Microwave Inverse Scattering for Colorectal Cancer Detection

Conference on Modern Challenges in Imaging
In the Footsteps of Allan MacLeod Cormack
On the Fortieth Anniversary of his Nobel Prize
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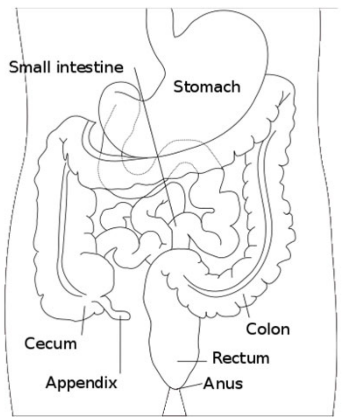
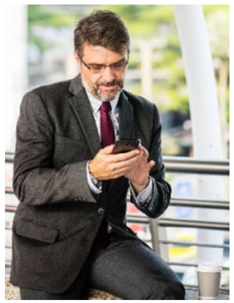
Motivation: Colorectal cancer (CRC) detection

3rd most common cancer worldwide
4th most common cause of death




50 - 75 years old

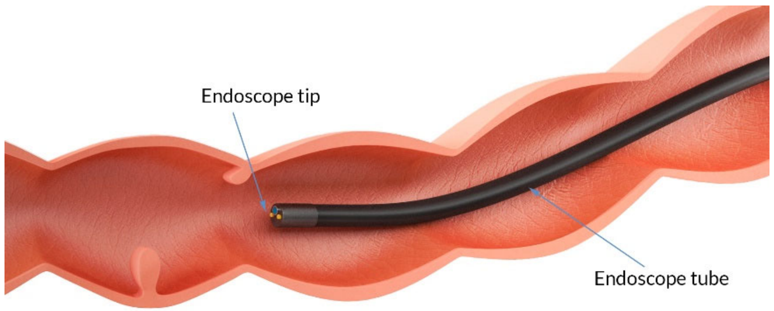
- When CRC is found at an early stage, the 5-year relative survival rate is about 90%.

Current and new techniques

- Colonoscopy still misses 22% of the polyps due to visualization limitations.

Colonoscopy

- Reduced field of view (≤ 180º).
- Subjective to the doctor.
- High economic and time burden: biopsy.



Current and new techniques

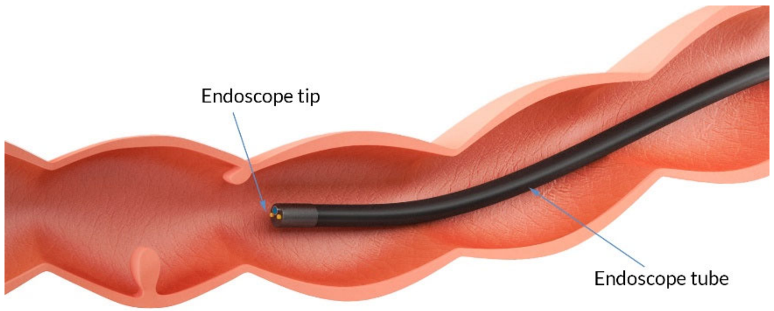
- We need to improve the current screening techniques

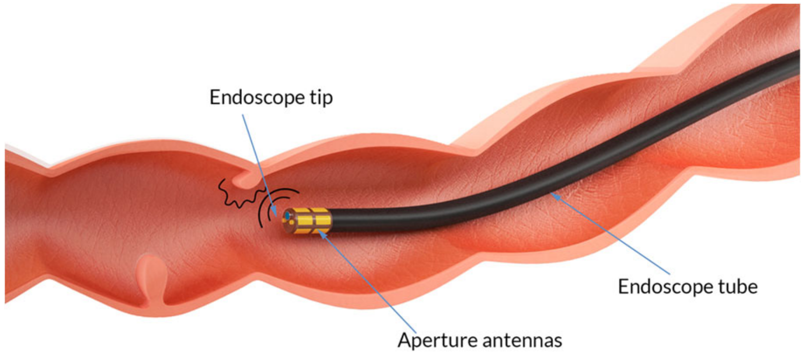
Colonoscopy

- Reduced field of view (≤ 180º).
- Subjective to the doctor.
- High economic and time burden: biopsy.

MiWEndo

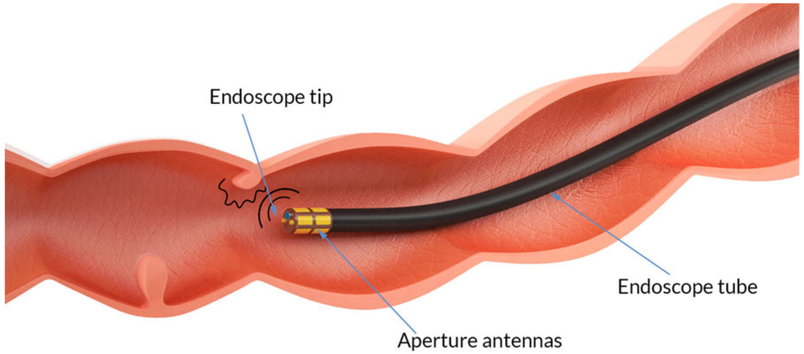
- Field of view 360º.
- May help to guide the doctor.
- Quantitative - It may reduce the biopsy costs.





