Microwave System for Breast Cancer Detection

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Outline

- Background: electrical properties of breast tissues
- Hemi-spherical antenna array
- Experimental results
- Clinical results
- Electromagnetic modelling issues
- Conclusions / future work

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Background:
electrical properties of breast tissues

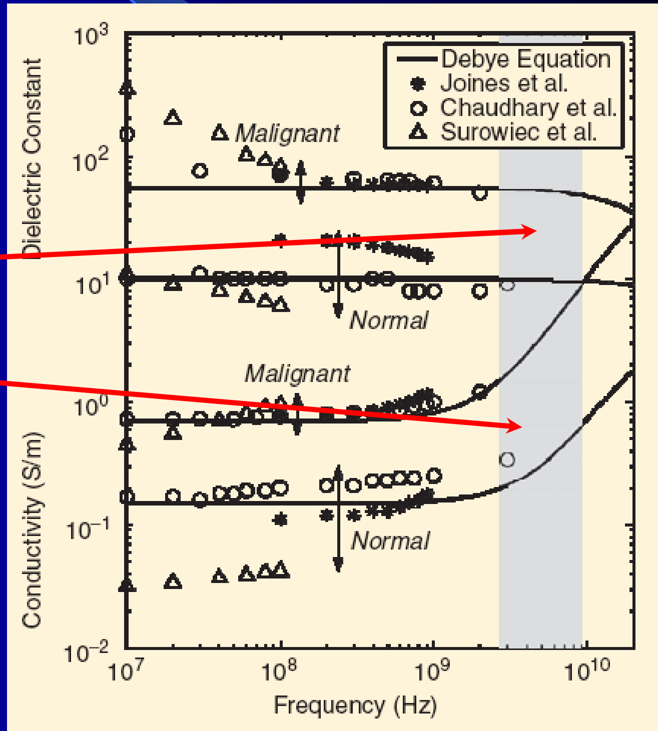
Background: electrical properties of breast tissues

Why microwaves (3-10 GHz) for breast cancer detection

Difference in dielectric properties between normal breast tissue and malignant tumours

~ 5:1 contrast in the permittivity (er)

~ 6:1 contrast in the conductivity



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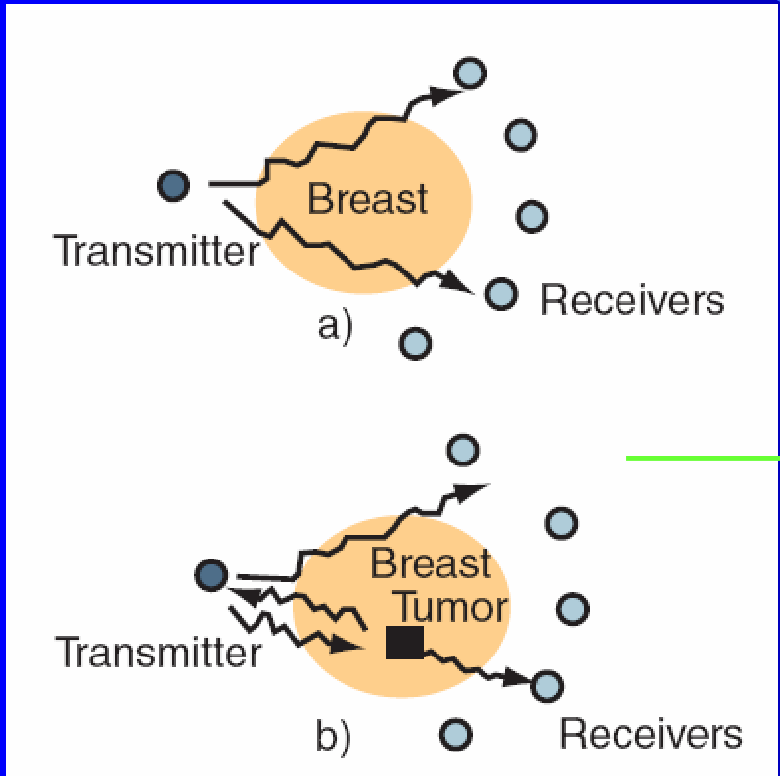
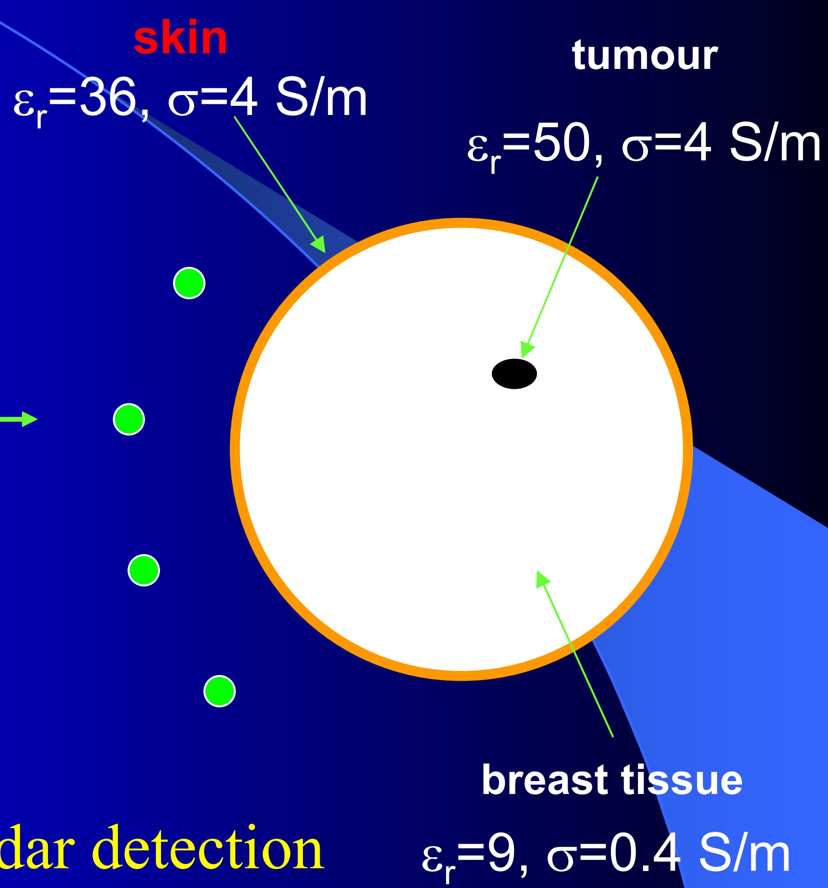
Possibility of **radar-based** detection

