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Time-Domain Microwave Imaging for Medical Applications

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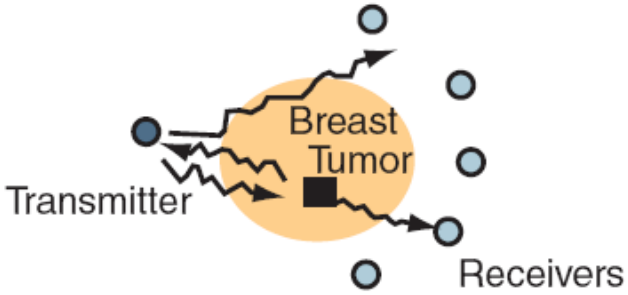
Overview

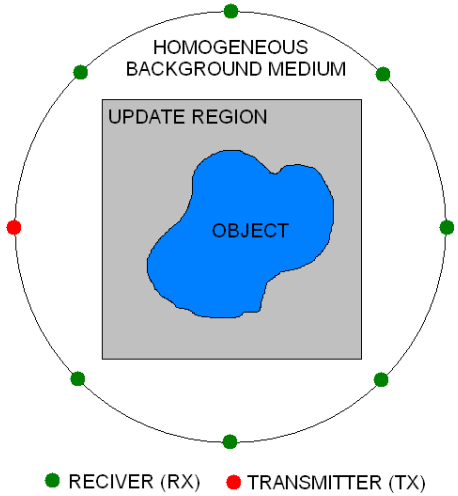
- Introduction to Time Domain Microwave Imaging
  - Radar Imaging
  - Time Domain Microwave Tomography
- 3 Pervious Generations of Prototype System
- 4th Generation Prototype (Latest)
- Clinical Radar Imaging Results
- Numerical Microwave Tomography (MRI based phantoms)
- Comparison of Results From the Two Modalities
- Discussion and Future Work

Introduction to Time Domain Microwave Imaging



Radar Based Imaging

- Finding the strongest scatters
- Time Domain Focusing algorithms
- Qualitative images
- Low computational cost



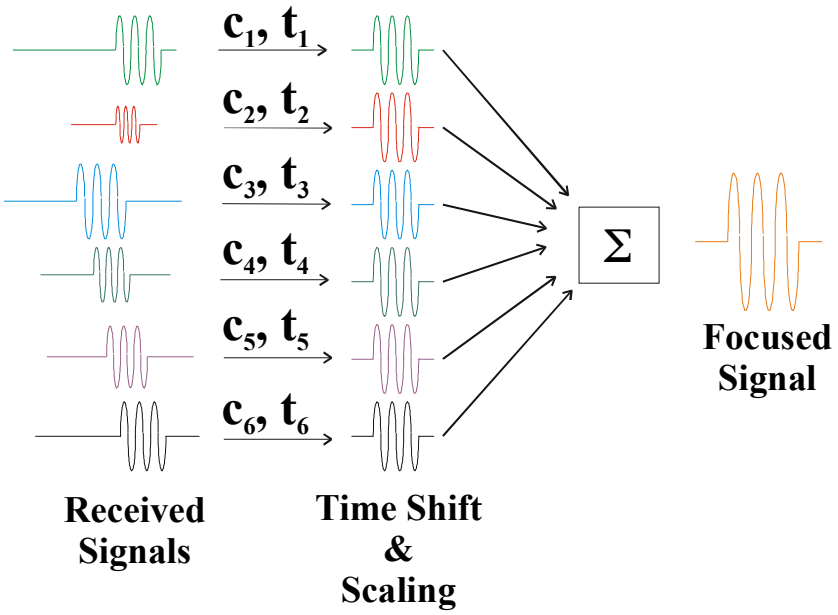
Microwave Tomography

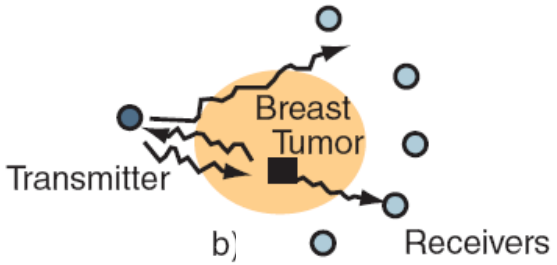
- Reconstructing the dielectric properties of the whole object
- Time Domain Inverse Scattering
- Quantitative results
- Very high computational cost

Bristol's Radar-Based Imaging Algorithm

Multistatic Delay-and-Sum

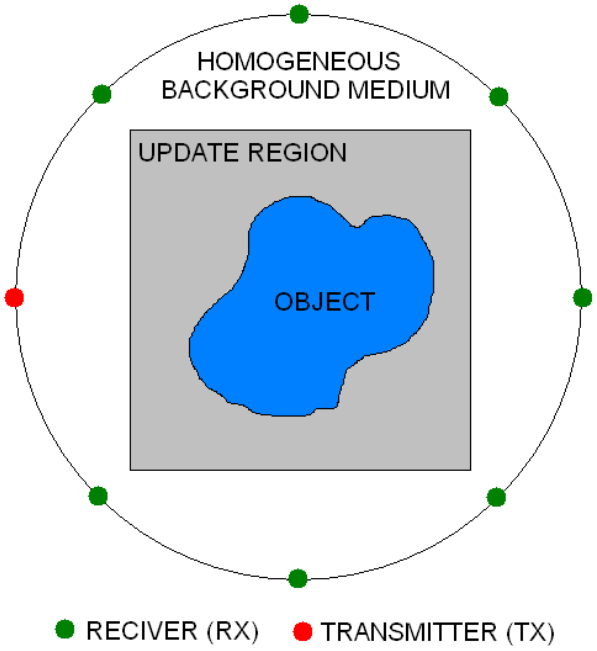
- Number of paths is $N(N-1)/2$
- Simple, quick, robust
- No forward model, no inversion
- Benefit from large numbers of antennas and wide bandwidths without high computational cost





$$V = \int_{t=0}^{T} \left(\sum_{i=1}^{N} c_i U_i(t - t_i) \right)^2 dt$$

Time Domain Inverse Scattering



- A nonlinear ill-posed problem to estimate the material properties of an unknown object from the measured fields $\hat{\mathbf{u}}_{m,n}$
- Minimise a time domain cost function
- Conjugate Gradient (GC) method with a Golden ratio line search
- Gradient Calculated Using the Forward Backwards Time Stepping (FBTS) algorithm