New challenges

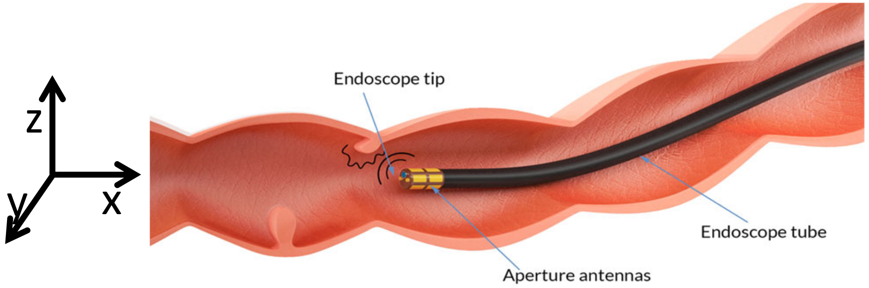
Main challenges in imaging reconstruction

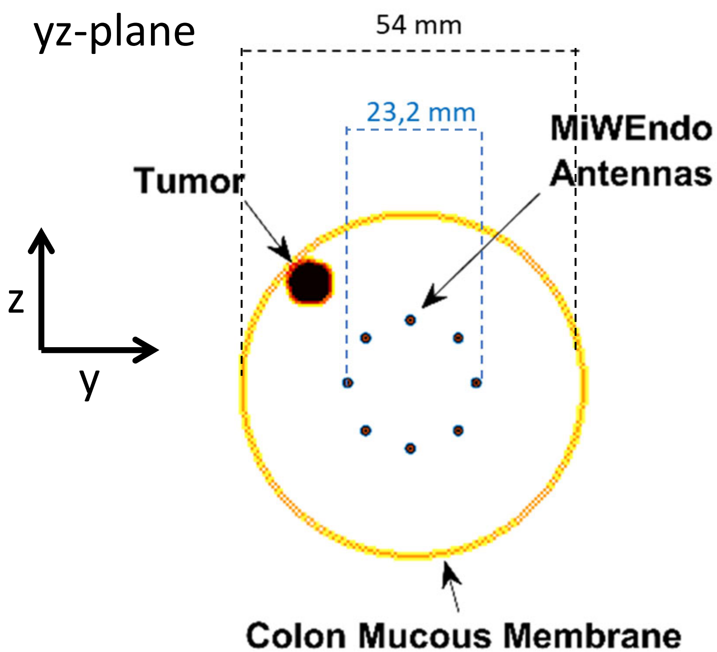


- Highly inverse problem (scattering).
- Position of the target to study.
- Only eight transmitter antennas and eight receiver ones.

MAIN GOALS

Objectives





Simplified 2D representation of the cross section of the MiWEndo inside the colon track.

Pedunculated tumors (circle<5mm radius)

- **Proof of concept of MWI reconstruction for CRC detection in a simplified 2D geometry.**
- **Help to improve the acquisition protocol of the future prototype.**

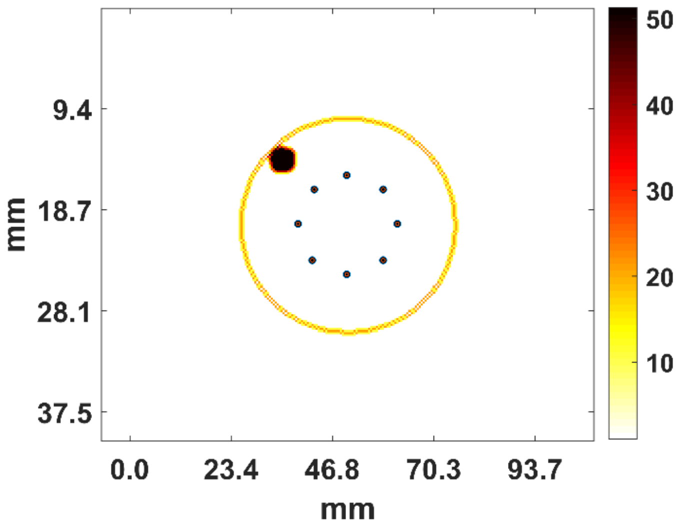
1. **Forward problem** – to simulate data.
2. **Inverse problem** – focusing in CRC detection.
3. **Most suitable antennas** for microwave image reconstruction /CRC detection.
4. **Most suitable frequencies** (Hardware limits the range of frequencies to 6-10GHz).

Forward Problem

Forward Problem

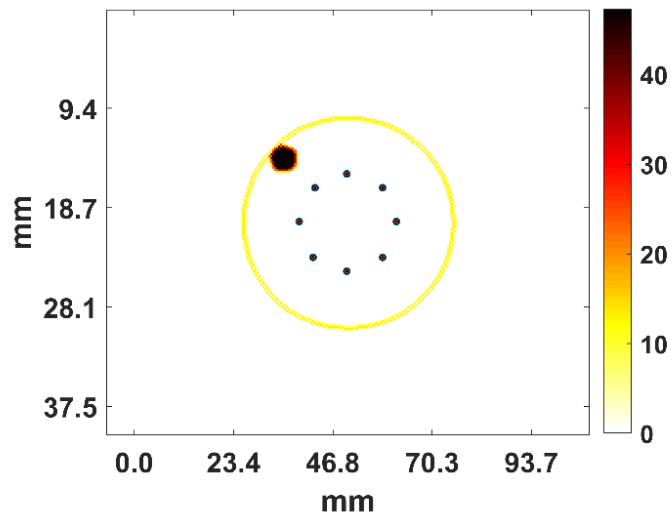
- **Dielectric properties:**

RELATIVE PERMITIVITY



KNOWN DIELECTRIC PROPERTIES FOR EACH FREQUENCY *

RELATIVE CONDUCTIVITY



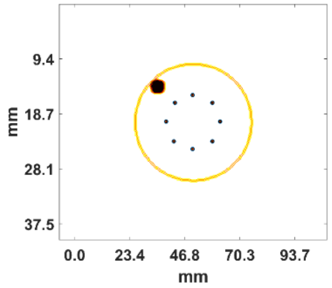
- *Using copper antennas – conductivity 5.8e7 S/m*

**Dielectric properties of colon mucosa and tumor from the experimental work done by using an open-ended coaxial probe for different frequencies*:

M. Guardiola, et al. "Dielectric properties of colon polyps, cancer, and normal mucosa: Ex vivo measurements from 0.5 to 20 GHz." *Medical physics* 45.8 (2018): 3768-3782.