Background: electrical properties of breast tissues



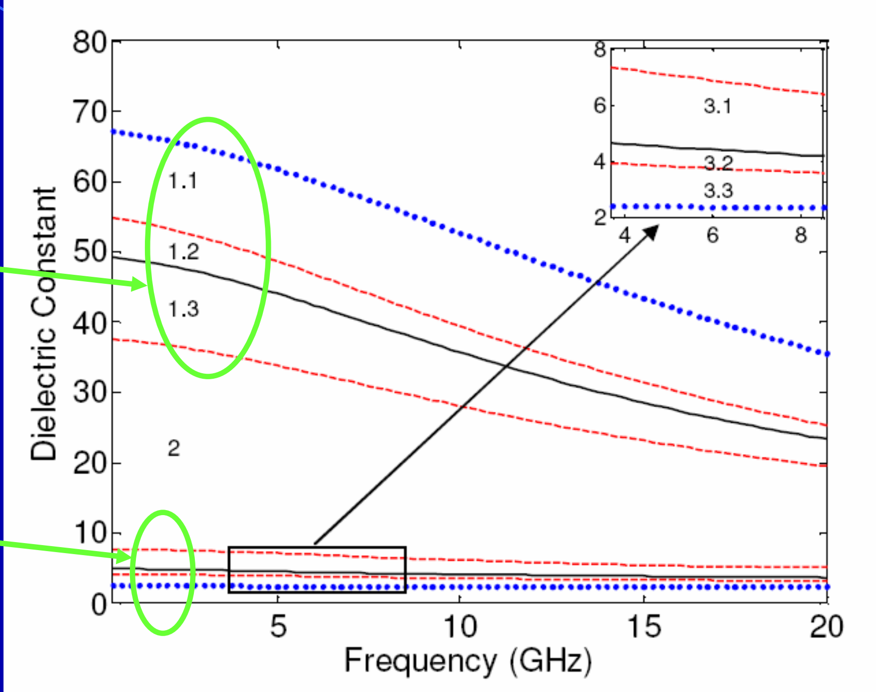


- Very promising scenario for radar detection
- However, very optimistic scenario

Background: electrical properties of breast tissues

but only ~ 1.1:1 contrast in the permittivity (er) for **fibroglandular** tissues

