experimental design

- Definition of the goal and number of samples needed to support the outcome
  - Preliminary experiments to test the instrumentation and the effect of chemicals, markers, or tools intended to use in the tissue dielectric measurements
- Analysis of tissue properties
  - Sample size, heterogeneity, tissue surface, presence of blood vessels, anisotropies
- Probe choice
  - Based on probe characteristics/specification and on tissue features: sample size, heterogeneity, tissue surface

Equipment set-up

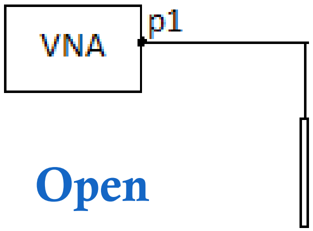
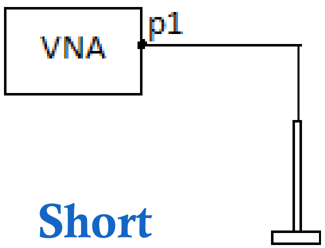
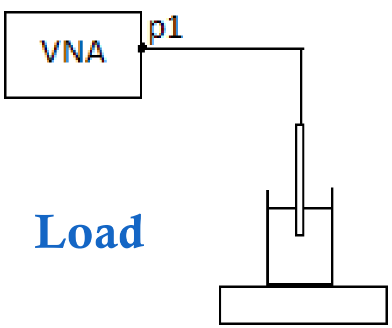
Confounders

- Environmental parameter change
- Probe contamination
- Imperfect connection
- Cable movement

Compensation

- Environmental parameter control
- Probe inspection and cleaning
- Connection check
- Cable fixing with tape

Calibration

	Confounders	Compensation
 **Open**	• Particles on probe tip	• Probe cleaning • Smith Chart check
 **Short**	• Poor probe-short block contact	• Short block and probe cleaning • Short block repositioning • Smith chart check
 **Load**	• Accuracy of liquid model • Liquid temperature • Air bubbles • Liquid contamination • Probe position in liquid	• DI water model -> best accuracy • Temperature monitoring/control • Probe re-immersion in liquid • Limited exposure to air • Probe distant from beaker sides

Validation overview

Validation enables:

- Verification of the calibration quality
- Monitoring of VNA drift, cable movements or other anomalies
  - VNA drift can be evaluated taking several measurements on a standard liquid in the following hours after calibration
- Determination of system performance by calculating the accuracy and repeatability
  - **Accuracy**: average percentage difference in the dielectric properties of the acquired data and the model
  - **Repeatability**: dispersion characteristics of the data acquired under the same measurement condition

Validation liquid: Alcohol

Alcohol

- Methanol
- Ethanediol
- Ethanol
- Butanol

Available models

Debye model (Gregory et al. 2009):
- f = 0.1 -5 GHz
- T= [10°C, 50°C], 5°C increments

Cole-Cole model (Jordan et al. 1978):
- f = 0.01-70 GHz
- T = [10°C, 40°C], 10°C increments

Davidson-Cole model (Gregory et al. 2009):
- f = 0.1 -5 GHz
- T= [10°C, 50°C], 5°C increments

Debye-Γ model (Gregory et al. 2009):
- f = 0.1 -5 GHz
- T= [10°C, 50°C], 5°C increments

Double Debye model (Gregory et al. 2009):
- f = 0.1 -5 GHz
- T= [10°C, 40°C], 5°C increments

➢ **Weakness**: Safety protocol to work with alcohol requires special fire-proof storage cabinets and handling under the fumehood

Validation liquid: Saline

- Available models at different concentrations between 0.001 mol/l and 5 mol/l

Debye model for c<0.5 and **Cole-Cole model** for c>0.5 (Peyman et al. 2007):

- f = 0.13-20 GHz
- T= [5°C, 35°C] (any intermediate T)

Cole-Davidson model (Gulich et al. 2009):

- f = 0.1-40 GHz
- 17 points in T= [10°C, 60°C]

- 0.1 M NaCl most common → properties similar to biological tissues

- Saline solutions do not require special handling or disposal

Tissue measurements

Uncertainty is higher in tissue dielectric measurements because biological tissues are inhomogeneous and show considerable variability in structure or composition

- **Main confounders**:
  - Water content
  - Temperature
  - Measurement region choice
  - Probe-tissue contact
  - Probe pressure
  - Sample handling

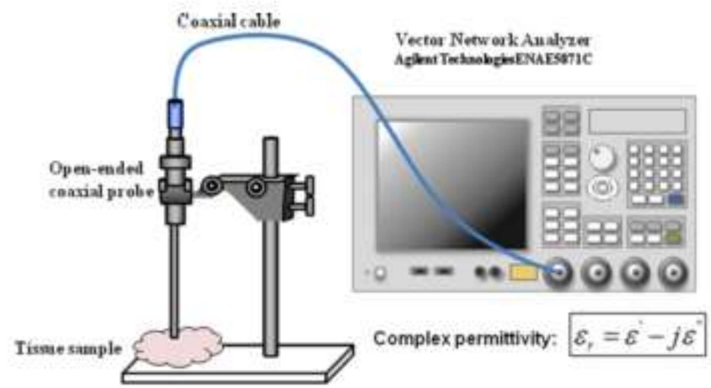


Image taken by Sugitani et al. 2014

- **Minor confounders**: probe invasiveness, probe temperature effects, physiological parameters (blood flow, heart rate, arterial pressure), probe-tissue chemical interaction

