# A portable microwave imaging device for brain stroke monitoring

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# URSI Commission K

- The youngest URSI Commission (created in 1990)
- Promotes research on biological effects of electromagnetic fields and waves, and their uses in medicine
- Strong interdisciplinary character and cooperation with international organizations
  - (International Commission on Non-Ionizing Radiation Protection – ICNIRP; Scientific Committee on Emerging and Newly Identified Health Risks – SCENIHR, World Health Organization - WHO)

# URSI Commission K

## Italian URSI Commission

- Two Commission K Chairs:
  - Paolo Bernardi (1993-1996)
  - Guglielmo D'Inzeo (2008-2011)

- National Interuniversity Research Center on Interactions between Electromagnetic Fields and Biosystem (ICEmB)

# URSI Commission K

- Risk assessment for wireless communication (mechanisms of interaction, biological effects)
- Multiscale modelling of the interaction of EM fields and human living systems
- Innovative medical devices for therapy and diagnostics based on EM fields

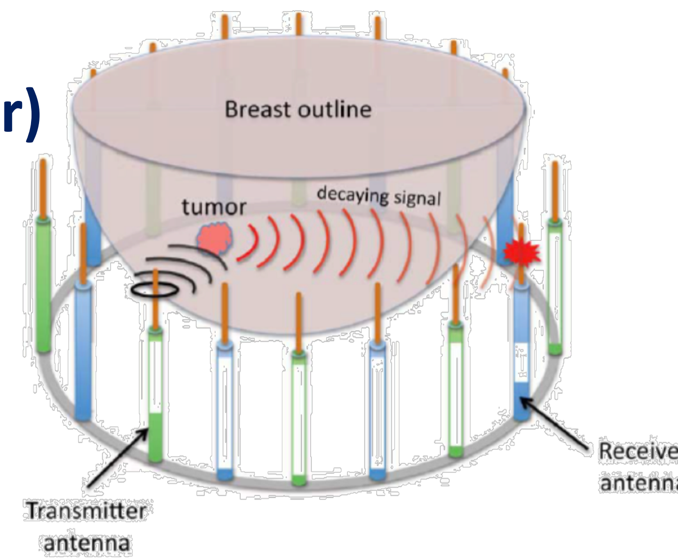
# Medical Microwave Imaging

Process scattered fields to create images of human tissues and characterize their physio-pathological status

Exploits **differences in dielectric properties**

(complex permittivity and conductivity)

- **kind of tissue**
- **pathological status (normal/tumor)**



# Medical Microwave Imaging

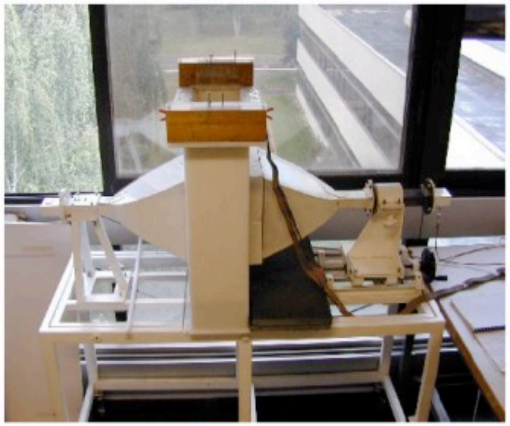
**Main attractive characteristics**

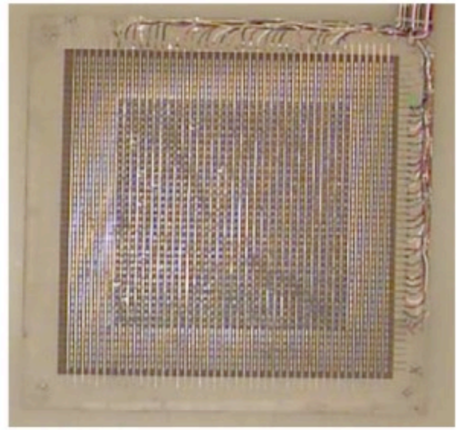
- ✓ non-destructive
- ✓ contactless
- ✓ totally safe for operators
- ✓ potentially real-time
- ✓ cost-efficient
- ✓ easy to operate

**Intrinsic constraints**

- ✓ Spatial resolution
- ✓ Penetration depth
- ✓ Complexity of underlying mechanism

# SUPELEC Microwave Camera





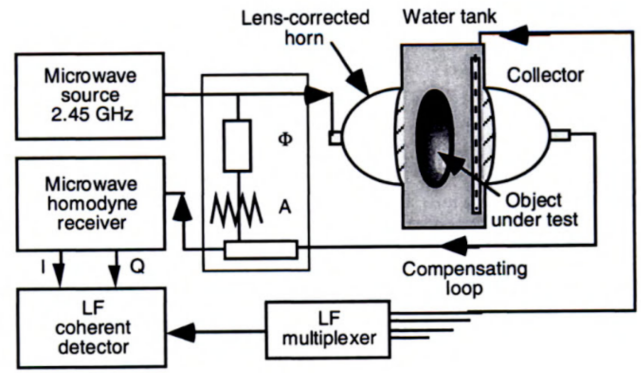



Figure 2: The 2.45 GHz microwave camera (left), the retina (right).

- 2.45 GHz planar microwave camera for non-invasive thermometry during hyperthermia
- Two horn antennas to approximate plane wave incidence
- A “retina” of 32x32 dipoles that measure scattered fields
- The medium is immersed in a rectangular tank filled with water
- Qualitative images from spectral processing at the rate of 25 images per second

# SUPELEC Microwave Camera

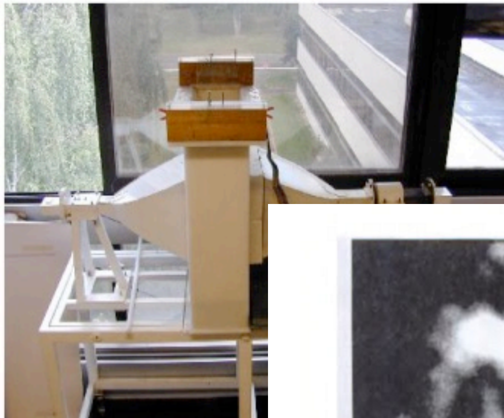
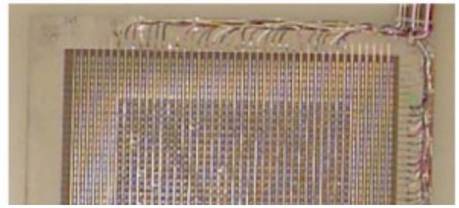
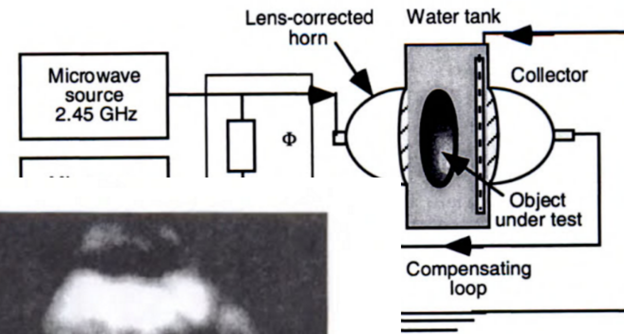


Figure 2:





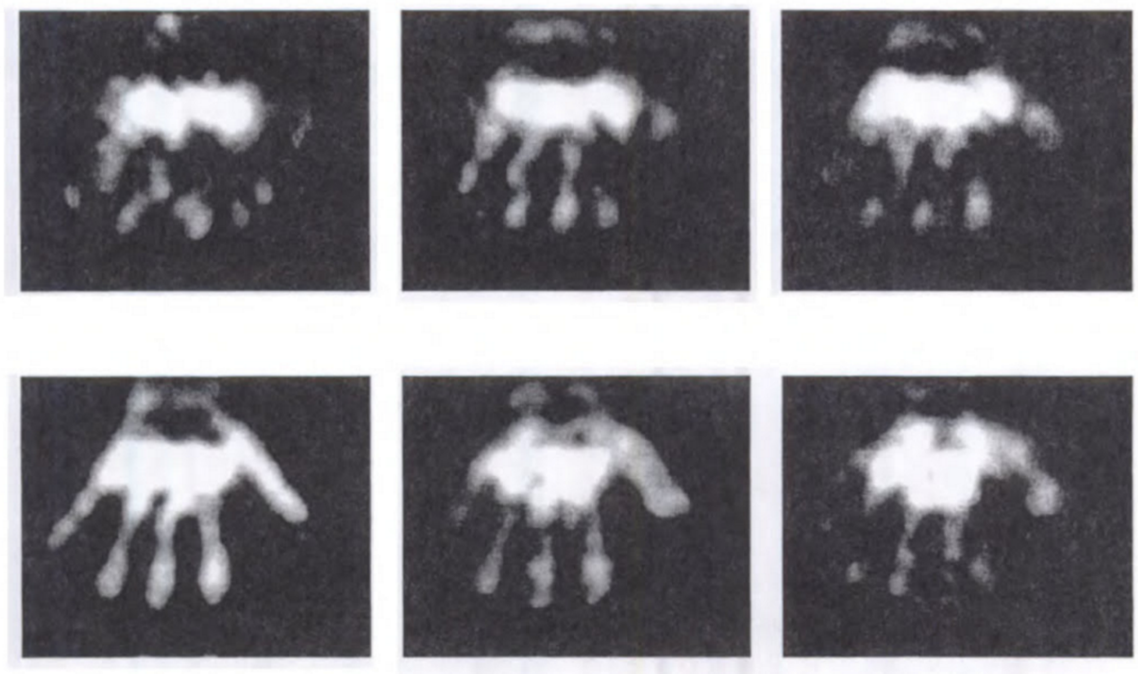
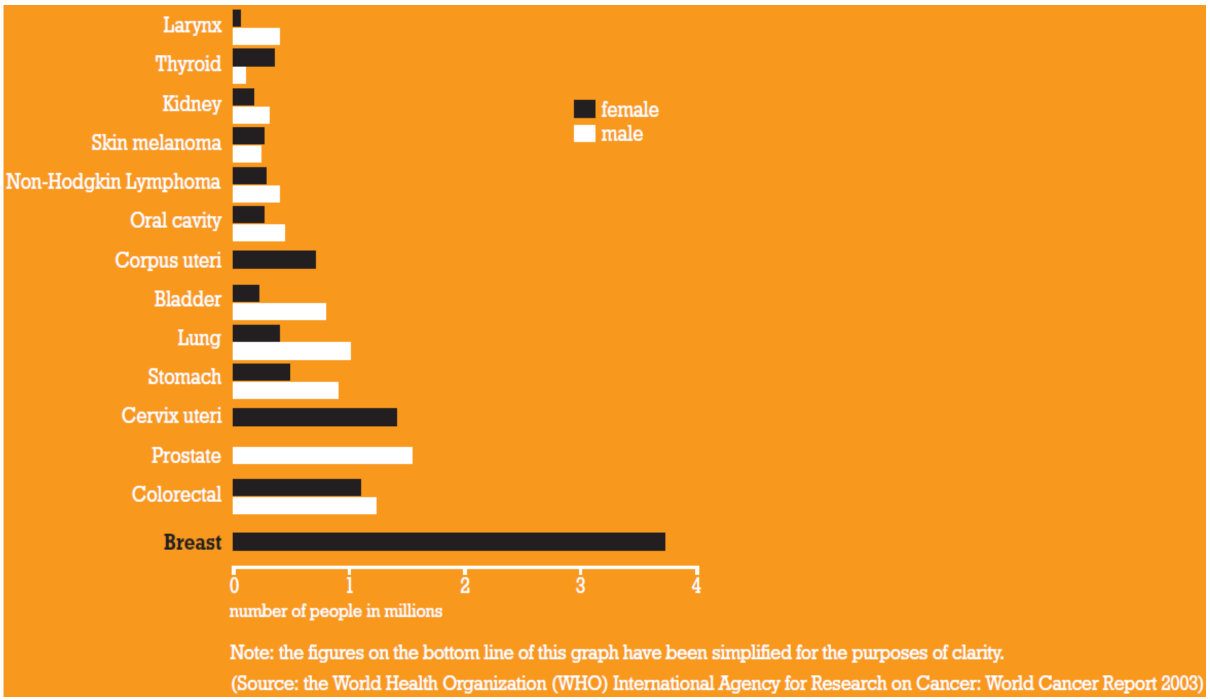