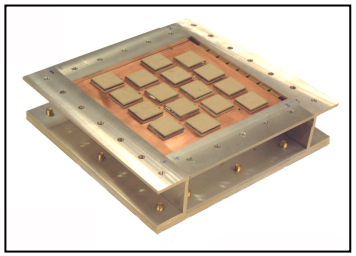
Time Domain Cost Function

$$Q(\mathbf{p}) = \int_0^T \sum_{m=1}^{M} \sum_{n=1}^{N} |\mathbf{u}_{m,n,\mathbf{p}} - \hat{\mathbf{u}}_{m,n}|^2 dt$$

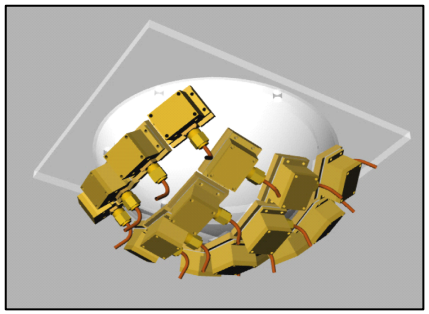
$\mathbf{u}_{m,n,\mathbf{p}}$ = **estimated** fields at Rx *m* produced by Tx *n* for parameter estimate **p**

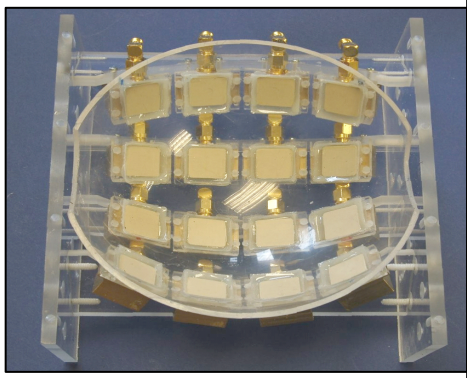
$\hat{\mathbf{u}}_{m,n}$ = **measured** fields at Rx *m* produced by Tx *n*

Prototype Systems - 3 First Generations



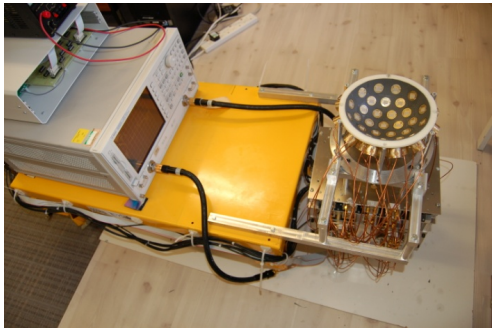
- Planar antenna array
- 16 stacked patch elements
- 2 minute scan





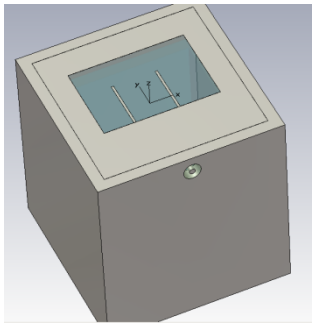
- Hemi-spherical antenna array
- 16 stacked patch elements
- Including mountings, elements -> 25mm x 25mm
- Array spacing limited by access to SMA connectors
- Phantom and limited clinical results collected

- Spherical antenna array
- 31 slot antenna elements
- Phantom and clinical trials of ~200 patients
- 90s scan

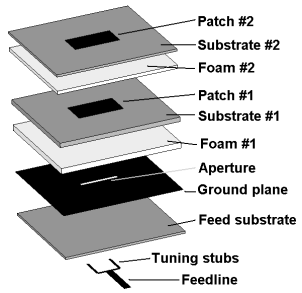


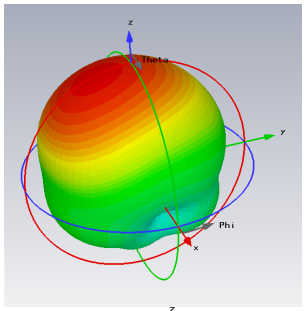
Improved UWB antenna

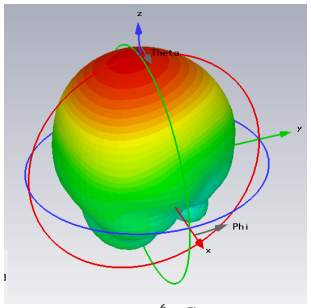
UWB wide slot antenna

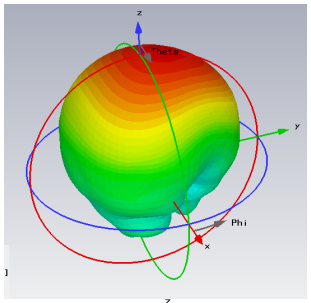


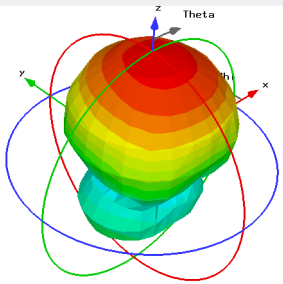
UWB stacked patch antenna



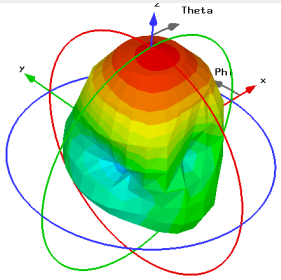




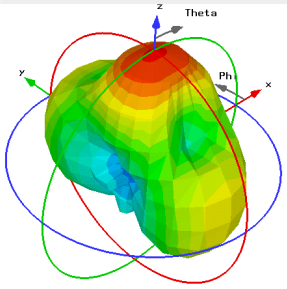




4GHz



6GHz

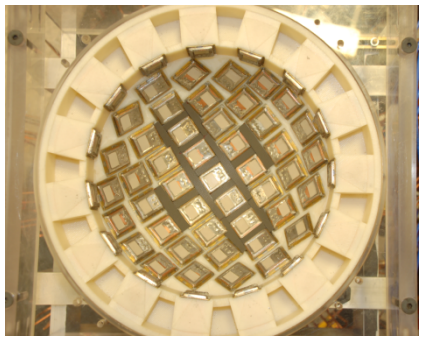


8GHz

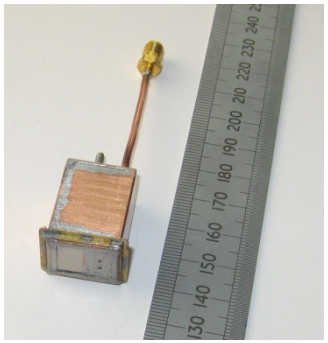
New antenna provides:

- stable radiation pattern between 3 and 10 GHz
- high fidelity (>95%) of radiated pulses
- antenna performance critical for good imaging

4th Generation prototype

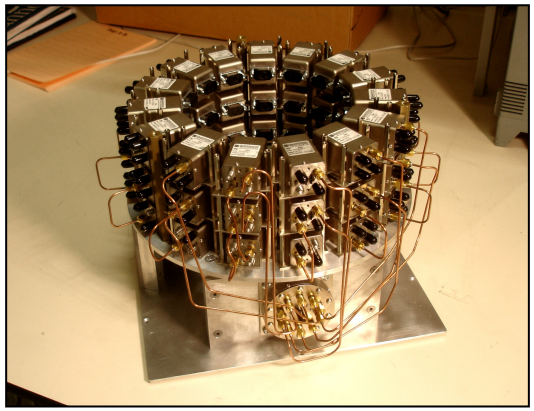


Complete 60 element antenna array



New antenna with redesigned cavity and vertical feed

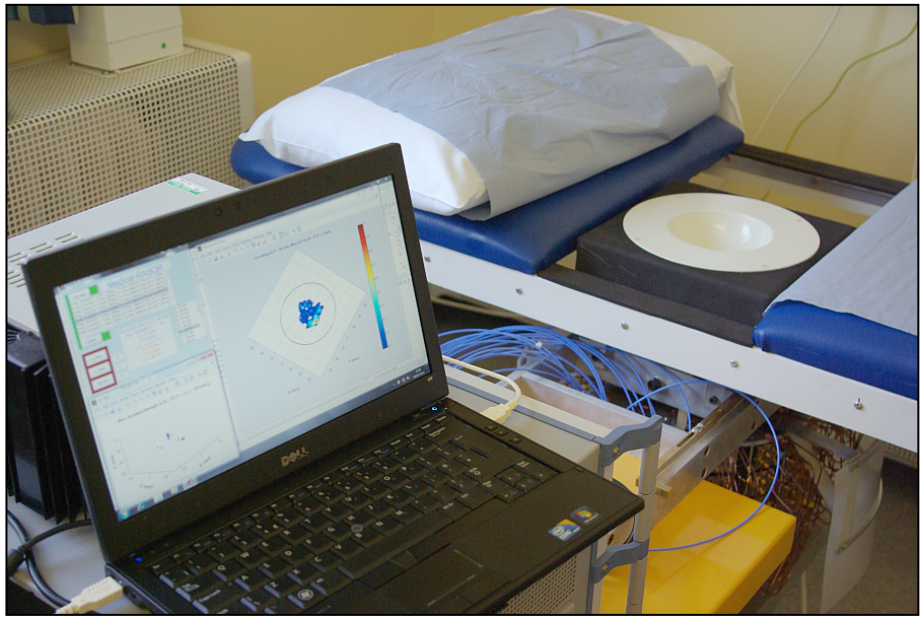
Switching interface (below) between 8 port VNA and antenna array (top)



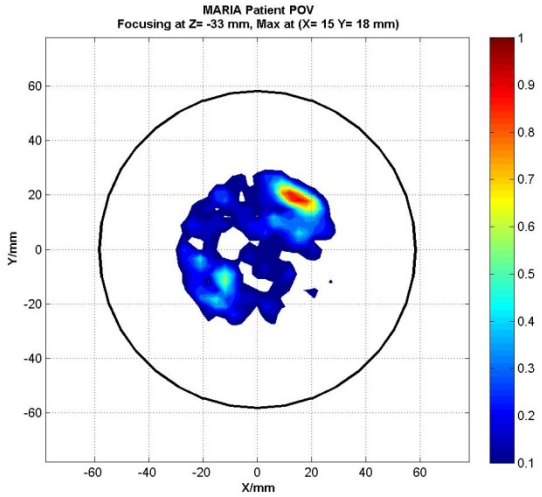
Complete switch matrix (60->15 TX/RX)

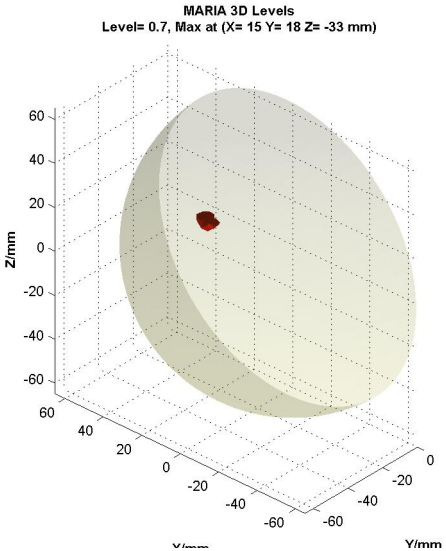
4th Generation Clinical Trials

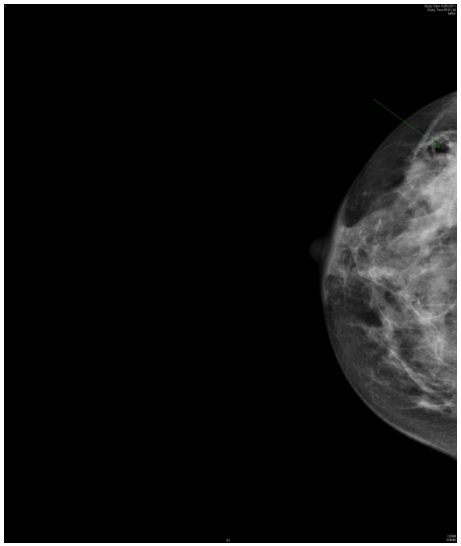
- ~ 95 patients imaged blind
- All patients had a cyst or cancer
- 2 scans for each breast
- Scan time 9 seconds
  (~1700 S-parameter measurements)
- The scan time is critical for avoiding patient movements