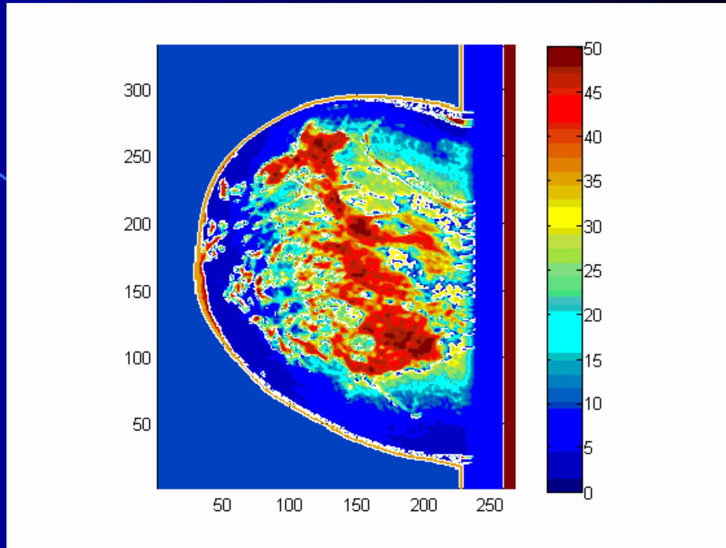
~ (10-5):(1) contrast in the permittivity (er) for **fatty** tissues



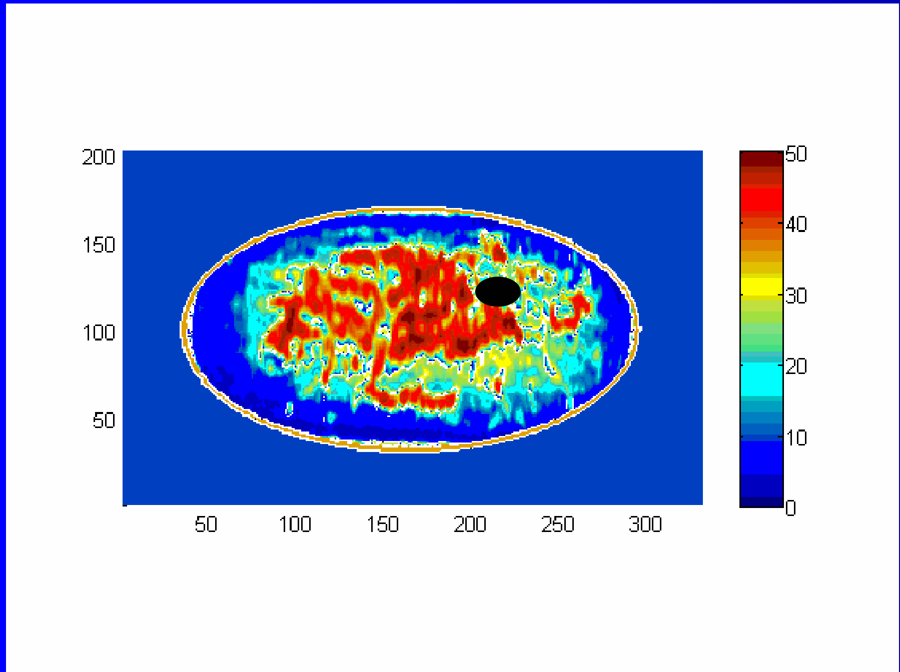
*M. Lazebnik, et.al., "A large-scale study of the ultrawideband microwave dielectric properties of normal, benign, and malignant breast tissues obtained from cancer surgeries," *Physics in Medicine and Biology*, vol. 52, pp. 6093-6115, 2007