Forward Problem

- Finite Difference Time Domain (FDTD) developed in *MatlabR2018* for a total of '*Nt*' time steps and in the rectangular field of view '*S1xS2*' :



for *n=1:Nt*

%%From the MiWEndo wall to the limits of the rectangular field of view *S1*x*S2:*

for *j=2:(S2-1)*

for *i=2:(S1-1)*

%To update the magnetic fields H_z and H_y

$$H_Z^{n+1}(i,j) = H_Z^n(i,j) - \frac{\Delta t\left(E_X^n(i,j+1) - E_X^n(i,j)\right)}{\Delta y * \mu_0} \quad and \quad H_y^{n+1}(i,j) = H_y^n(i,j) - \frac{\Delta t\left(E_X^n(i+1,j) - E_X^n(i,j)\right)}{\Delta z * \mu_0}$$

%To update the electrical fields E_z and E_y

$$E_x^{n+1}(i,j) = \frac{1}{2*\Delta z}\left(H_y^{n+1}(i,j) - H_y^{n+1}(i-1,j)\right) \quad and \quad E_y^{n+1}(i,j) = \frac{1}{2*\Delta y}\left(H_z^{n+1}(i,j) - H_z^{n+1}(i,j-1)\right)$$

% To compute the modulated Gaussian pulse, $E_{pulse}^n(i,j)$, if (i,j) correspond to the transmitter position and n is between the transmitting time, otherwise $E_{pulse}^n(i,j) = 0$.

%To update the transverse electrical field

$$E_x^{n+1}(i,j) = \frac{1+\frac{\sigma(i,j)*\Delta t}{2*\varepsilon\prime(i,j)}}{1-\frac{\sigma(i,j)*\Delta t}{2*\varepsilon\prime(i,j)}} * E_x^n(i,j) + \frac{1}{1-\frac{\sigma(i,j)*\Delta t}{2*\varepsilon\prime(i,j)}}\left(\frac{\Delta t}{\varepsilon\prime(i,j)} * \left(E_z^{n+1}(i,j) - E_y^{n+1}(i,j) - E_{pulse}^n(i,j)\right)\right)$$

% μ_0 denotes the vacuum permeability, σ the conductivity in S/m, and $\varepsilon' = \varepsilon_r * \varepsilon_0$ the real part of the complex permittivity.

Transverse magnetic (TM) mode of 2D-*Maxwell's* equations

%To apply the boundary conditions in *z* and *y* considering that one wave takes two-time steps to cross one cell.

end

end

end

Soon in https://github.com/bcnmedtech

Absorbing boundary conditions

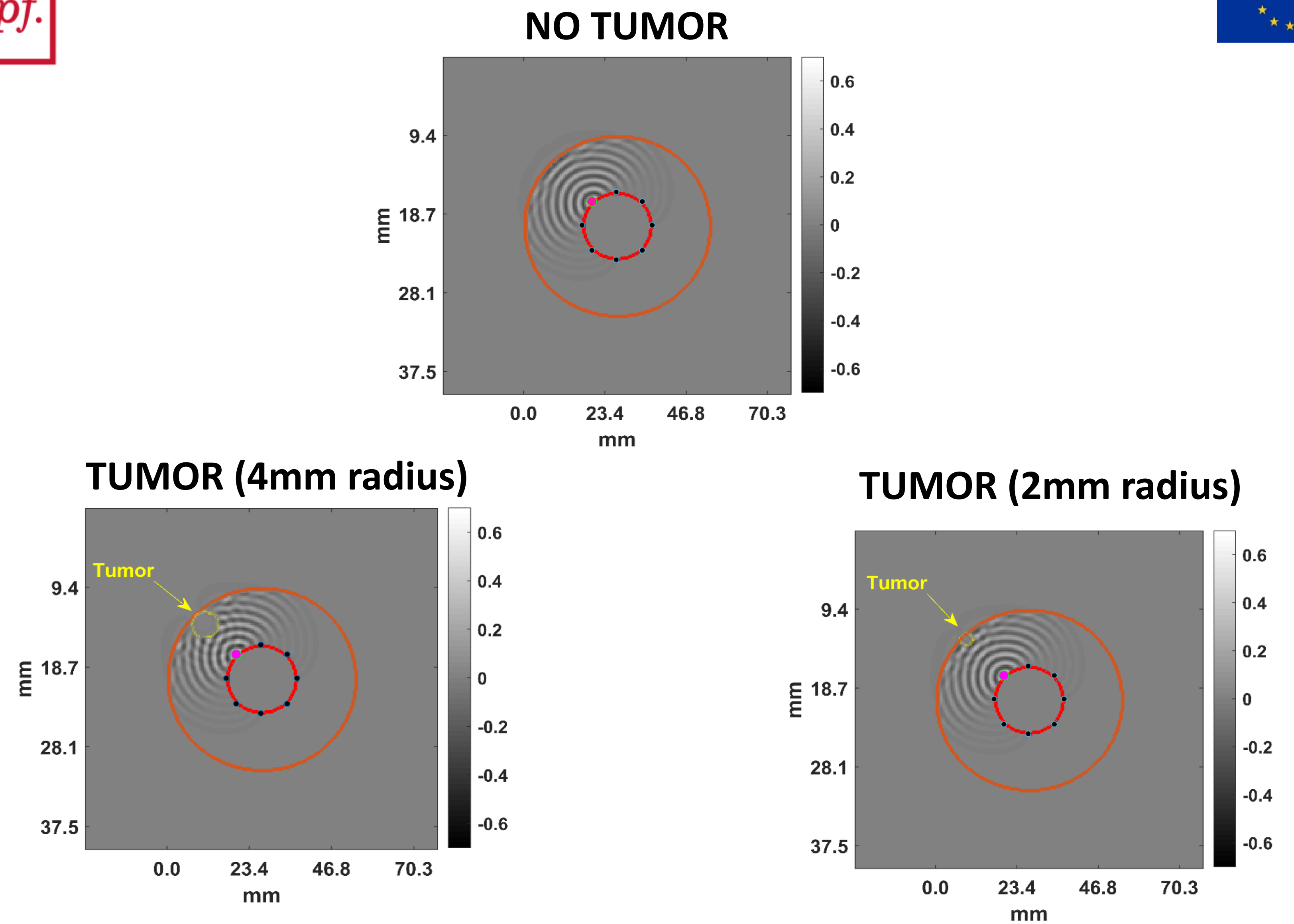
➢ **To simulate reflection-free propagation out of the computation domain.**