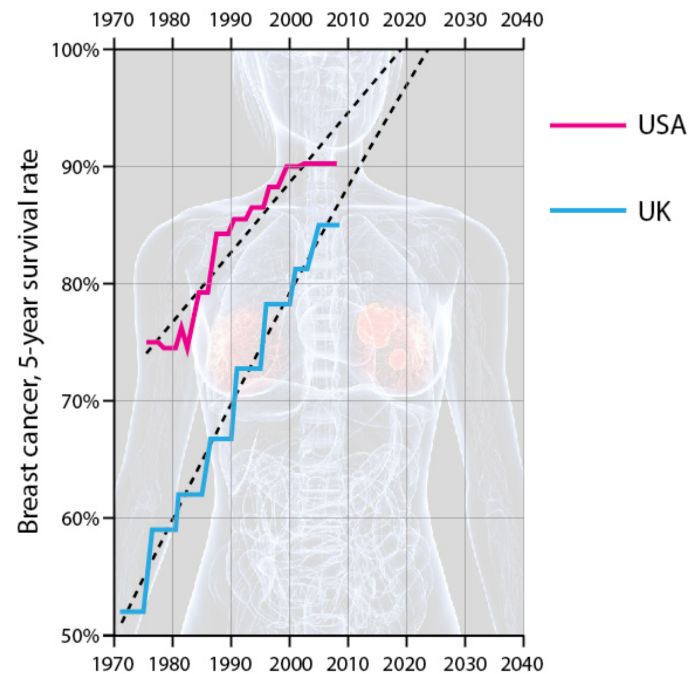
Figure 7.36 Sequence of images reconstructed at different distances showing focusing capability.

- 2.45 GHz yperthermia
- Two horn
- A "retina"
- The medi
- Qualitativ cond

# MWI for Breast Cancer Diagnosis

By far the most common cancer in women

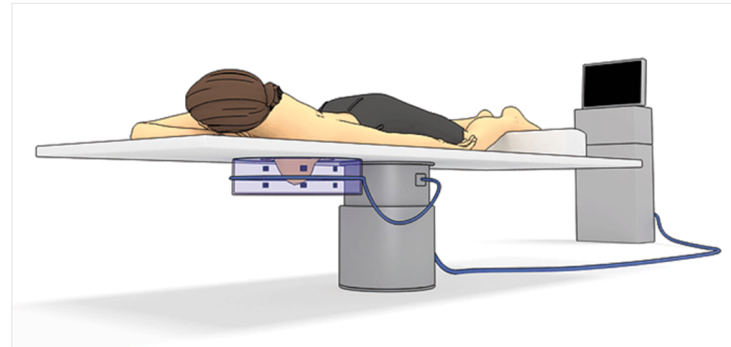


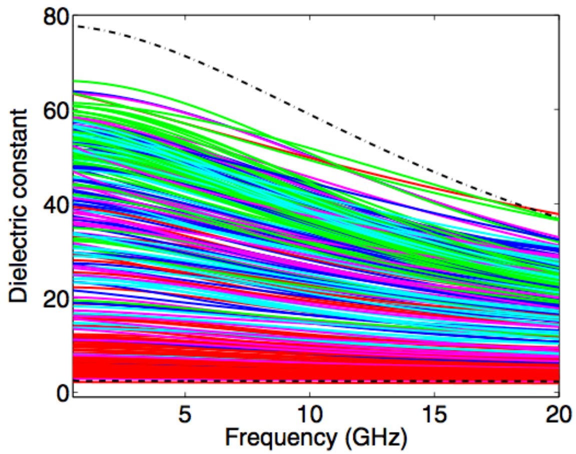



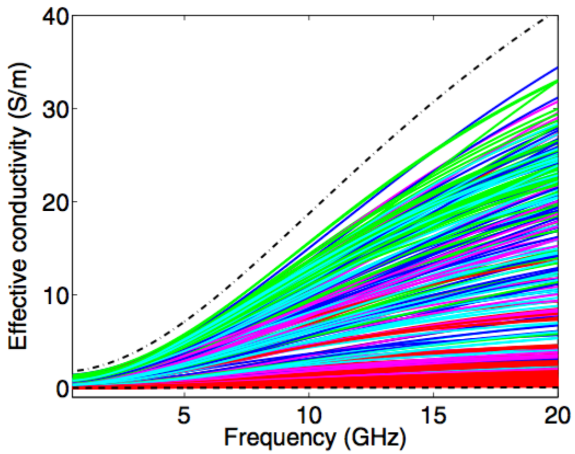

Source: Cancer research UK, futuretimesline.net

Early detection and treatment is crucial for survival

# MWI for Breast Cancer Diagnosis

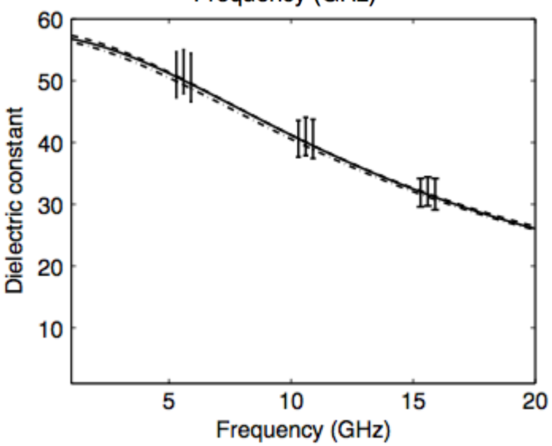


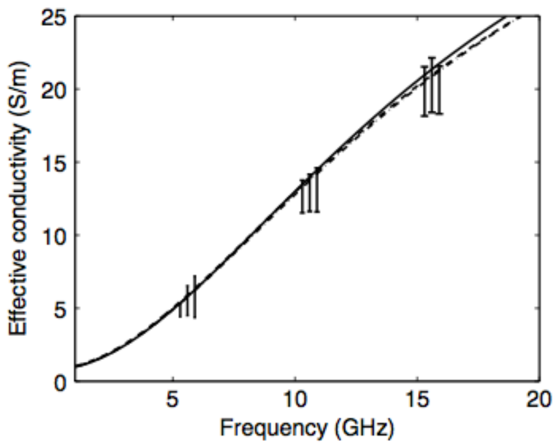



Normal tissue

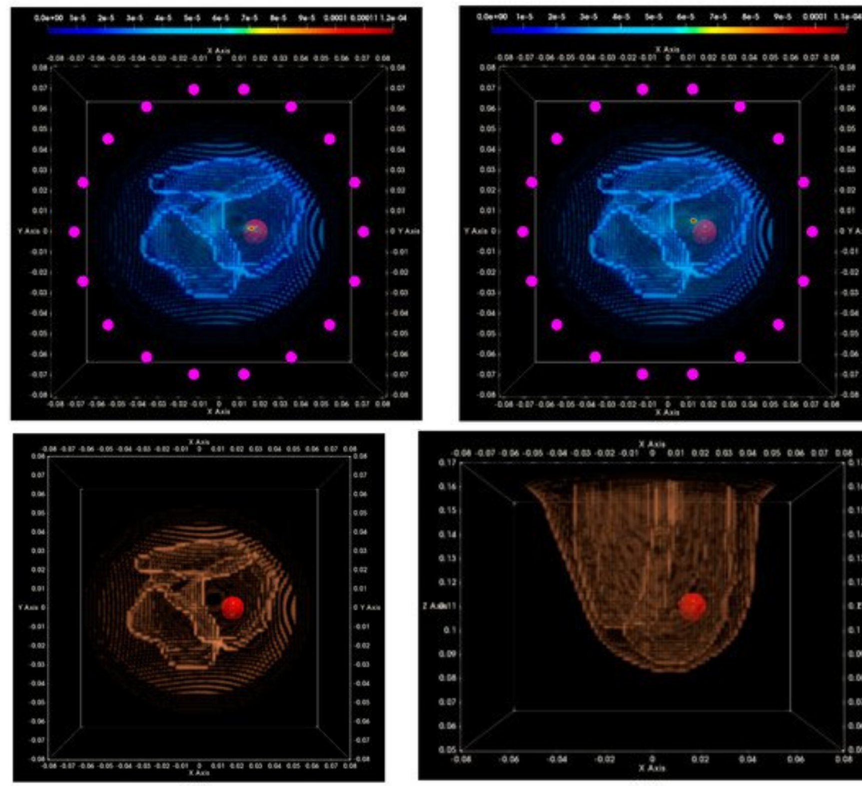
Malignant tissue




M. Lazebnik et al., Phys. Med. Biol. 52, 6093, 2007

# Current clinical trials (Wavelia – MW Vision)

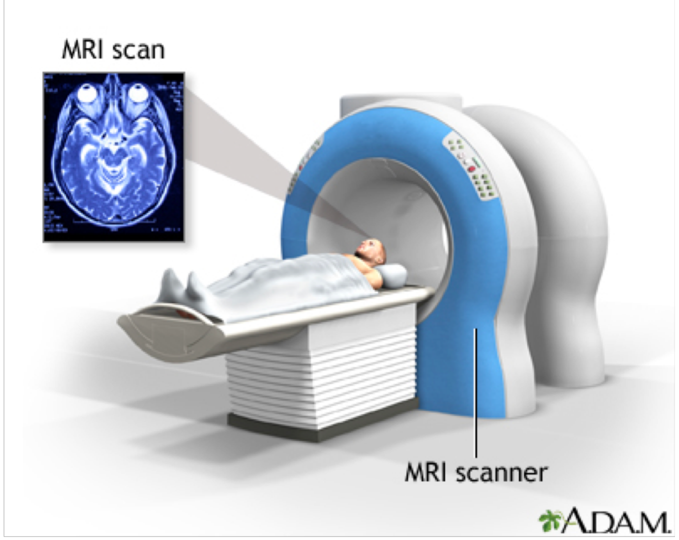



Fasoula, A et al. *Diagnostics* **2018**, *3*, 53.