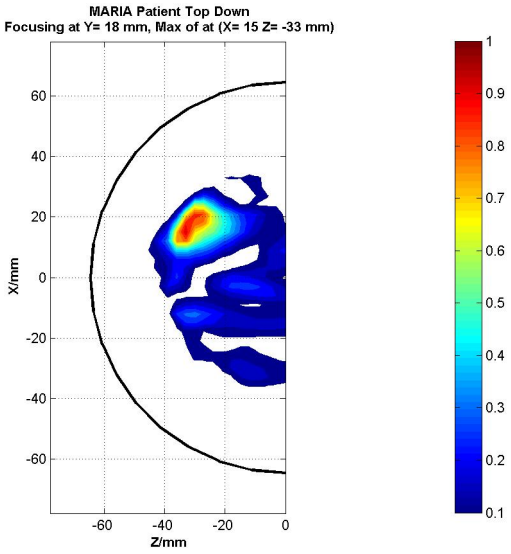


Clinical Results - Good - 16mm Cancer



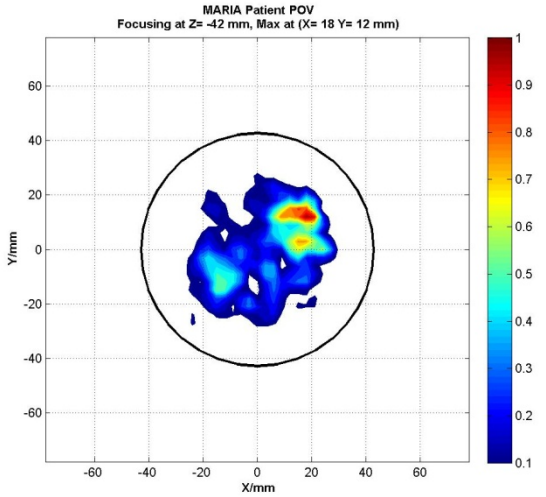


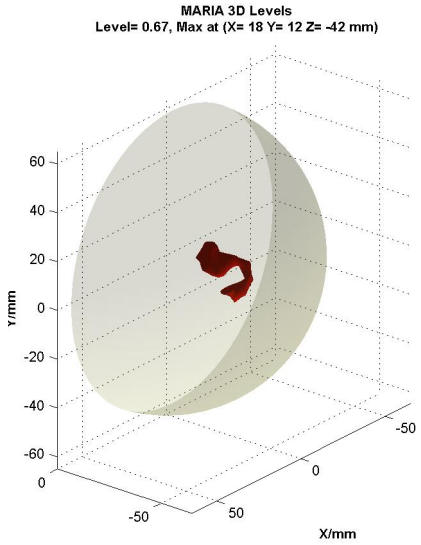


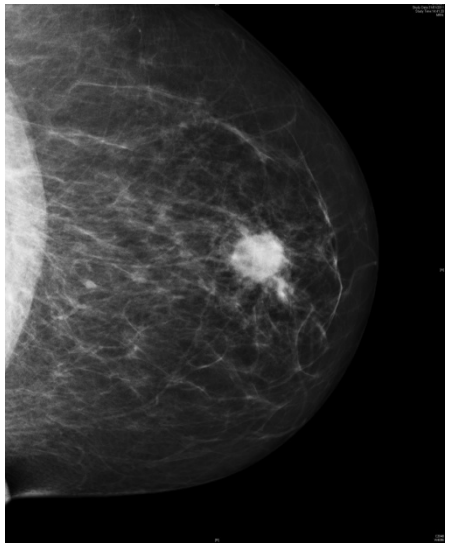


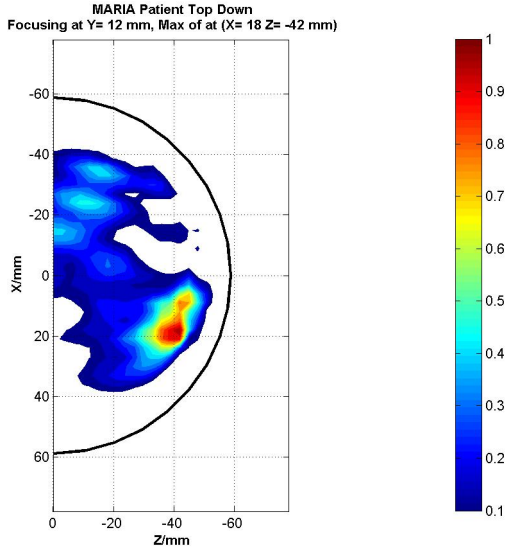
- post-menopausal patient
- 63 years old
- A 16 mm cancer in right breast
- Upper slightly outer