- **Mur 1st and 2ond order:** Mur expands the *partial derivatives* in the operators using central finite differences of the field component *about an auxiliary grid point displaced half a step along the direction of absorption and along the time*.

- **Perfectly Matched Layers** : PML *plays with the intrinsic impedance of a fictitious medium.* For reflection-free propagation through the interface between two mediums, their intrinsic impedances must be matched.

➢ **2nd Mur and PML** are the best choices when there is the colon wall. In an empty scenario PML performs better.

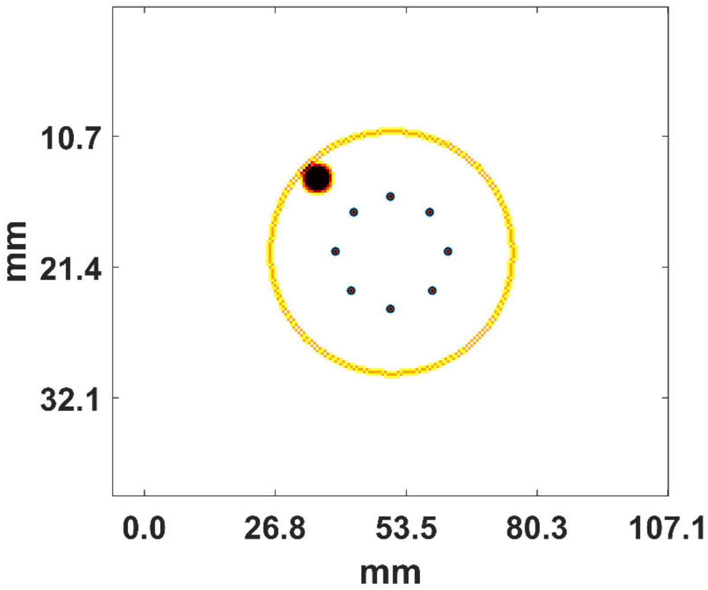
Forward Problem



Simulated spatial propagation of the electromagnetic field for different simulation scenarios at the same time instant, and for the same frequency, 8GHz.

Forward Problem

TUMOR (3.5mm radius)



Simulated spatial propagation of the electromagnetic field for 7GHz frequency.