# MWI for brain stroke

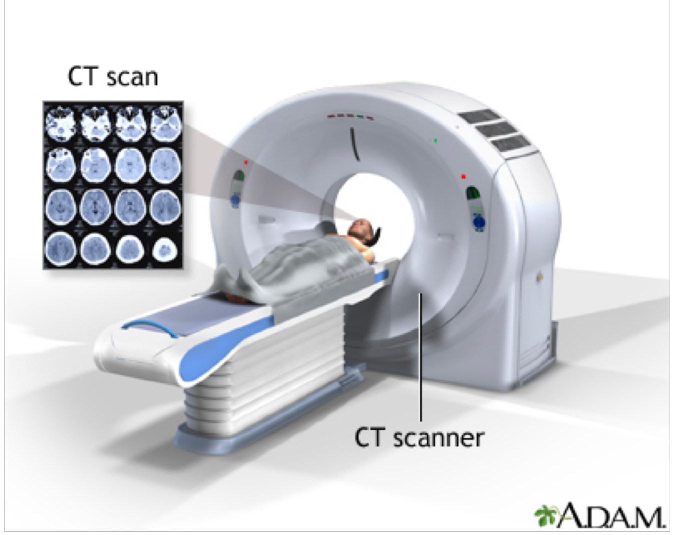
- **Brain stroke** is one of the most common diseases worldwide
- **Diagnostic/imaging methodologies** are a great support to the clinician
- MRI and CT are the currently most assessed and reliable diagnostic tools

Magnetic resonance imaging (MRI)



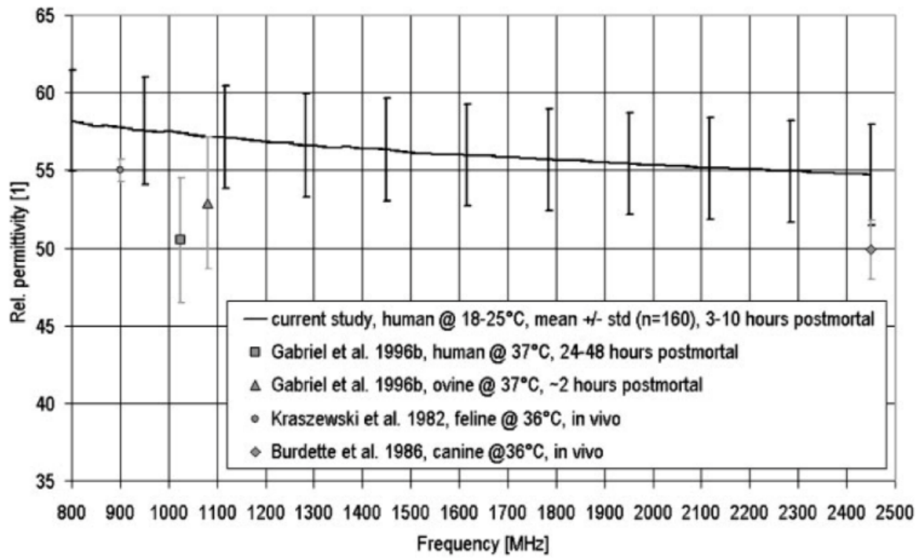

https://www.scripps.org/encyclopedia/graphics/images/en/23269.jpg

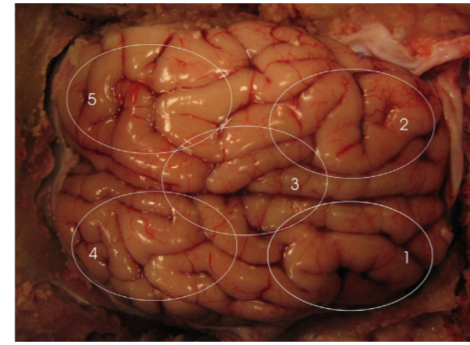
Computerized tomography (CT)

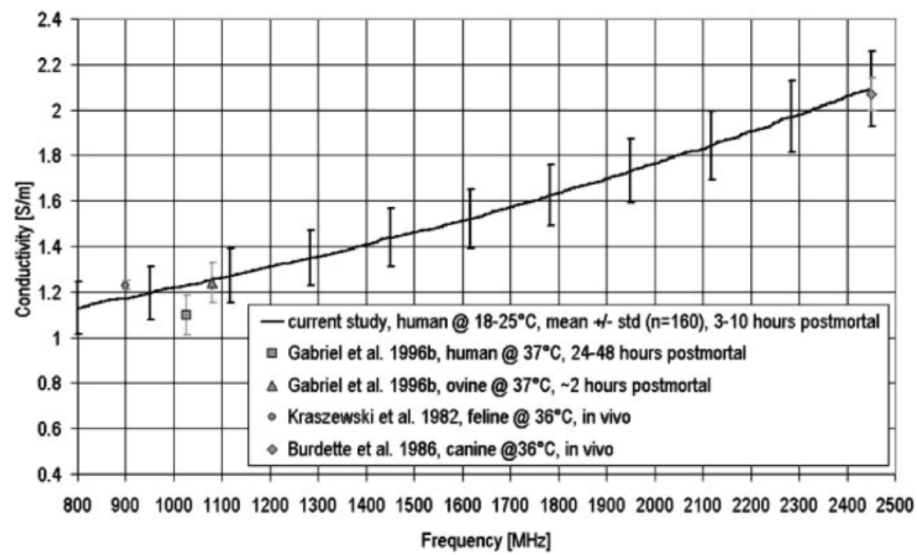



http://keckmedicine.adam.com/graphics/images/en/23268.jpg

# MWI for brain stroke



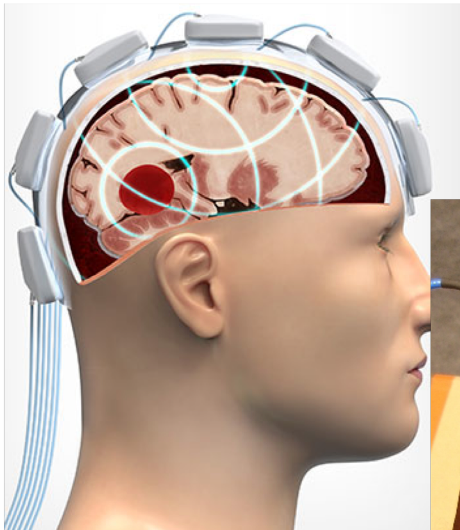



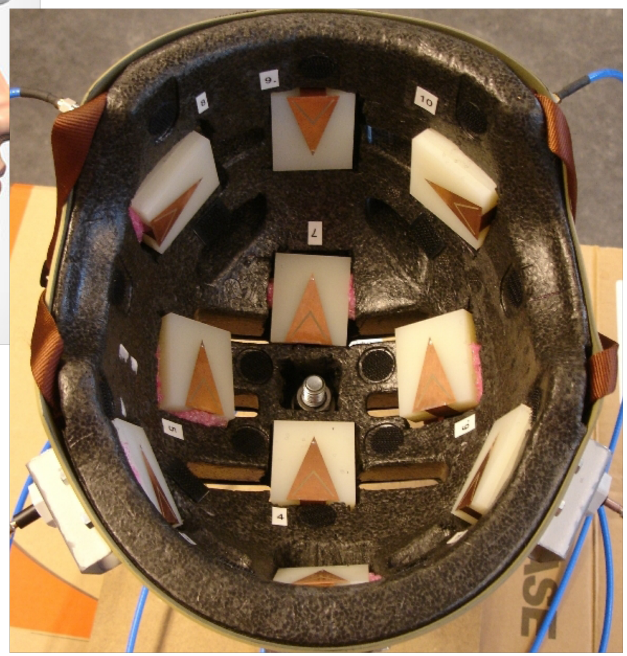





1. G. Schmid et al., *Bioelectromagnetics*, Vol.24 (6), pp 423–430, 2003.
2. S. Semenov, et al., *Bioelectromagnetics*, vol. 38, no. 2, pp. 158-163, 2016.

# MWI for classifying stroke
## (hemorrhage vs. cloth)

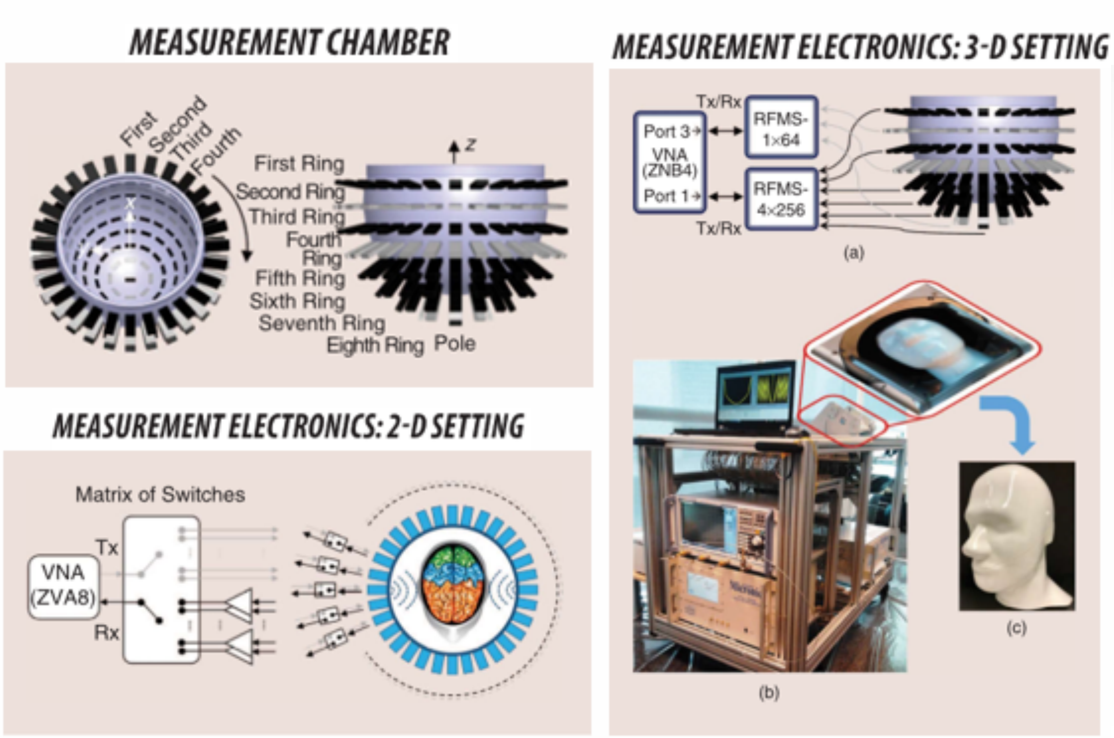





http://www.chalmers.se/en/projects/Pages/Strokefinder.aspx

A. Fhager et al., EUCAP2013, pp.845,846, 2013

# MWI for brain stroke diagnosis





emtensor

M. Hopfer et al, ”*IEEE Antennas and Propagation Magazine*, vol. 59, 2017.

# Monitoring stroke after onset

**Continuous monitoring** in the acute stage allows increasing recovery rate

**Close clinical observation** after the onset improves treatment effectiveness

- MRI/CT:
  - time consuming / not portable / costly
  - not available for bedside monitoring
  - harmful due to ionizing radiations (CT)