Background: electrical properties of breast tissues

University of Wisconsin CEM
Numerical Breast Phantom Repository



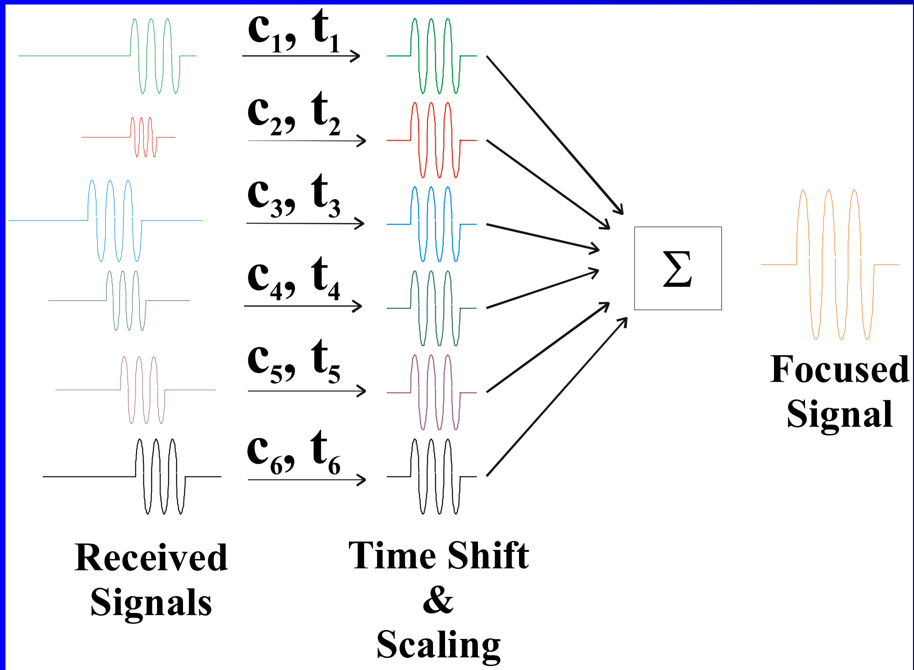
anatomically-realistic MRI-derived numerical breast phantoms



- Very challenging scenario for radar detection

Background: signal processing

Real Aperture Synthetically Organised Radar



$$V = \int_0^{\tau} \left(\sum_{i=1}^{N} {}_iU_i(t - t_i) \right)^2 dt$$

- Specifically designed to defeat clutter
- Very simple, but efficient

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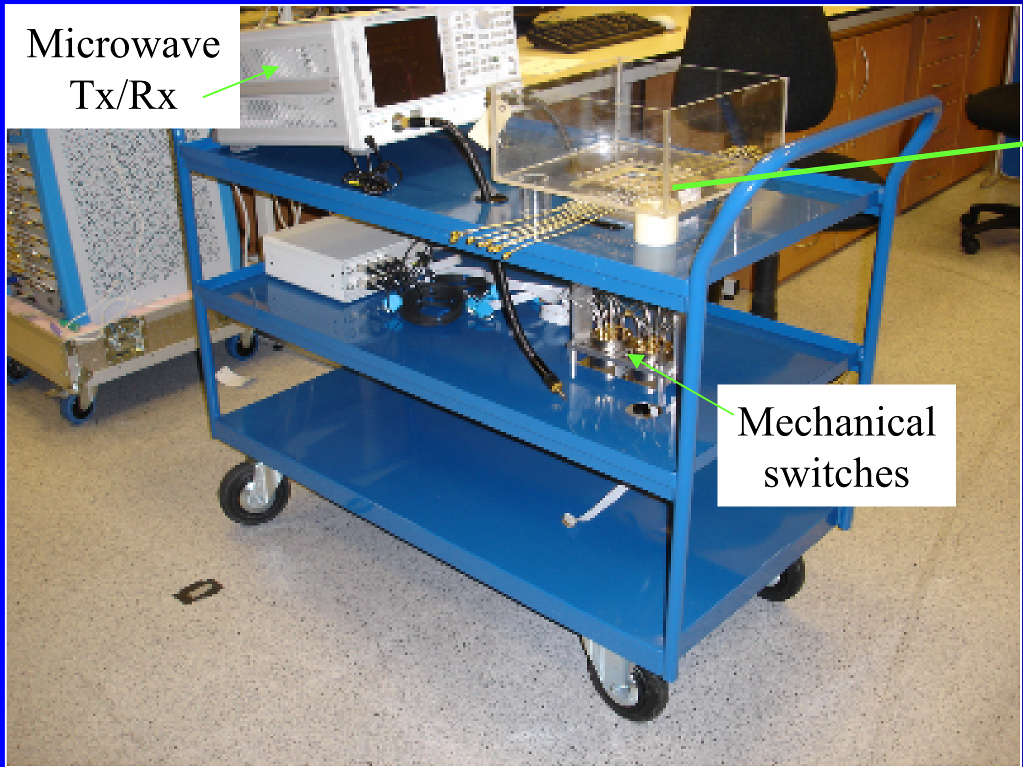
Development of the radar imaging system for breast cancer detection