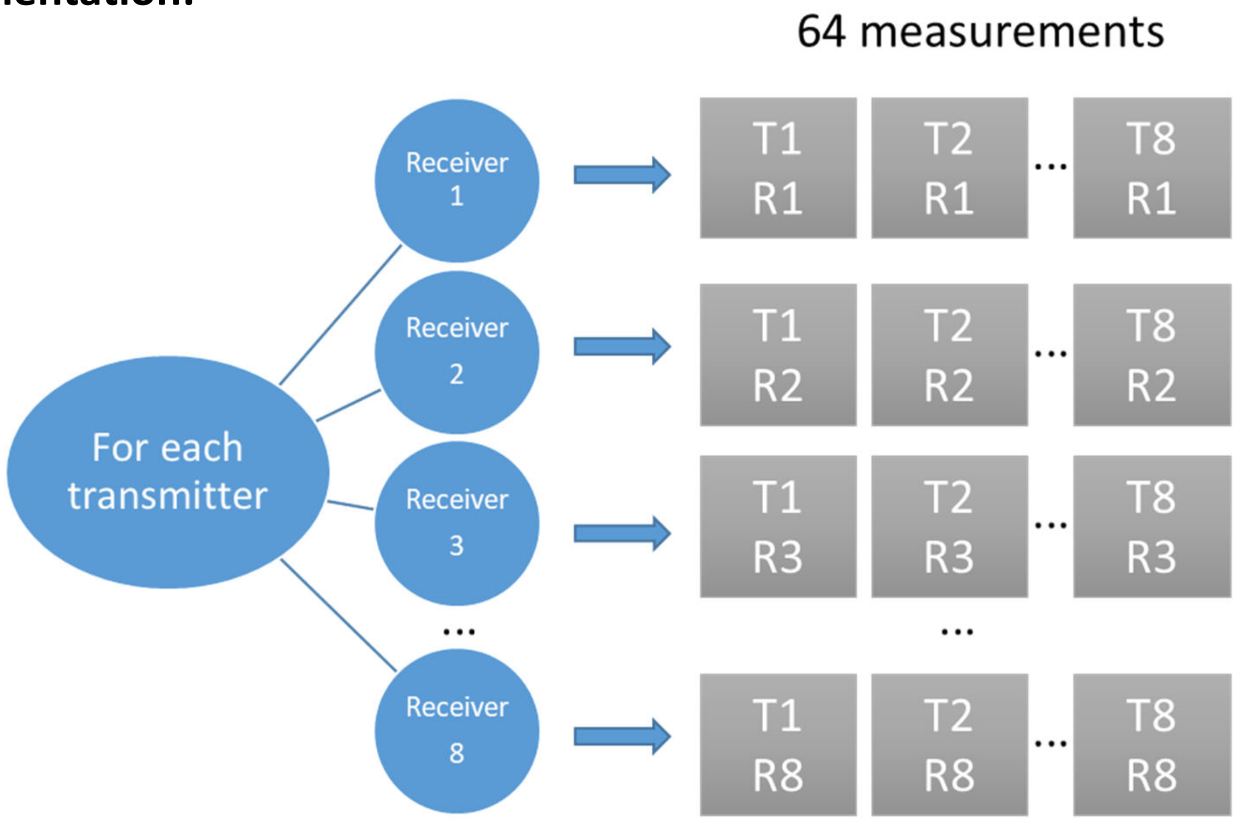
Closer antenna

Farther away antenna

Videos

Forward Problem

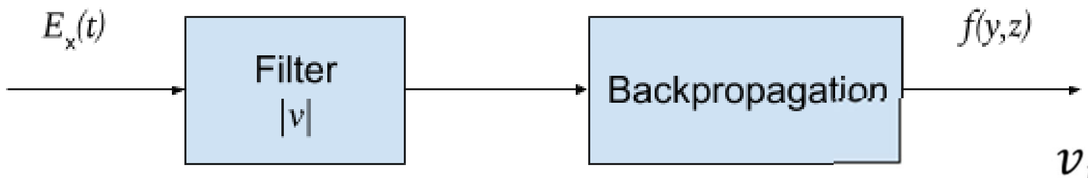
- **Implementation:**



Inverse Problem

1^{st} step inverse problem

- **Time reversal FDTD:**



$$v_i(t) = E_x(y_i, z_i)e^{-(\frac{t-tc}{\sigma})^2}$$

Under the time reversal transformation, ***T***, we can do the backpropagation by using the temporal reciprocity principle:

- Electric field: $TE(r,t) = E(r,-t)$
- Magnetic field: $TH(r,t) = -H(r,-t)$ $\quad \forall r = (y,z) \in$ yz-plane
- Current: $TJ(r,t) = -J(r,-t)$

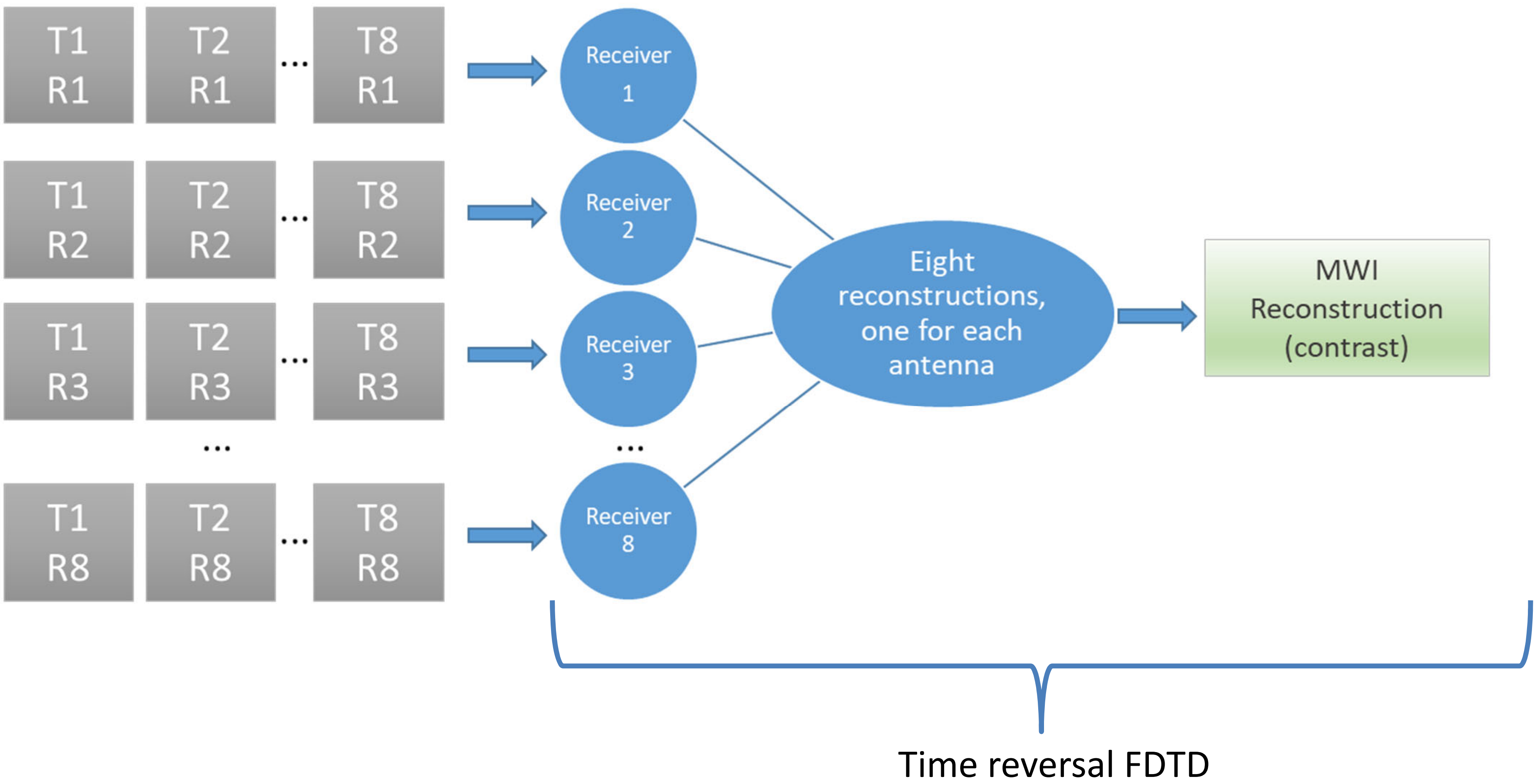
**Adapted from the Time reversal FDTD method*:

P. Kosmas, and M.C. Rappaport. "Time reversal with the FDTD method for microwave breast cancer detection." *IEEE Transactions on Microwave Theory and Techniques* 53.7 (2005): 2317-2323.