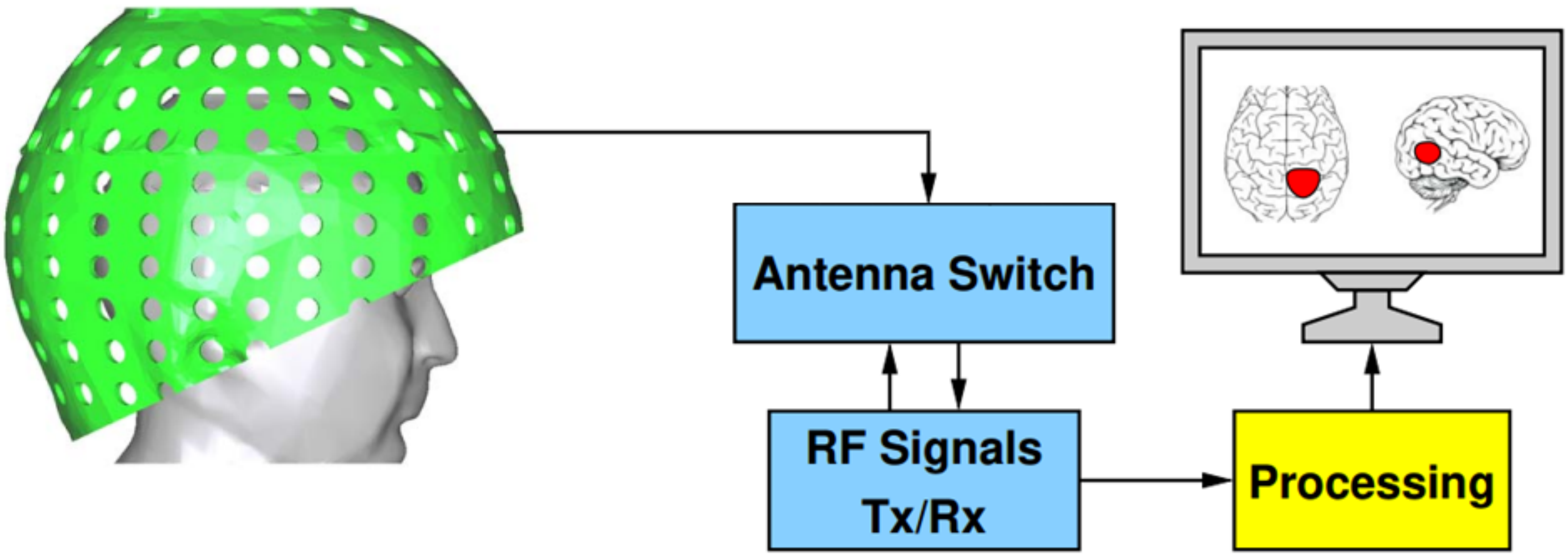
Need of **portable device** for **continuous monitoring** of patients in the post-acute stage

# "MiBraScan" – Microwave Brain Scanner for Cerebrovascular Diseases

Realization of **novel** device able to **continuously monitor** a patient after the stroke onset

National Relevance Project funded by Italian Ministry of Education (2017-2020)

# A portable MWI device for brain stroke monitoring




- ✓ **Conformal array of antennas** around the upper part of head
- ✓ The antenna array is connected to the control electronics
- ✓ Each antenna acts as transmitter and receiver

# Medical Microwave Imaging

## Key ingredients

Ad-hoc problem-based design procedure

Reliable & effective forward solver

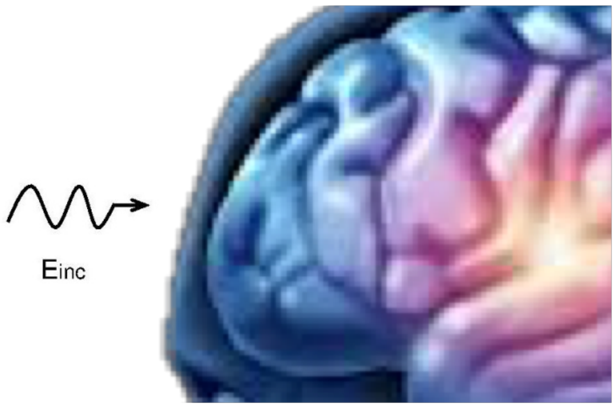
**Microwave imaging system for specific clinical need**

Model-based imaging technique

Specialized hardware

# Imaging system design

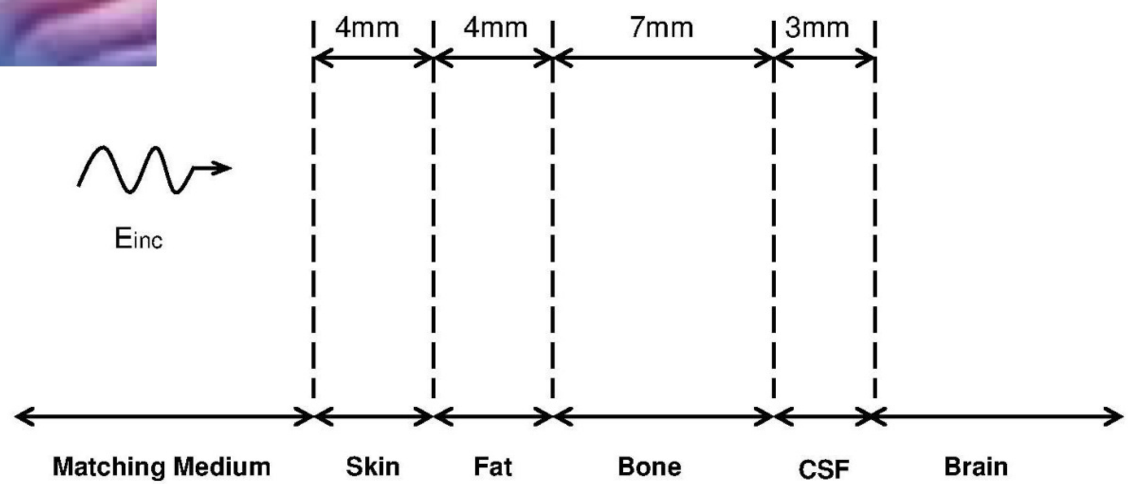
## Frequency range & coupling medium




Wave-head interaction modeled through a layered medium

Frequency

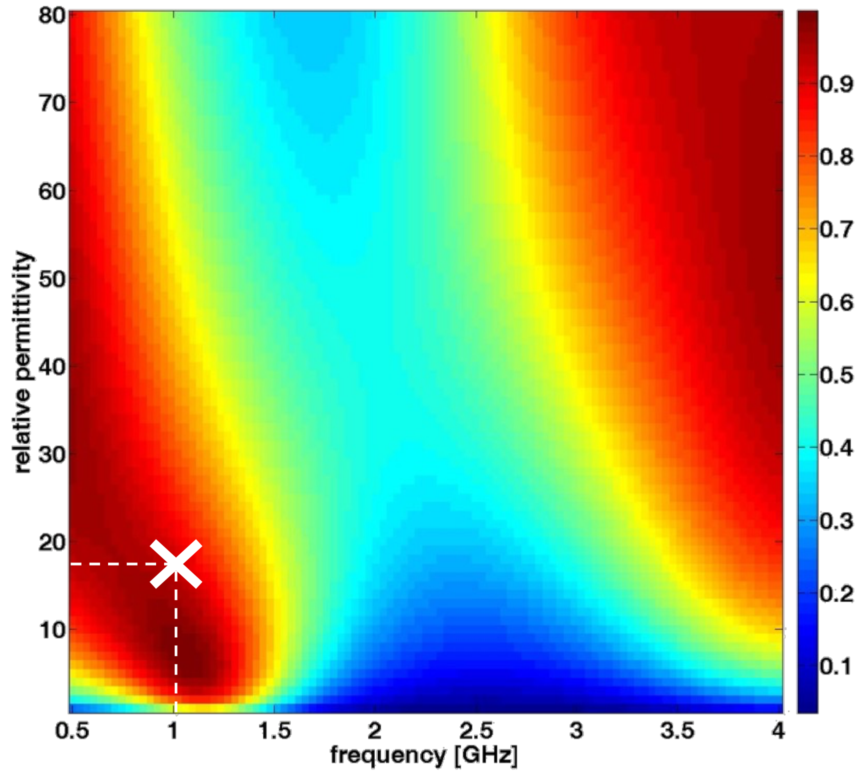
Medium properties




R. Scapaticci, et al., Progress in Electromagnetics Research B, 2012

# Imaging system design

## Frequency range & coupling medium

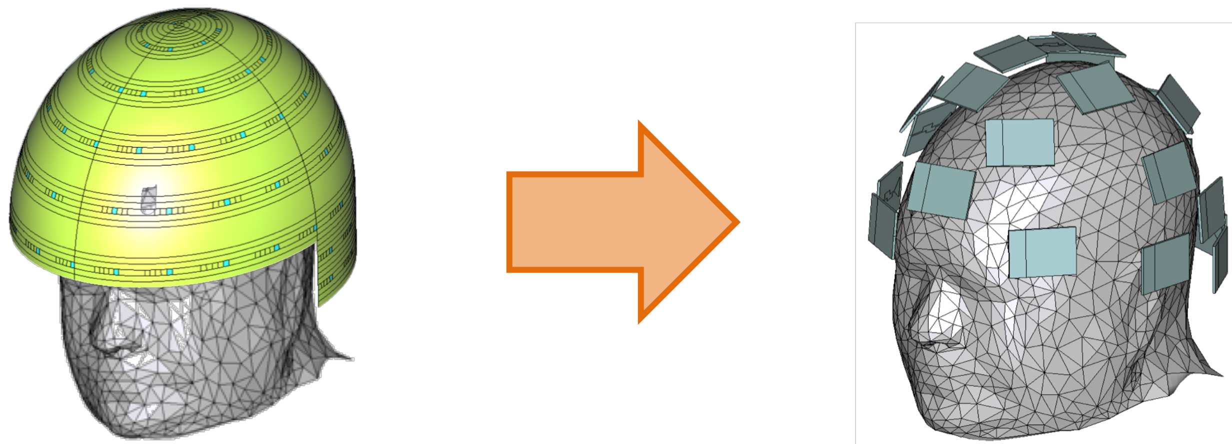



**Chosen working conditions**

- Narrow working frequency band centered on **1 GHz** (0.8-1.2 GHz)
- Coupling medium with $\varepsilon_r$ **equal to around 20**

# Imaging system design

## Antennas number and positions



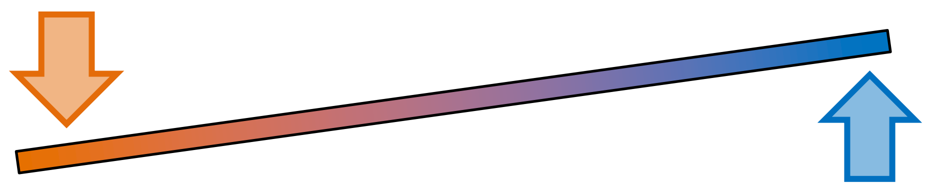
R. Scapaticci et al. IEEE-TAP, vol. 66, no. 12, pp. 7328-7338, Dec. 2018.