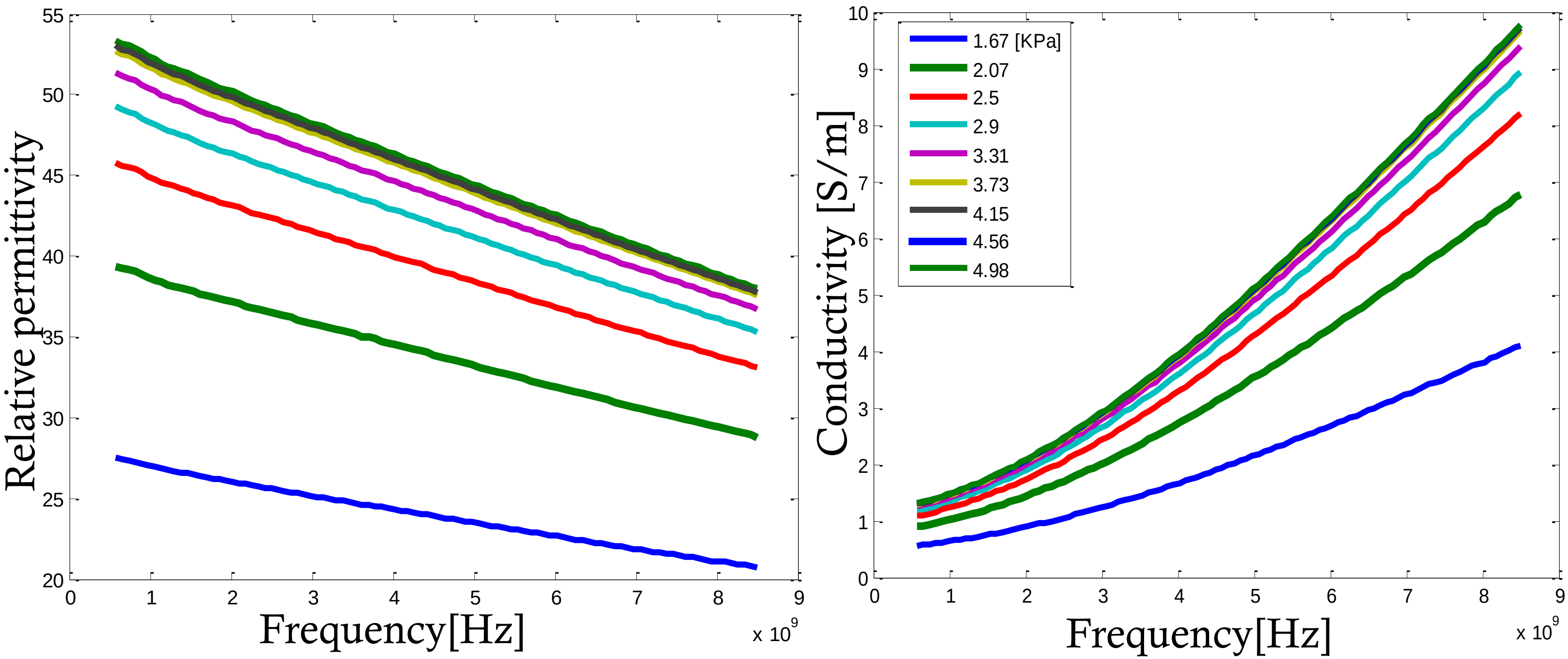
Probe-tissue contact

- Firm contact avoiding:
  - Pressure difference
  - Air gaps due to low pressure
  - Fluid accumulation at the probe tip due to high pressure

➢ Suggested solution: application of a steady pressure, monitored by a weigh scale or force sensor