Clinical Results - Good - Complex Structure



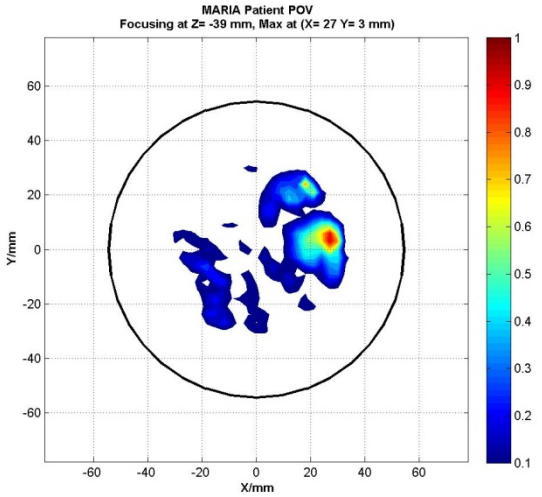


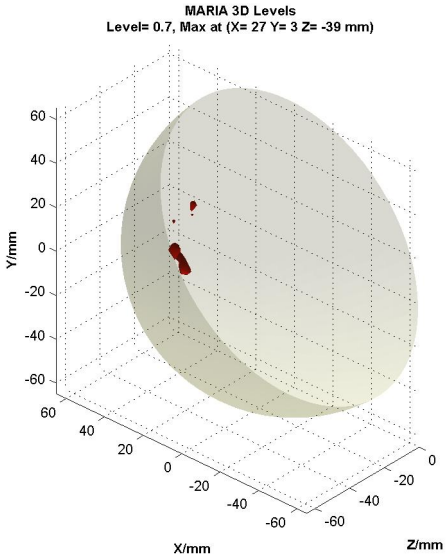


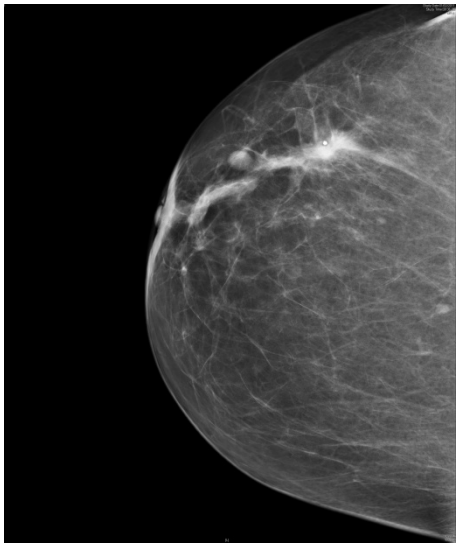


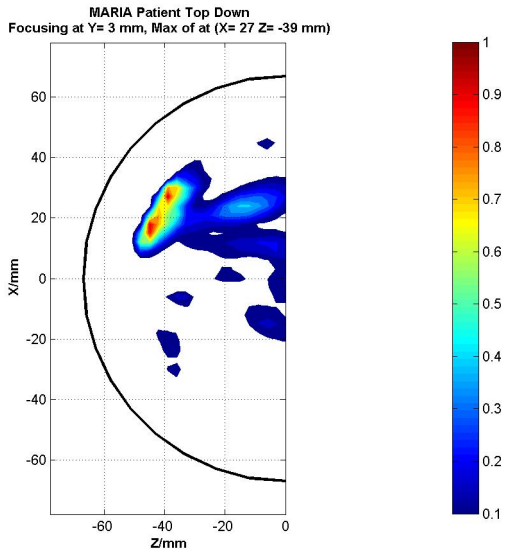
- post-menopausal patient
- 70 years old
- A cancer in the left breast
- just above left nipple
  - milk duct involvement

Clinical Results - Good – 2 Tumours Together



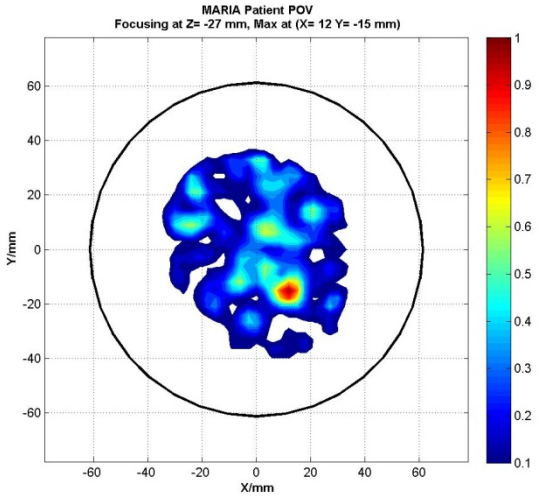


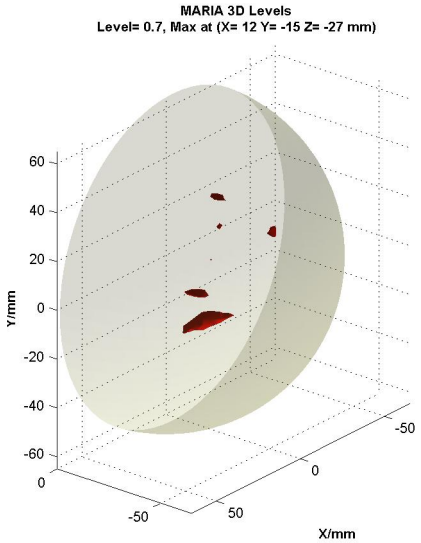


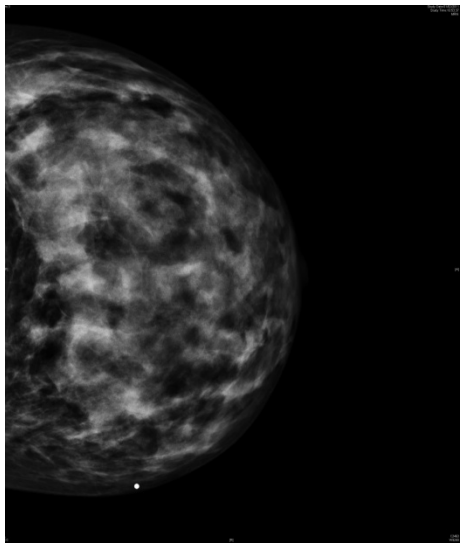


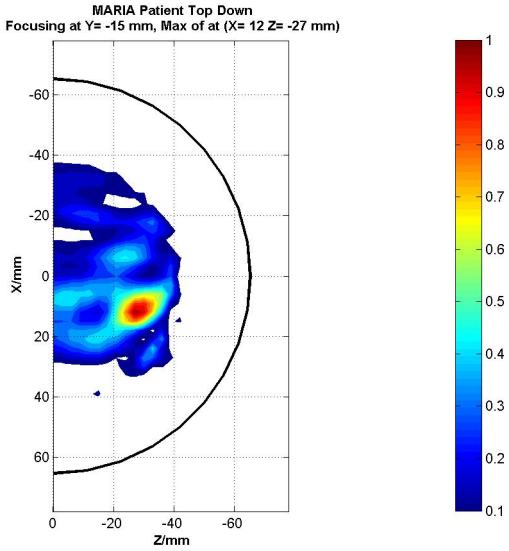
- post-menopausal patient
- 68 years old
- A cancer in the right breast
- Interesting duct involvement (two lesions close together)
- Upper outer quadrant