1st step inverse problem

- **Implementation:**

64 measurements



1st step inverse problem

- **Implementation:**

64 measurements

T1 R1	T2 R1	…	T8 R1
T1 R2	T2 R2	…	T8 R2
T1 R3	T2 R3	…	T8 R3
…			
T1 R8	T2 R8	…	T8 R8

Receiver 1

Receiver 2

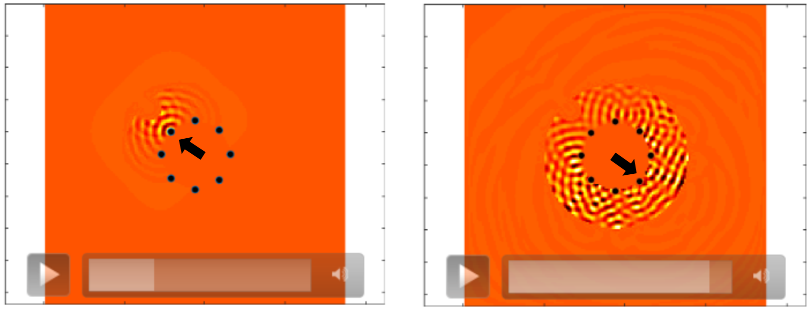
Receiver 3

…

Receiver 8

Eight reconstructions, one for each antenna

MWI Reconstruction (contrast)



Optimal time instant differs depending on the transmitter antenna – tumor locations

Fields at the time instant where the varimax norm is minimized – Related to the most suitable antennas for entropy (three)

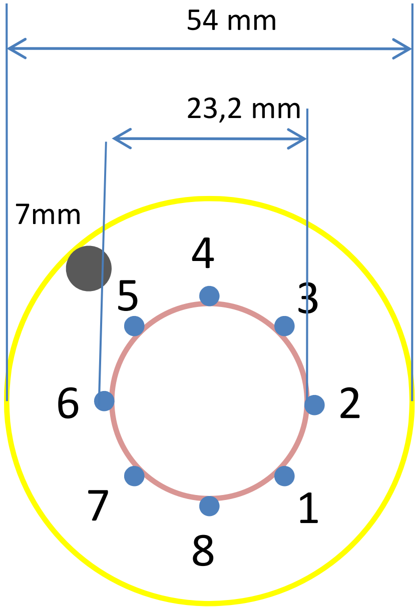
Time reversal FDTD

Suitable antennas

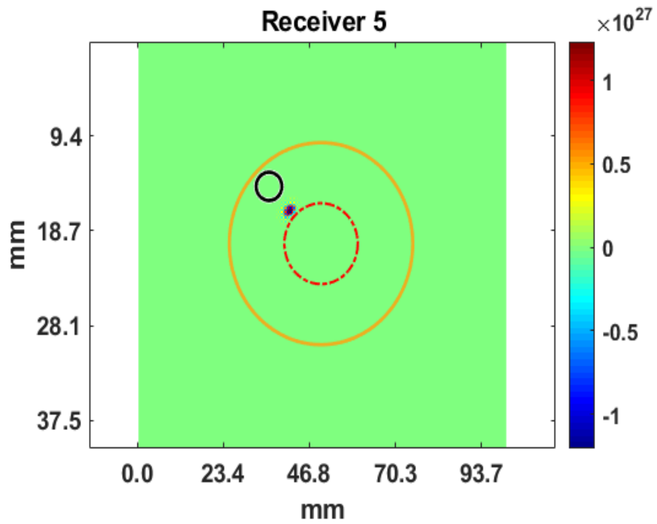
Most suitable antennas

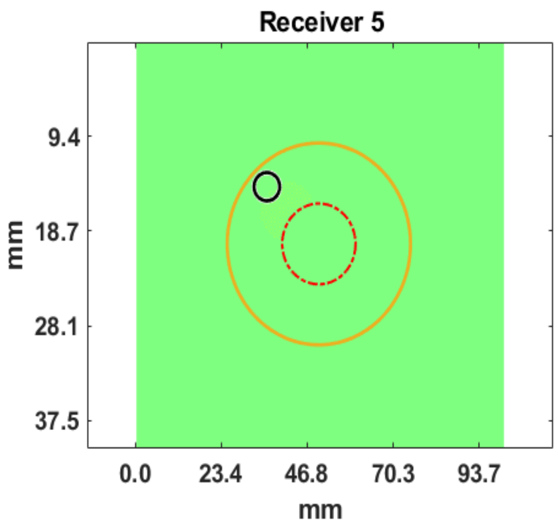
3.5mm radius

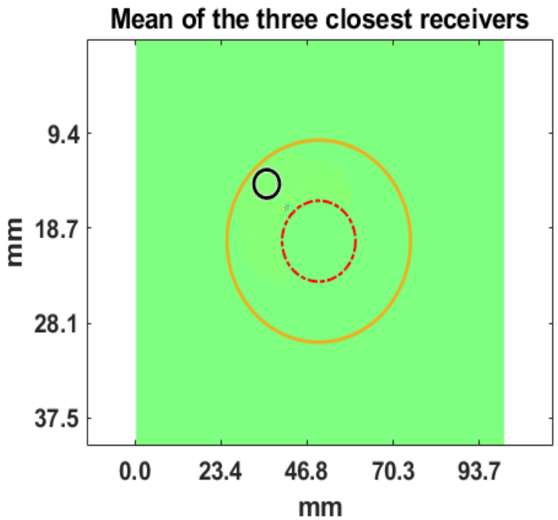
REFERENCE SCENARIO (A)