# Imaging system design

## Antennas number and positions

**Rigorous design based on fulfillment of suitable metrics**

**Discretization error**

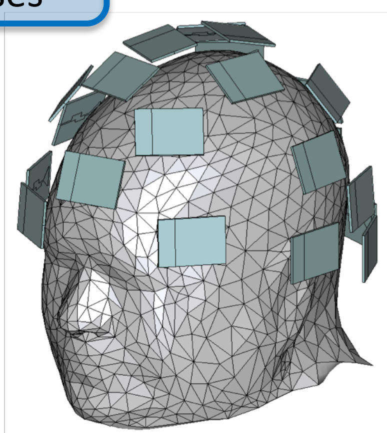


**Condition Number**

Model accuracy increases when $N_m$ increases

Imaging problem becomes unstable $N_m$ increases

$$N_m=24$$



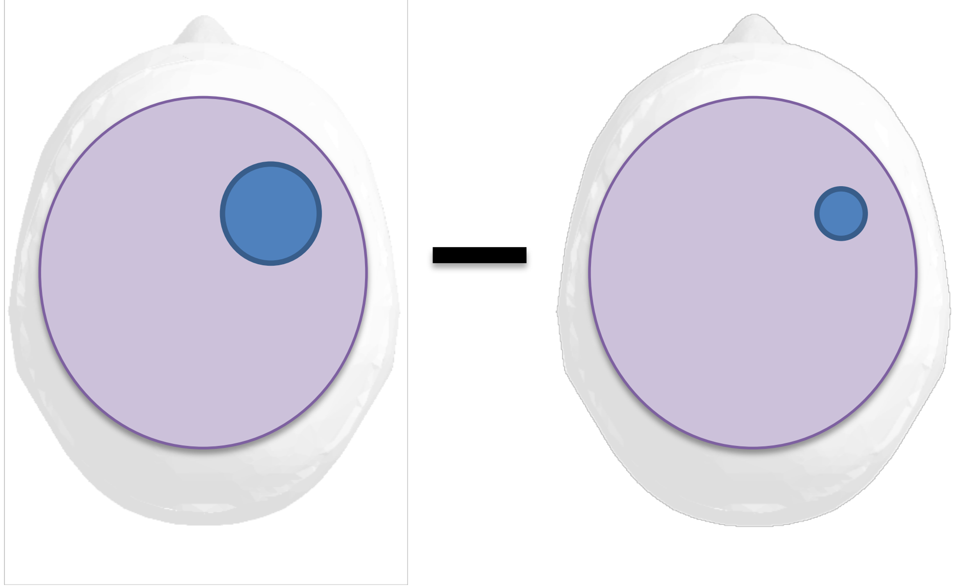
R. Scapaticci et al. IEEE-TAP, vol. 66, no. 12, pp. 7328-7338, Dec. 2018.

# Imaging system design

## Imaging algorithm

**Differential imaging**

Scenario time = T1 | Scenario time = T0



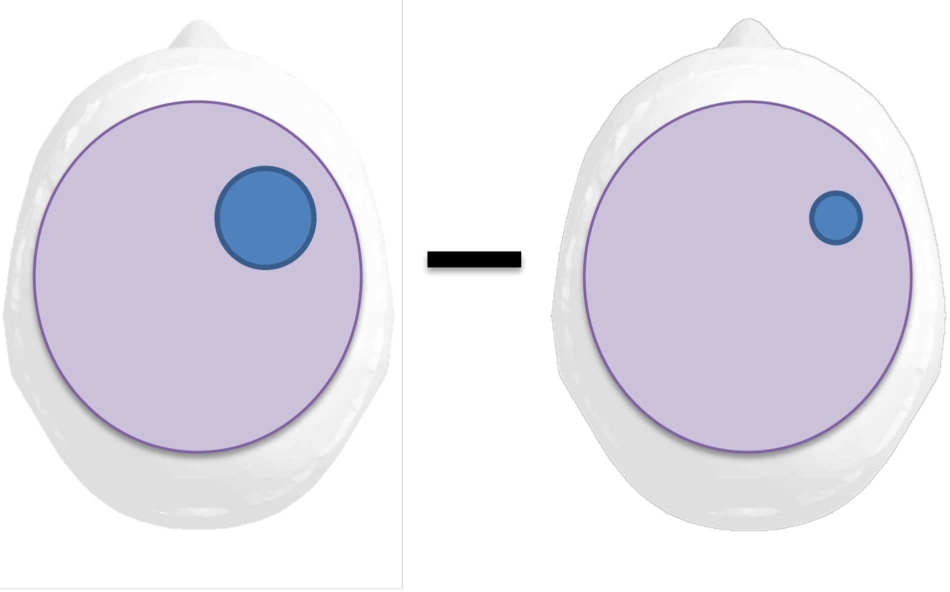
R. Scapaticci et al., in Emerging Electromagnetic Technologies for Brain Diseases Diagnostics, Monitoring and Therapy. Springer int. pub., 2018, Ch. 2

# Imaging system design

## Imaging algorithm

### Differential imaging

Scenario time = T1 Scenario time = T0



### Linear model: TSVD algorithm

(Distorted Born approximation)

TX/RX antennas

Background field in the reference scenario

$$\Delta S(\boldsymbol{r}_p, \boldsymbol{r}_q) = \frac{-j\omega\epsilon_b}{4} \int_D \boldsymbol{E}_b(\boldsymbol{r}_p, \boldsymbol{r}) \cdot \boldsymbol{E}_b(\boldsymbol{r}, \boldsymbol{r}_q) \Delta\chi(\boldsymbol{r}) d\boldsymbol{r}$$

Domain of interest

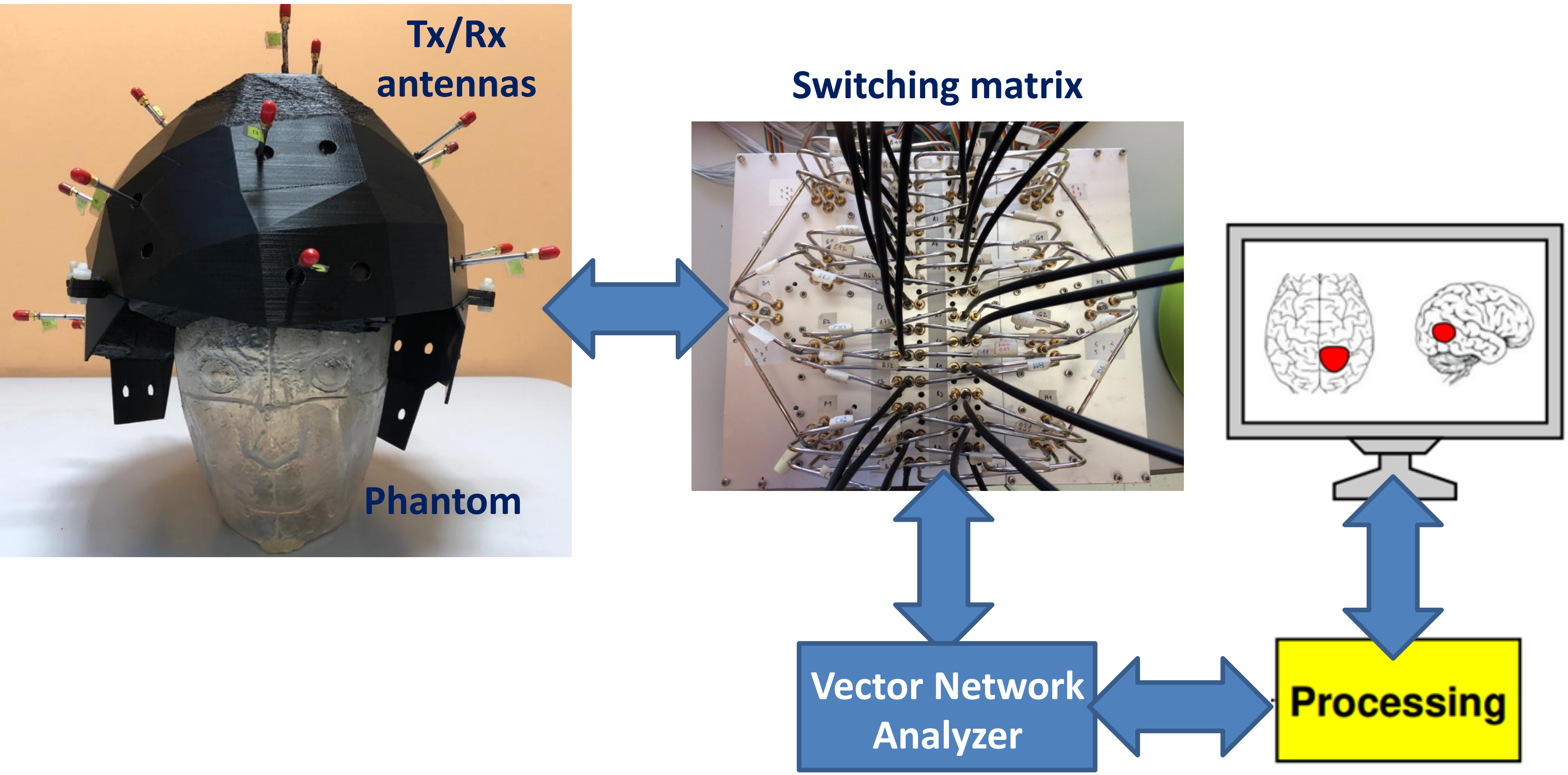
Variation of the contrast

$$\Delta S(\boldsymbol{r}_p, \boldsymbol{r}_q) = L(\Delta\chi) \qquad [u_n, \sigma_n, v_n] = SVD(L)$$