Clinical Results - Difficult – Dense Breast





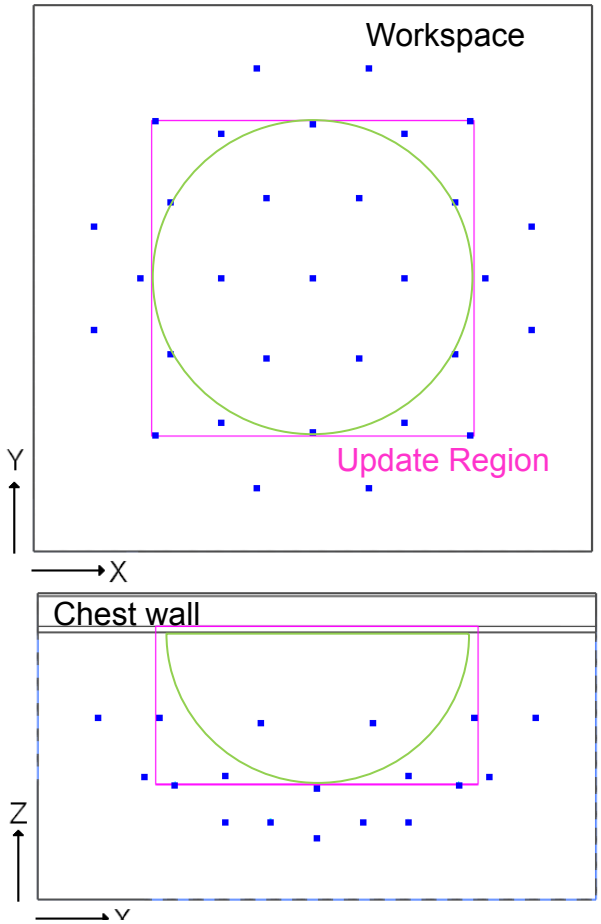




- pre-menopausal patient
- 41 years old
- A cyst in the left breast
- Very dense breast (difficult)
- Lower central region
- Should be Lower outer region

Time Domain Microwave Tomography

Numerical Investigation (f_0 = 2 GHz)

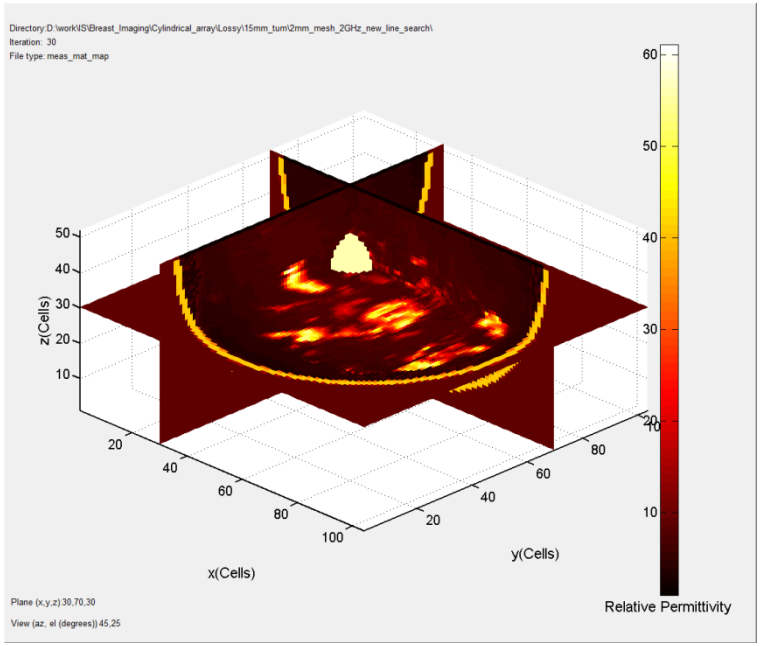


- Point Source Tx/Rx position

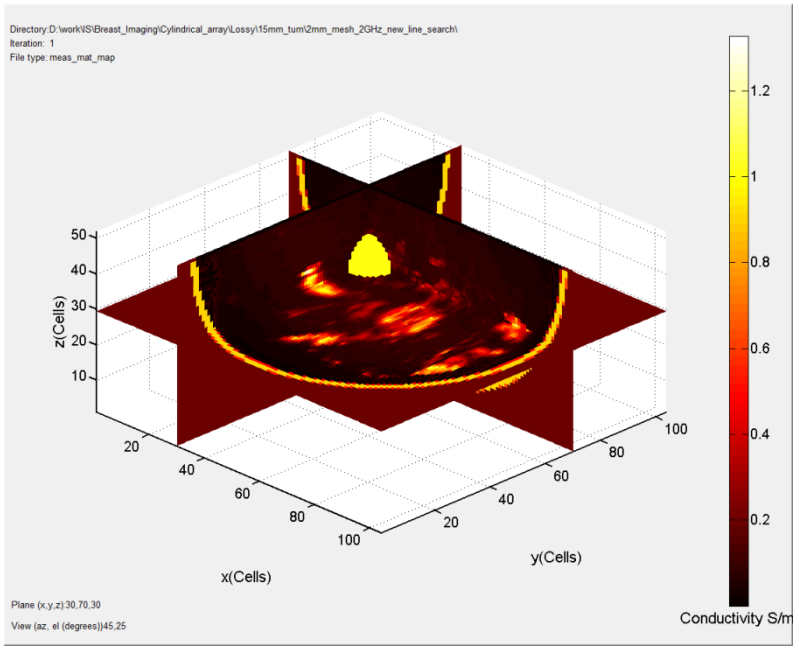
- 180 x 180 x 89 mm workspace
- 0.5 mm FDTD mesh (measured data)
  1 mm FDTD mesh (inversion)
  (Avoiding the inverse crime)
- 104 x104 x 52 mm update region
- z-polarised, point sources, in a hemi-spherical arrangement (same geometrical arrangement as 3rd generation prototype)
- Single-cycle sinusoid pulse, f_0 = 2 GHz,
  1.8 GHz 3 dB Bandwidth