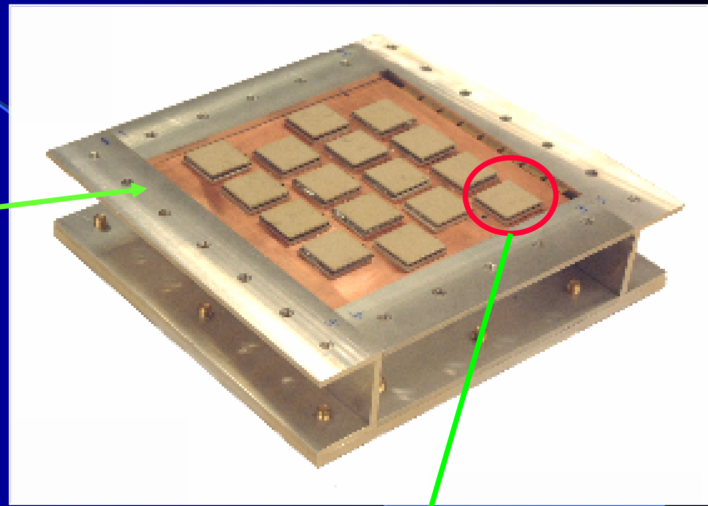
Centre for Communications Research CCR

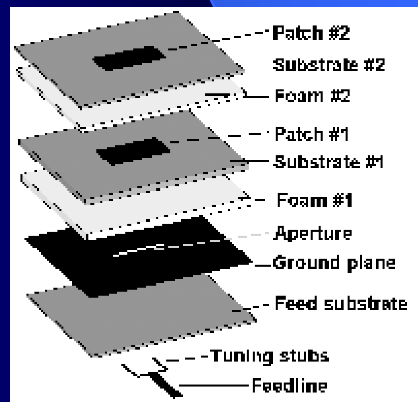
Maciej Klemm, *University of Bristol, UK*