$$\boxed{\Delta\chi = \sum_{n=1}^{T} \frac{1}{\sigma_n} < \Delta S, u_n > v_n}$$

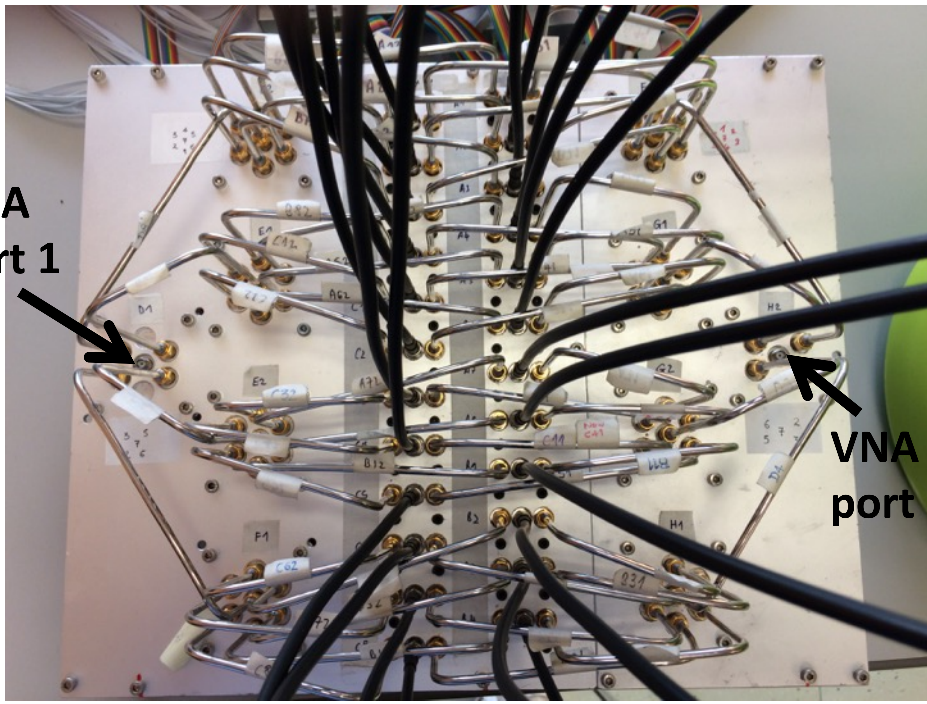
R. Scapaticci et al., in Emerging Electromagnetic Technologies for Brain Diseases Diagnostics, Monitoring and Therapy. Springer int. pub., 2018, Ch. 2

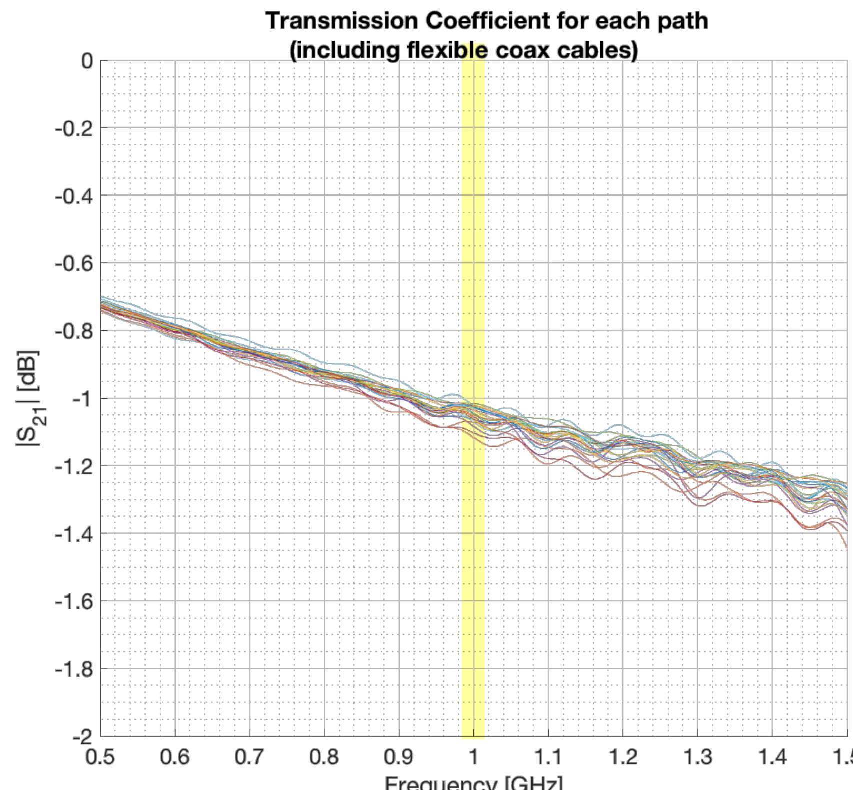
# 3-D prototype: overview



# 3-D prototype: overview

## Switching matrix



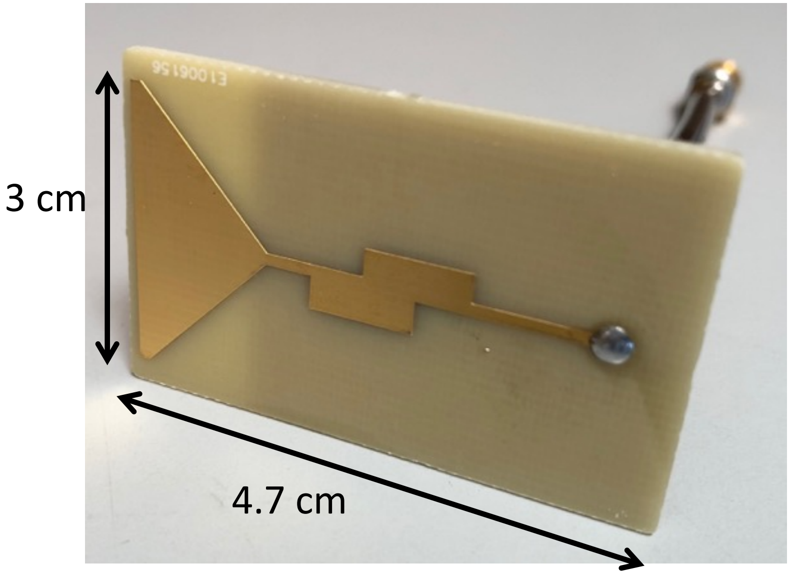



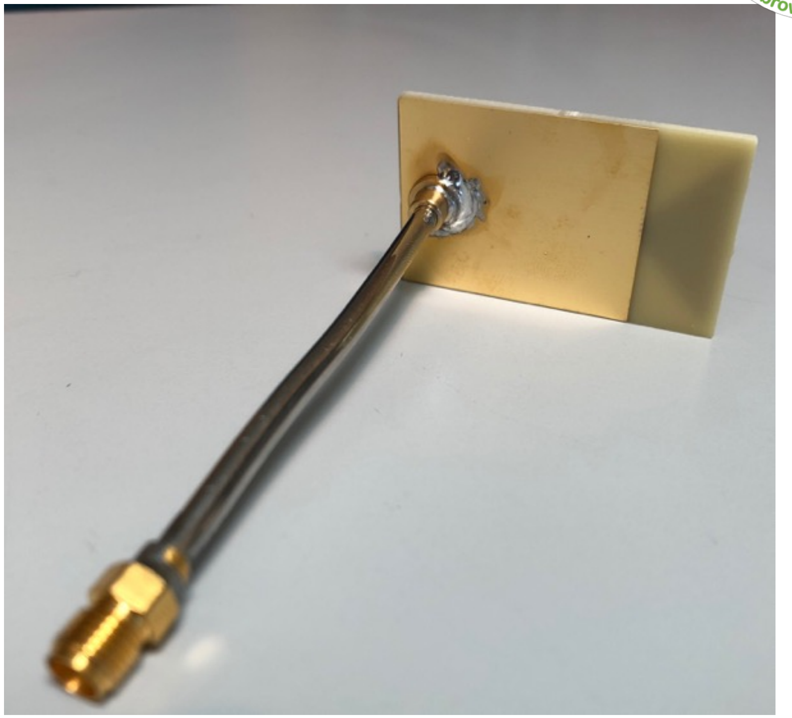

- Two SP4T, eight SP6T and twenty-four SPDP electromechanical coaxial switches
- The switches are connected with semi-rigid coaxial cables to realize a **2 × 24 switching matrix**.
- Measurement time for 24 × 24 Scattering matrix around 4 min. (1 freq. point, not optimized, IF=1kHz)