MRI-Based Hemi-Spherical Breast Phantom

Permittivity



Conductivity



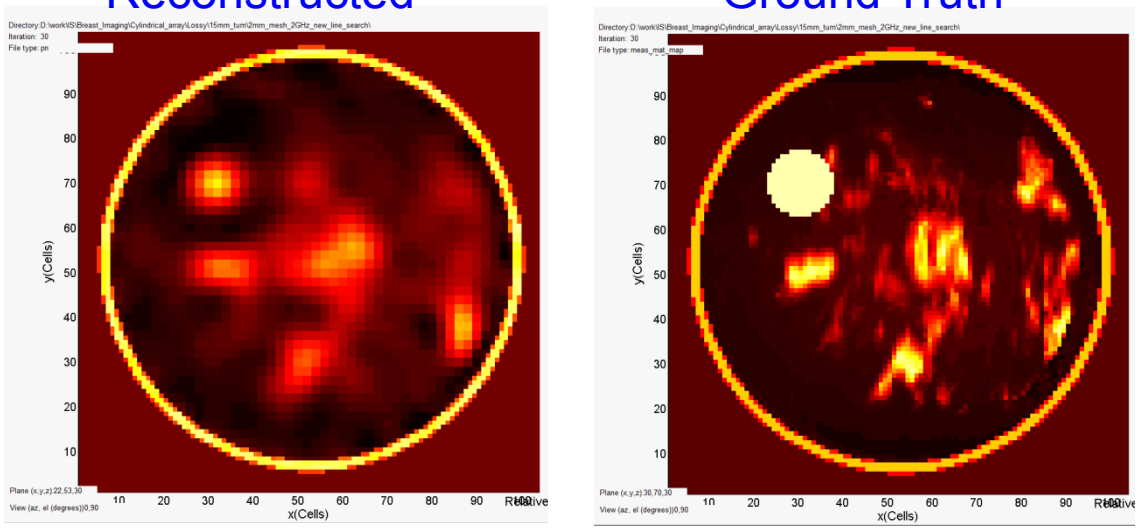
- Derived from University of Wisconsin's MRI breast phantom data
- Transformed in to a hemi-sphere fitting the experimental radar system
- Non dispersive permittivity and conductivity, estimated for the centre frequency

Reconstructed Image – 30 iterations

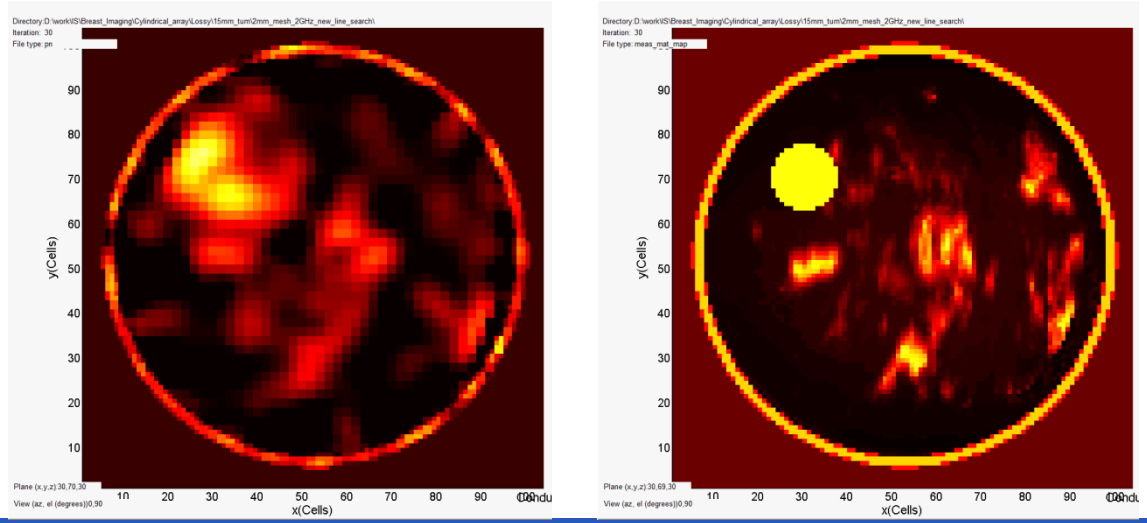
Reconstructed

Ground Truth

Permittivity



Conductivity



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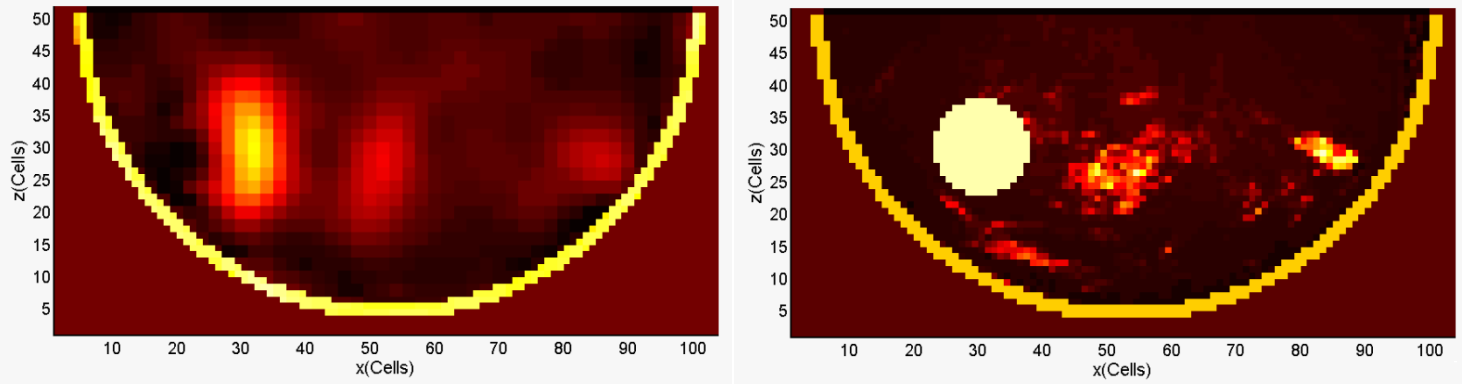
Reconstructed Image – 30 iterations