Development of the radar imaging system

Prototype 1 (Mk1): planar 16-antenna array

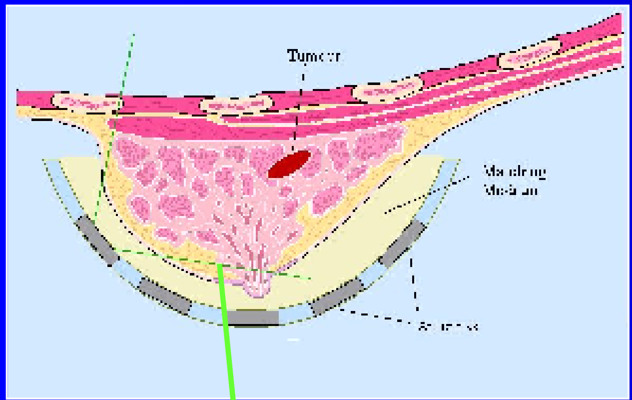


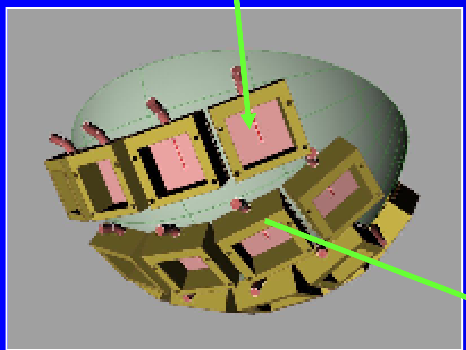


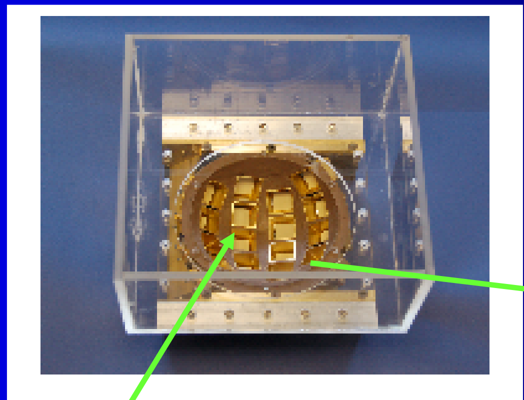


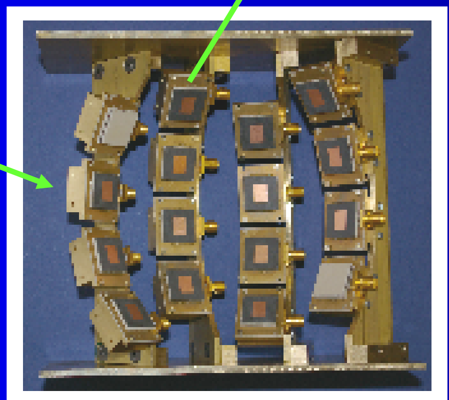
Development of the radar imaging system

Mk2: conformal 16-antenna array









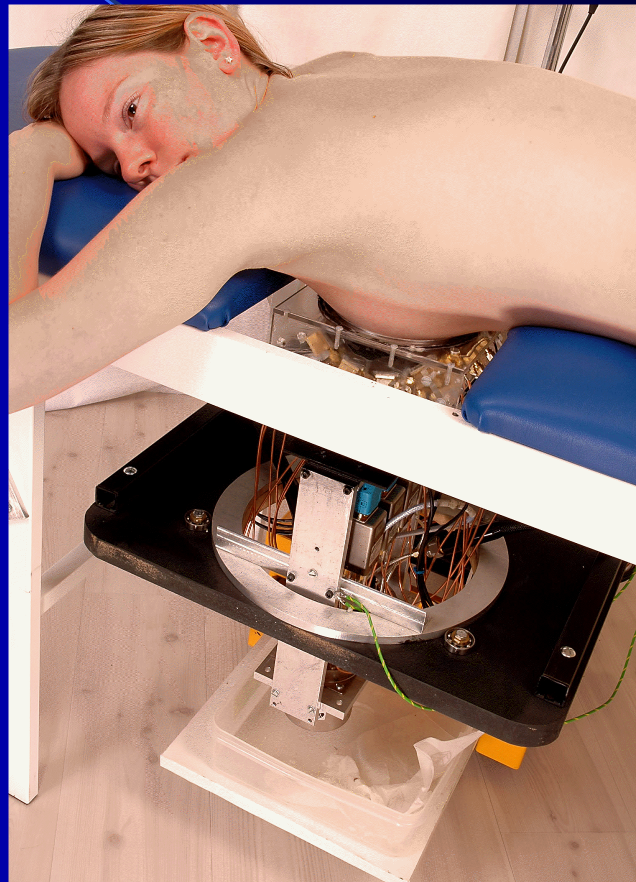
Experimental setup

Development of the radar imaging system

Mk2: conformal 16-antenna array

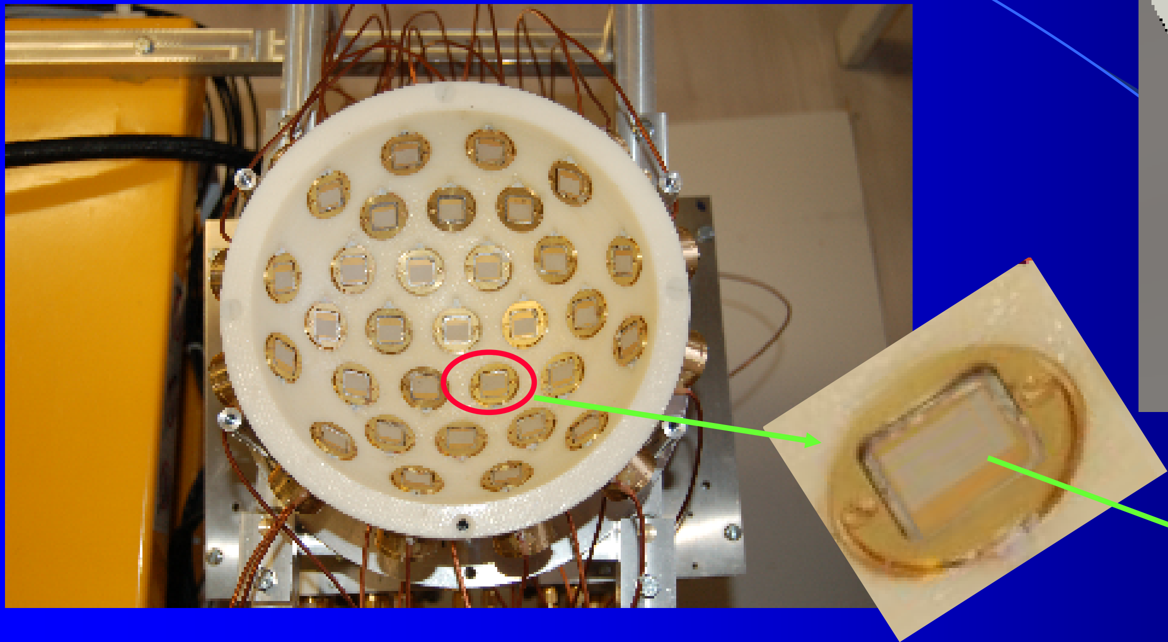
Clinical setup at Bristol Oncology Centre