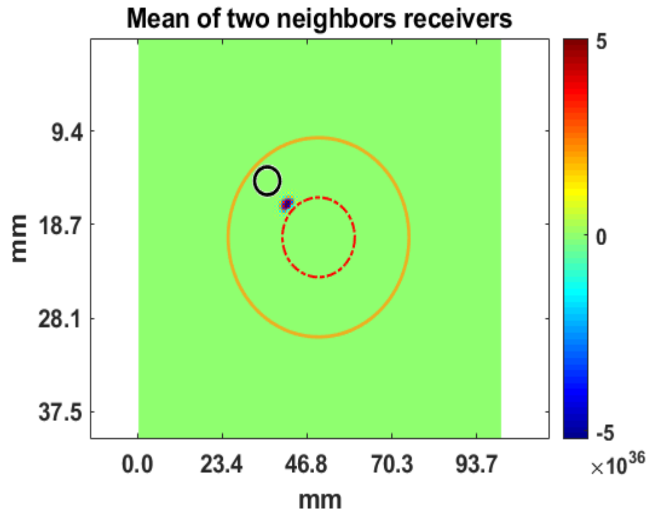


THE HIGHEST ENTROPY IS PROVIDED BY the RECEIVERS: 4, 5 and 6.





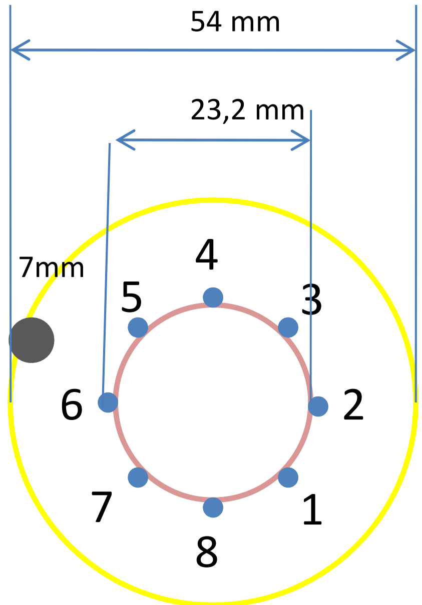




Most suitable antennas

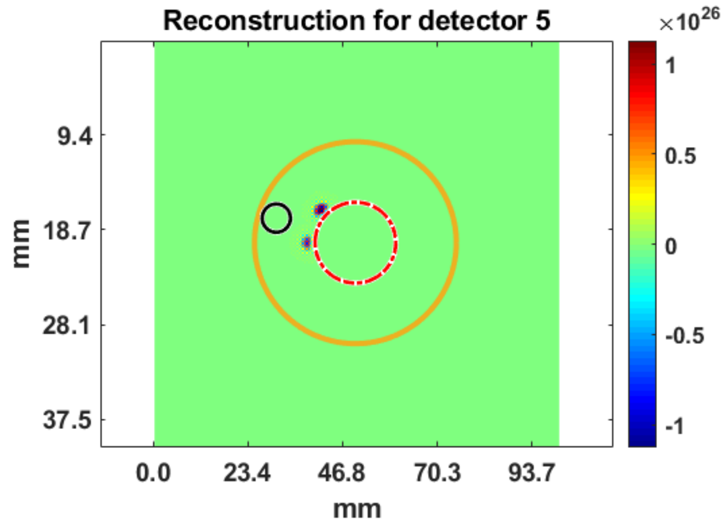
3.5mm radius

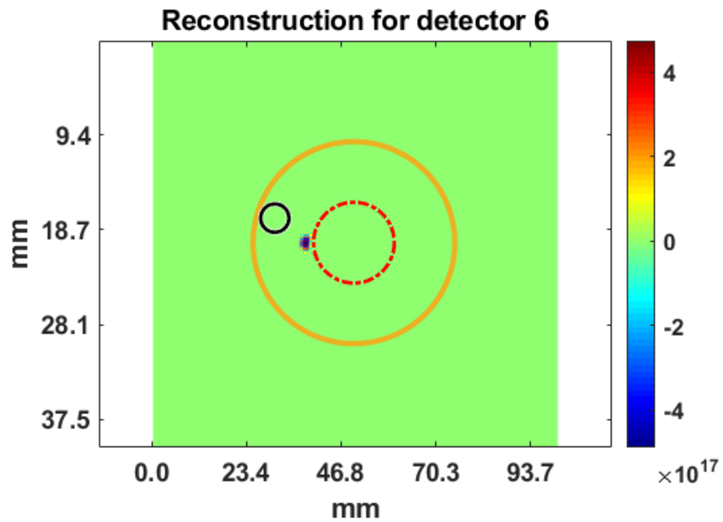
REFERENCE SCENARIO (B)



THE HIGHEST ENTROPY IS PROVIDED BY the RECEIVERS 5 and 6.

The 1st step inverse problem provides the angular information of the tumor location in both scenarios.

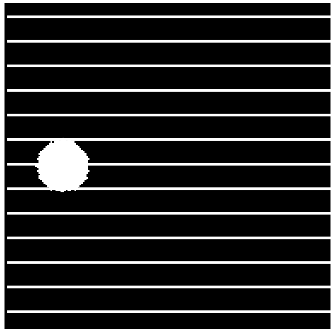




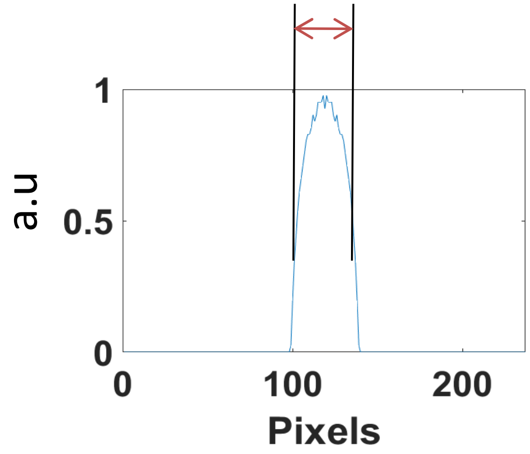
Most suitable Frequencies (Initial Range: 6-10GHz)