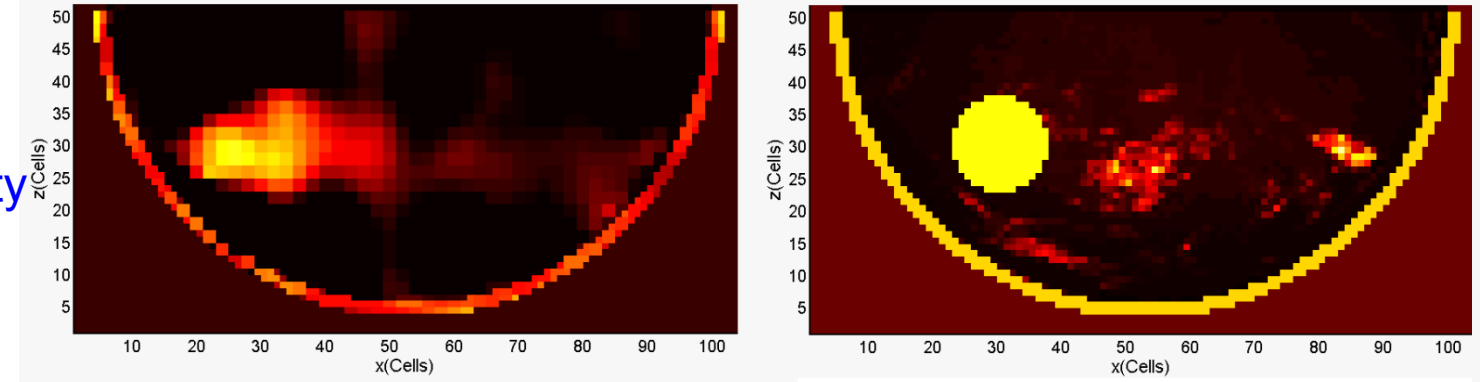
Reconstructed

Ground Truth

Permittivity

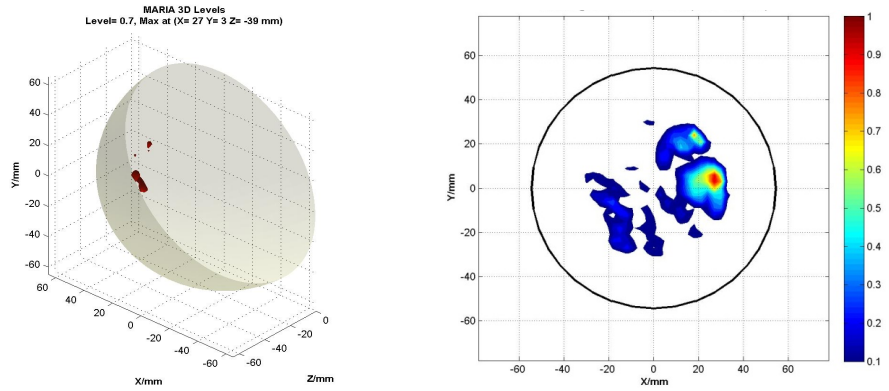


Conductivity



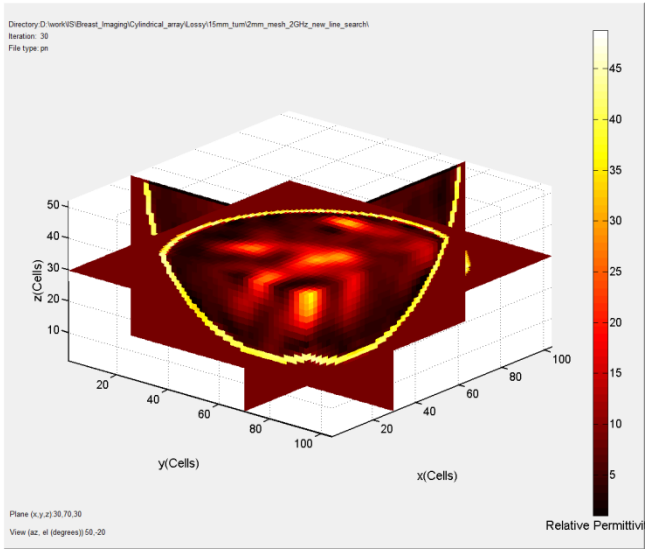
Summery – Result Comparison

Radar



- Images of the relative power at the focusing points
- Give information about the strongest scatters inside the object
- Sensitive to skin reflections and variations of the “unknown” permittivity along the focusing path

Microwave Tomography



- Images of the permittivity and conductivity distribution
- Give information about the whole tissue distribution inside the breast
- Sensitive to model errors and prior information to avoid “local minima”

Discussion

- The focus at Bristol has evolved a quite steeply development of experimental system in terms of sophistication and speed
- Increased speed in the data-acquisition results in more repeatable clinical results
- Clinical results have shown the potential of radar breast imaging
- The results from microwave tomography can be used as prior information of the background breast tissues, to improve the focusing parameter estimation
- The radar images with the implemented skin surface estimation can be used as prior information to the microwave tomography

Current and Future Work

- Currently a numerical platform is under development to exchange the prior information between the modalities
- A skin surface and average permittivity estimation process using the “time of flight” information in the time domain signals have been developed to give prior information to both the radar and microwave tomography algorithm
- Other medical imaging applications

Acknowledgment

- Dr Mike Shere, the staff and the patients at Frenchay Hospital's Breast Care Centre, Bristol
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- The rest of the team:

Dr Maciej Klemm, Dr David Gibbins, Prof. Alan Preece, Prof. Ralph Benjamin, Dr Tony Horseman, Mr Jack Leendertz, Dr Mantalena Sarafianou, Dr Dallan Byrne, Dr Beatriz Monsalve

Thank you for listening

Any questions?