J. A. Tobon Vasquez et al., Int. Journal of Antennas and Propagation, 2019

# 3-D prototype: overview

## “Brick” antenna



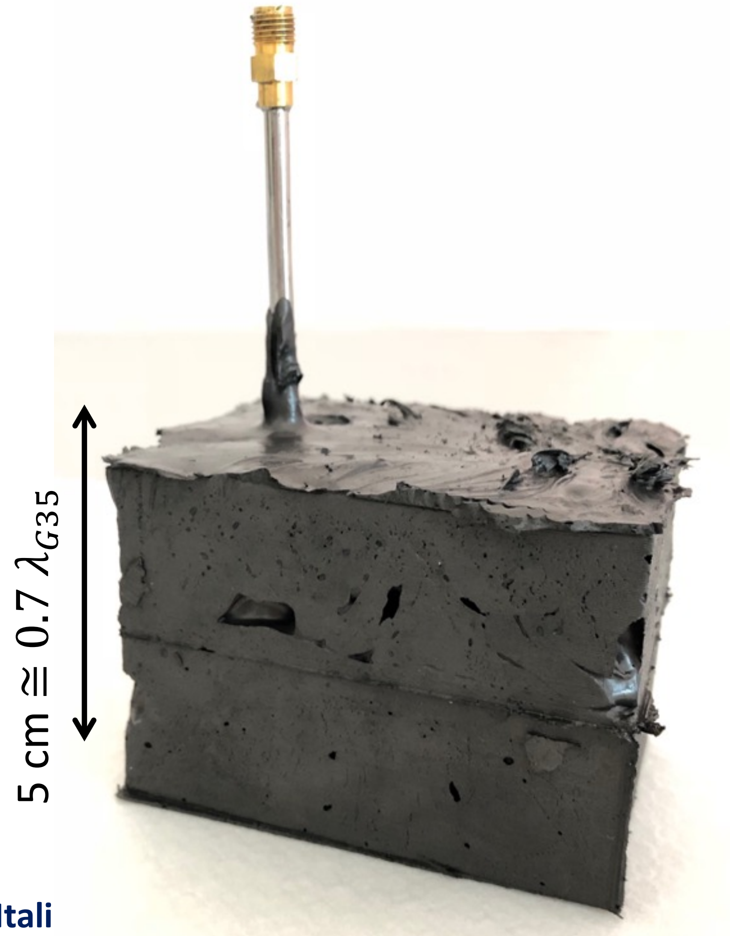
# 3-D prototype: overview

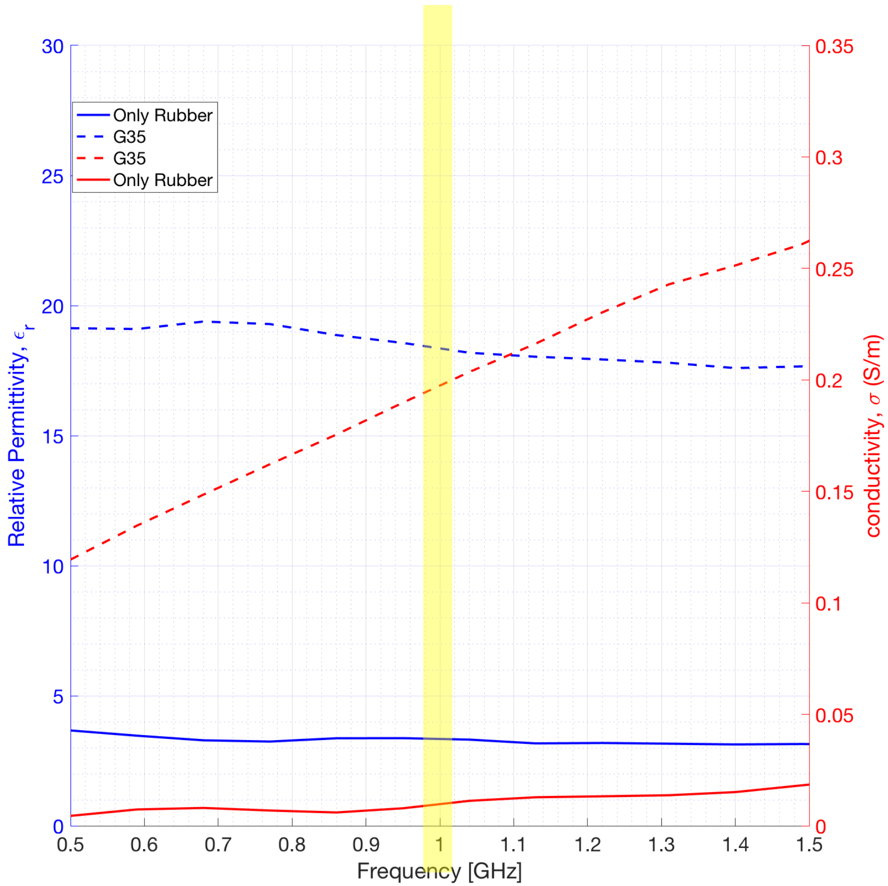
## “Brick” antenna

**G35 composition**:

35% Graphite powder (synthetic, APS 7-11 micron, 99%)*

65% Urethane Rubber (Smooth-on PMC 121/30)*




*J. Garrett, E. Fear, IEEE Trans. Antenna and Propagation, 2015

# 3-D prototype: overview

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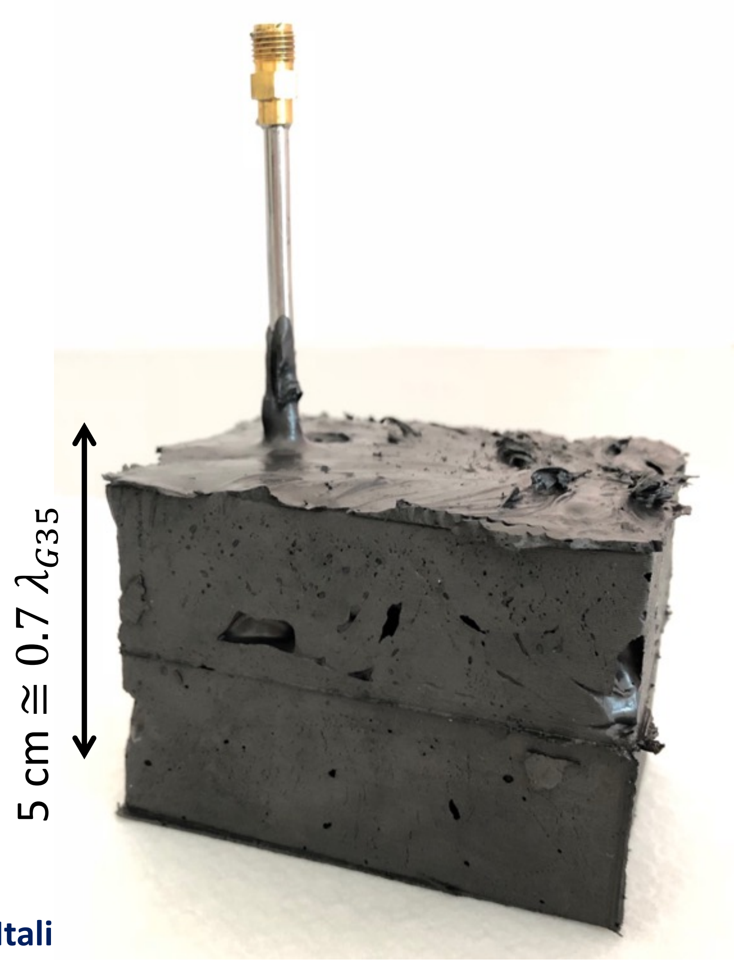
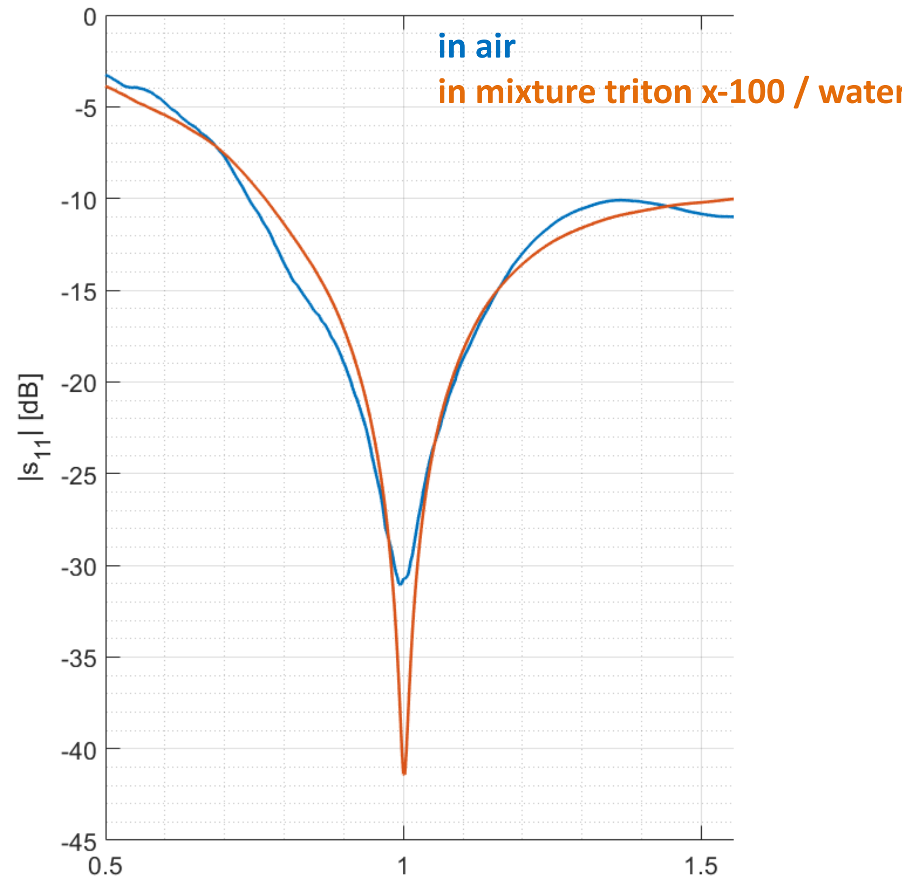
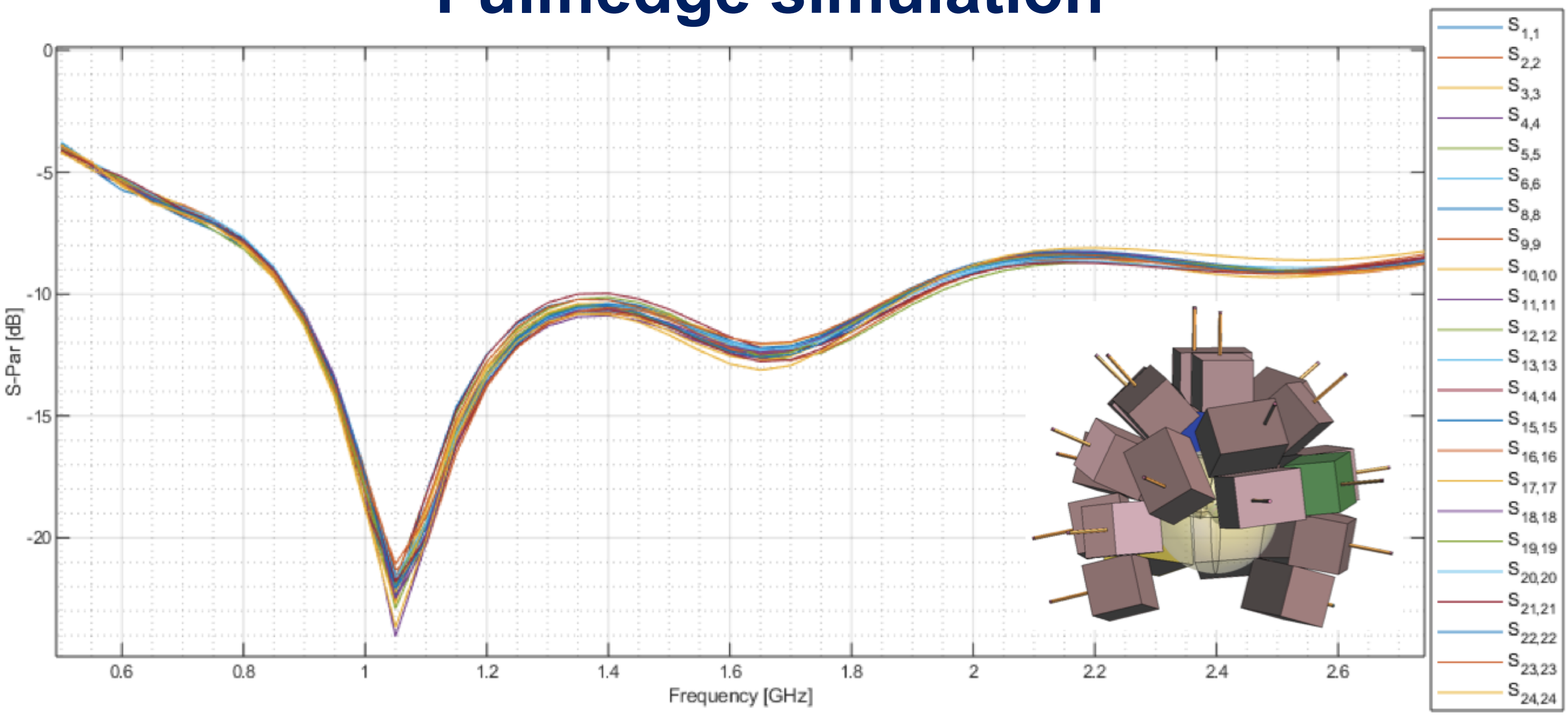