Most suitable frequencies

Reference



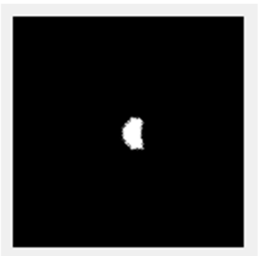
ROI

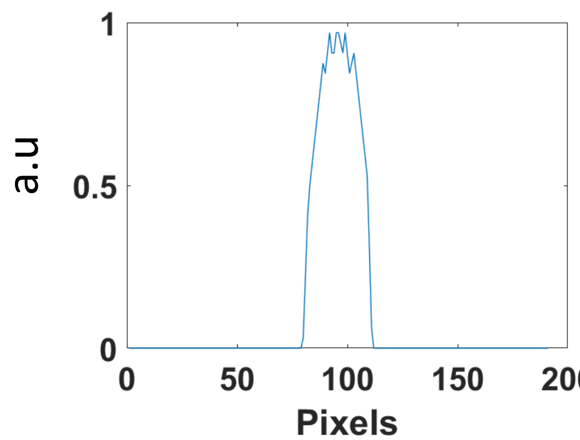


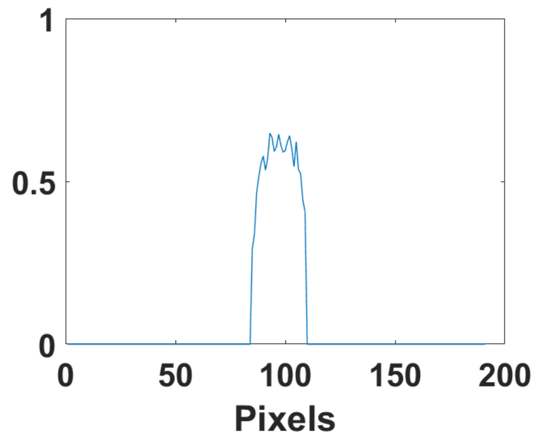
For pedunculated tumors - We can estimate the tumor diameter from FWHM *dx

Radius of the tumor: 5mm

Reconstruction



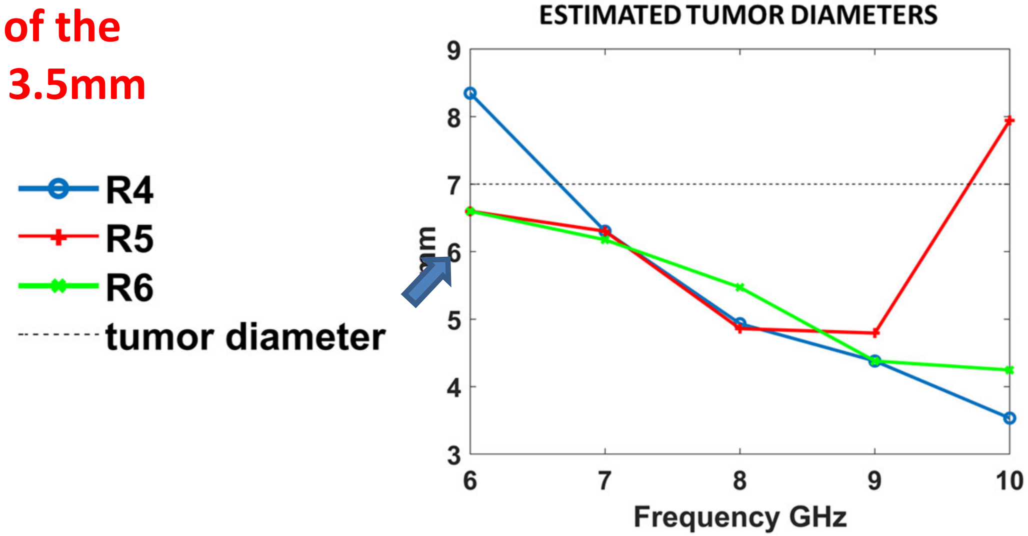




At 8GHz FWHM*dx=10mm=diameter

Most suitable frequencies

Radius of the tumor: 3.5mm



- When adding Gaussian random noise (3.5 mm radius):
  - At 6GHz, it is possible to add 10%.
  - At 7GHz, it is possible to add 5% (at 6% noise the artefacts start to appear).
  - At 8GHz, it becomes very sensitive to the noise.
- Smaller tumors:
  - Minimum 2.5mm without noise (2 steps-first all antennas to see where, then ROI-reconstruction).

CONCLUSIONS

Conclusions

- *These simulation drive to an acquisition protocol change:* For each transmitter antenna, three receivers seems to be a good choice.

- Around 7GHz seems to be the best frequency choice. It arrives to localize 2.5mm radius tumors with no-noise and 3.5 mm radius tumors with 5% noise.

- A first step based on a Time reversal adapted algorithm seems to provide a good angular localization of the tumor and an approximated size of the tumor (for the pedunculated ones).
- A ROI second step improves the localization.

- Quite future lines still to solve (To start improving the entropy criterium or with a second ROI-linearized step).

Thank you for your attention!!

Computational and technical validation

Oscar Camara, PhD, Prof.

Miguel Ángel González, PhD, Prof.

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Clinical validation

Glòria Fernández-Esparrach, MD. & her team (Henry Córdova, Miriam Cuatrecasas)

Transfer /Hardware

Marta Guardiola, PhD.

Hardware

Roberto Sont, M.Sc.

Hardware

Jordi Romeu, PhD, Prof.