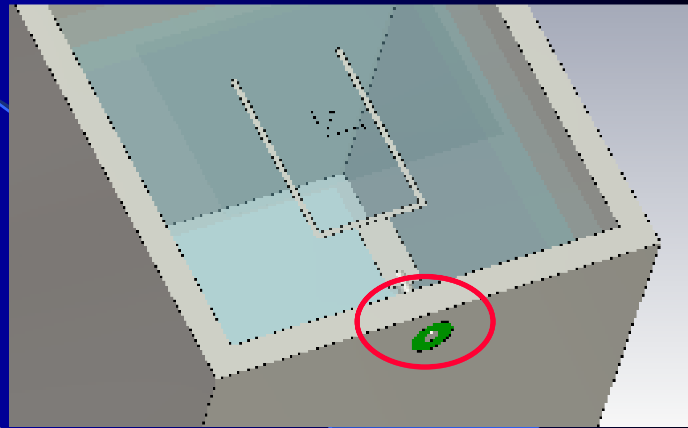
(Summer 2007)

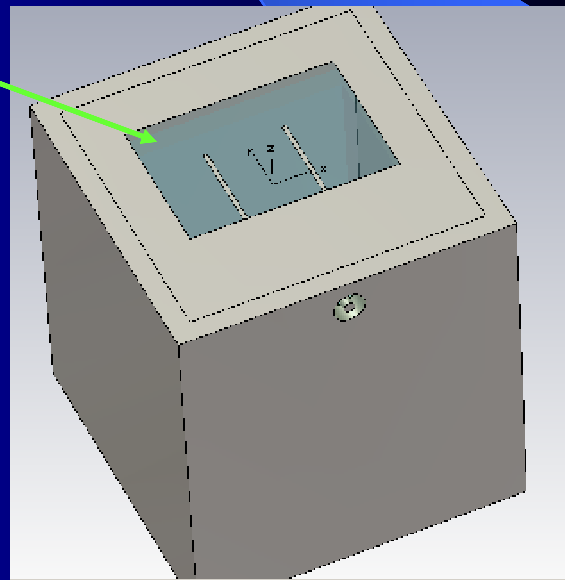


Development of the radar imaging system

Mk3: conformal 31-antenna array



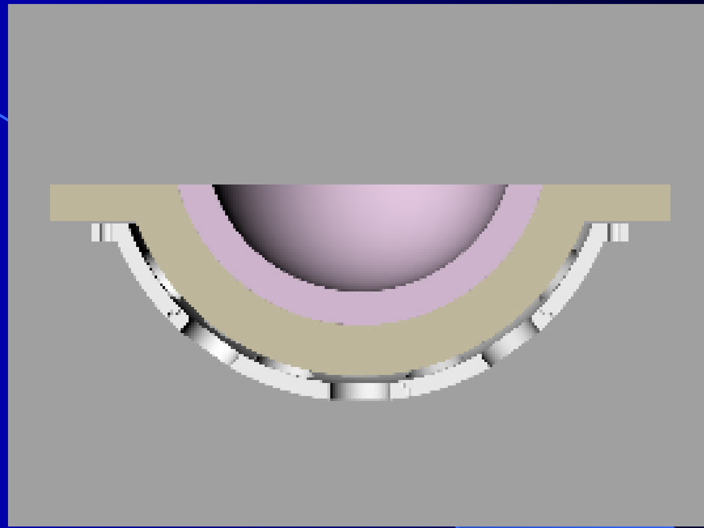


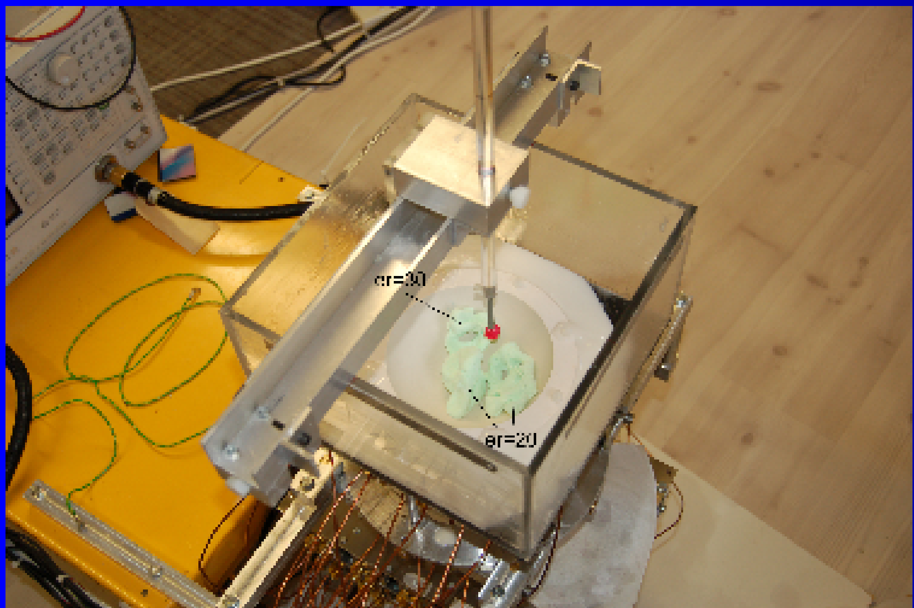


- Array based on the **UWB wide-slot antenna**

- New antenna found critical in improved performance

Development of the radar imaging system





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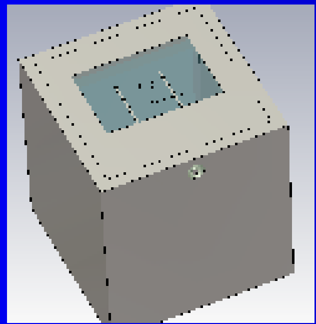
Experimental imaging results