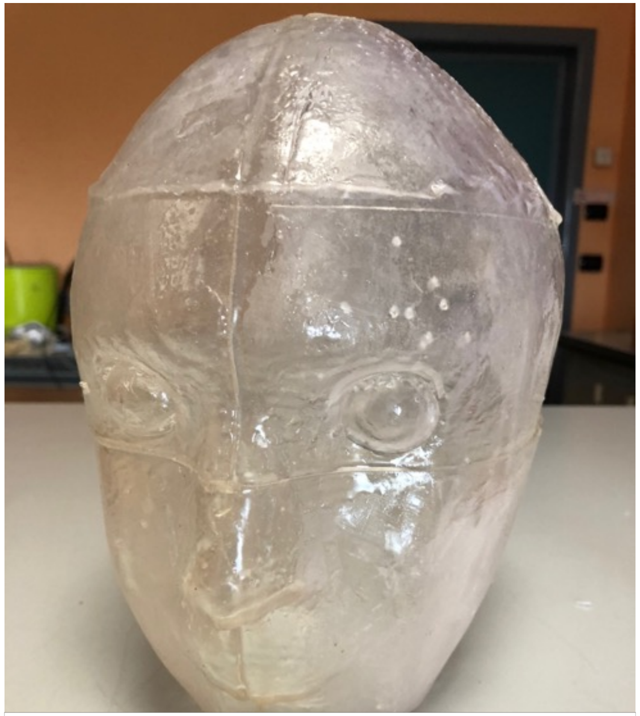
# 3-D prototype: overview

## Fullfledge simulation



# 3-D prototype: overview

## Phantom



«Jean-Paul Sartre»
(JPS from GeePs-L2S , Paris, FR)*

**Triton X / water /NACl mixtures to mimic brain tissue**

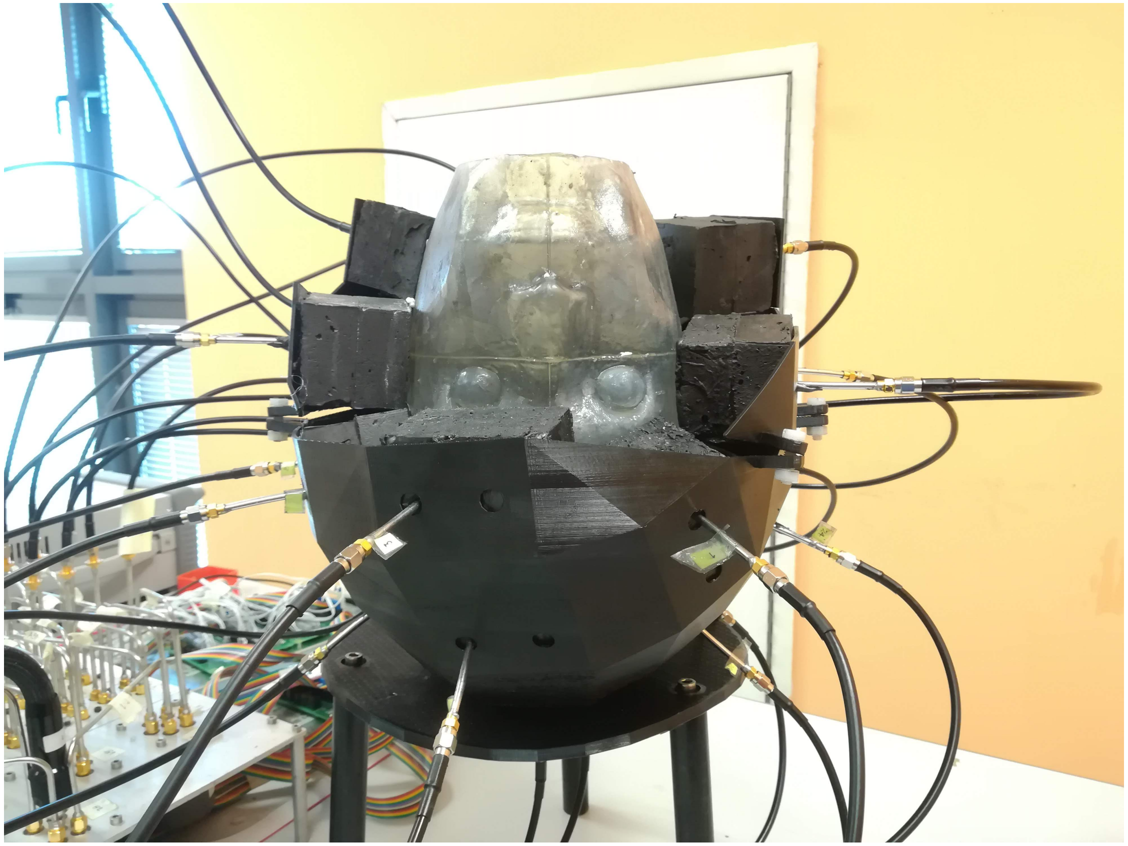
TABLE I
COMPOSITION AND PROPERTIES OF HEAD TMM AT 1 GHZ AND 37°C VERSUS THE VALUES INFERRED FROM COLE-COLE MODELS.

| | mixture | | measurements | | Cole-Cole | |
|---|---|---|---|---|---|---|
| Tissue | TX-100 (vol %) | NaCl (g/L) | $\epsilon_r$ | $\sigma$ (S/m) | $\epsilon_r$ | $\sigma$ (S/m) |
| Brain | 38 | 5.2 | 44±1 | 0.84±0.02 | 42 | 1.0 |
| CSF | 6 | 13.7 | 70±4 | 2.7±0.2 | 68 | 2.5 |
| Muscle | 24 | 5.0 | 54±1 | 0.97±0.02 | 55 | 1.0 |
| Bone | 75 | 0.8 | 16.7±0.4 | 0.30±0.03 | 12 | 0.2 |
| Blood | 14 | 9.4 | 61±2 | 1.72±0.05 | 61 | 1.6 |

*N. Joachimowicz, et al., Proc. CAMA, 2018.

# First experimental validation

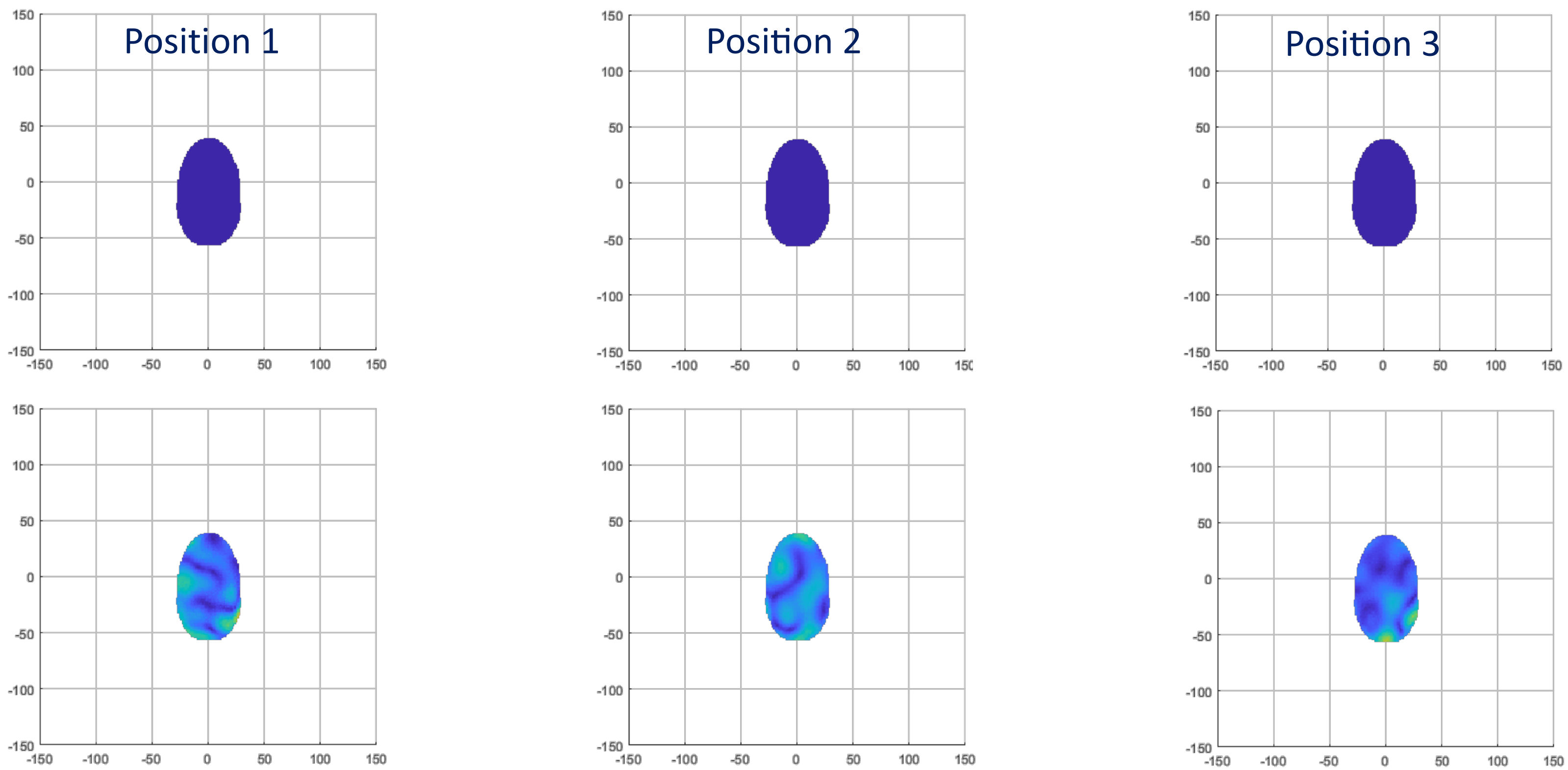
- ✓ **Complete multi-view measurements (24 antennas)**
- ✓ **Differential measurements @ 1GHz: with and without target**



# First experimental validation

**Target: plastic sphere (1.25 cm radius),**

Freq.=1 GHz, Brain mimicking mixture: $\varepsilon_r$=44, $\sigma$=0.84 $S$/m




Forward model: Proprietary FEM solver,

Algorithm: Truncated Singular Value Decomposition (TSVD)

# Acknowledgements

**MIUR-PRIN 2017**

**MiBraScan, Microwave Brain Scanner for Cerebrovascular Diseases Monitoring**

Francesca Vipiana & Mario R. Casu

Rosa Scapaticci

Gennaro Bellizzi and Enrico Tedeschi

Nadine Joachimowicz and Bernard Duchêne