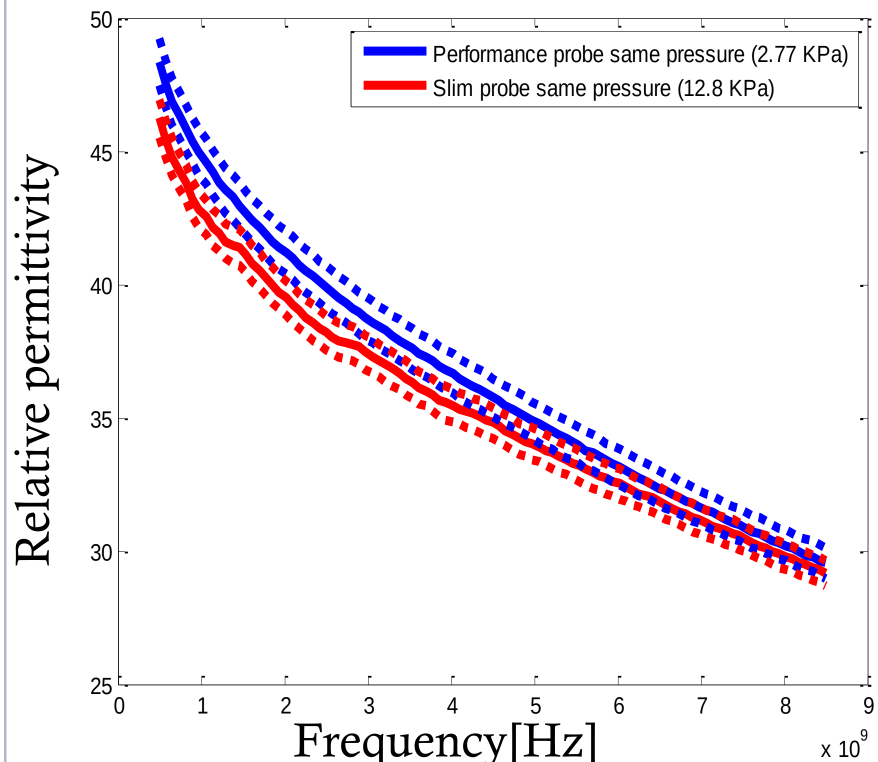
Steady pressure by weigh scale

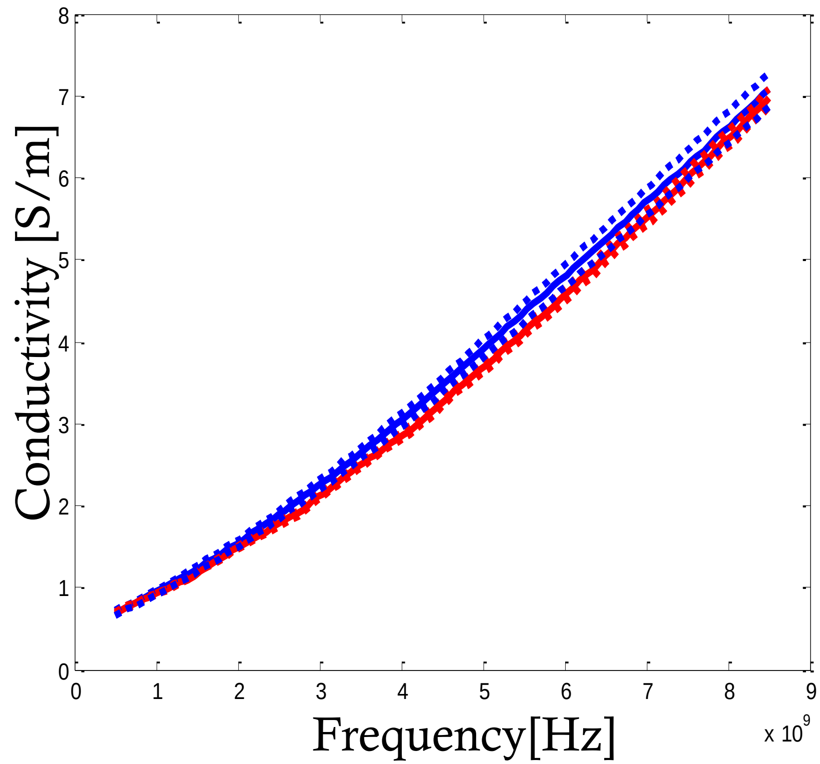
Correlation between probe pressure and permittivity



- Pressure monitored with weigh scale
- Phantom experiments demonstrate that relative permittivity increases with pressure

Steady pressure in tissue measurements





Repeatability on lamb liver measurements using a weigh scale:

- 3-4% for performance probe
- 1.5-2% for slim probe

Probe pressure monitoring

Low pressure → poor contact → inconsistent data on any sample

High pressure → high contact
- Rigid, dry tissue → Tissue damage occurs, permittivity decreases
- Moist, elastic → Fluids surface, permittivity increases
- Non moist, elastic → Stable permittivity

- Pros
  - More repeatable measurements
- Cons
  - Introduction of new confounders: precision and accuracy of the instrument
  - more complex set-up

Summary

The probe pressure was monitored by weight scale in phantom and tissue experiments

- **Conclusion**
  - Permittivity magnitude increases while increasing the pressure
  - Higher repeatability when the pressure is controlled
- **Future experiments using**
  - homogeneous and elastic phantoms
  - varied tissue samples
  - more accurate sensors

➢ More experiments needed to evaluate the effect of fluid accumulation at the probe tip and probe sensing volume according to the tissue

Thank you!

European Research Council

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An Chomhairle um Thaighde in Éirinn

Fondúreacht Eolaíochta Éireann
Dá bhfuil romhainn
Science Foundation Ireland
For what's next

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