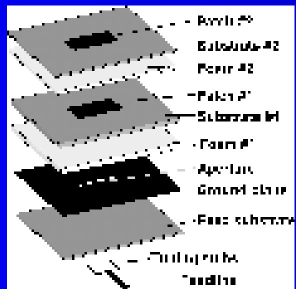
Experimental imaging results

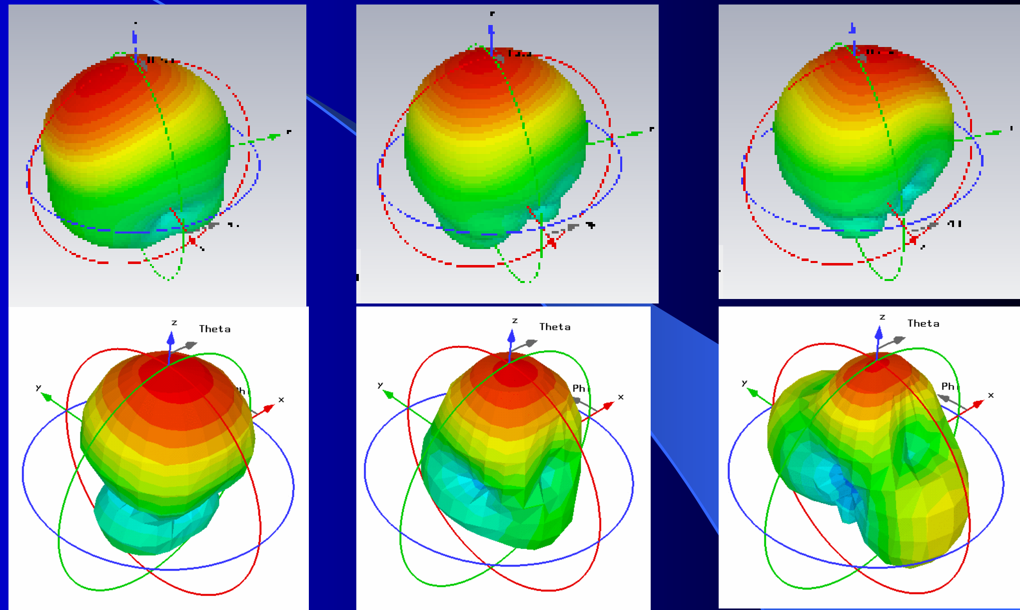
Comparison of antennas

UWB wide slot antenna



UWB stacked patch antenna



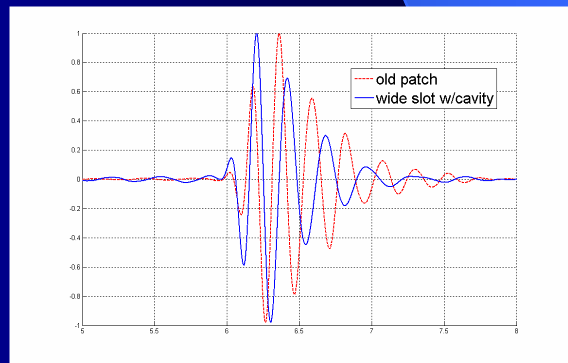


4GHz 6GHz 8GHz

New slot antenna provides:

- stable radiation pattern between 3 and 10 GHz
- high fidelity (>95%) of radiated pulses

Antenna performance critical for good imaging!!!



H-plane, 45deg

Experimental imaging results

16-patch-antenna array vs. 31-slot-antenna-array

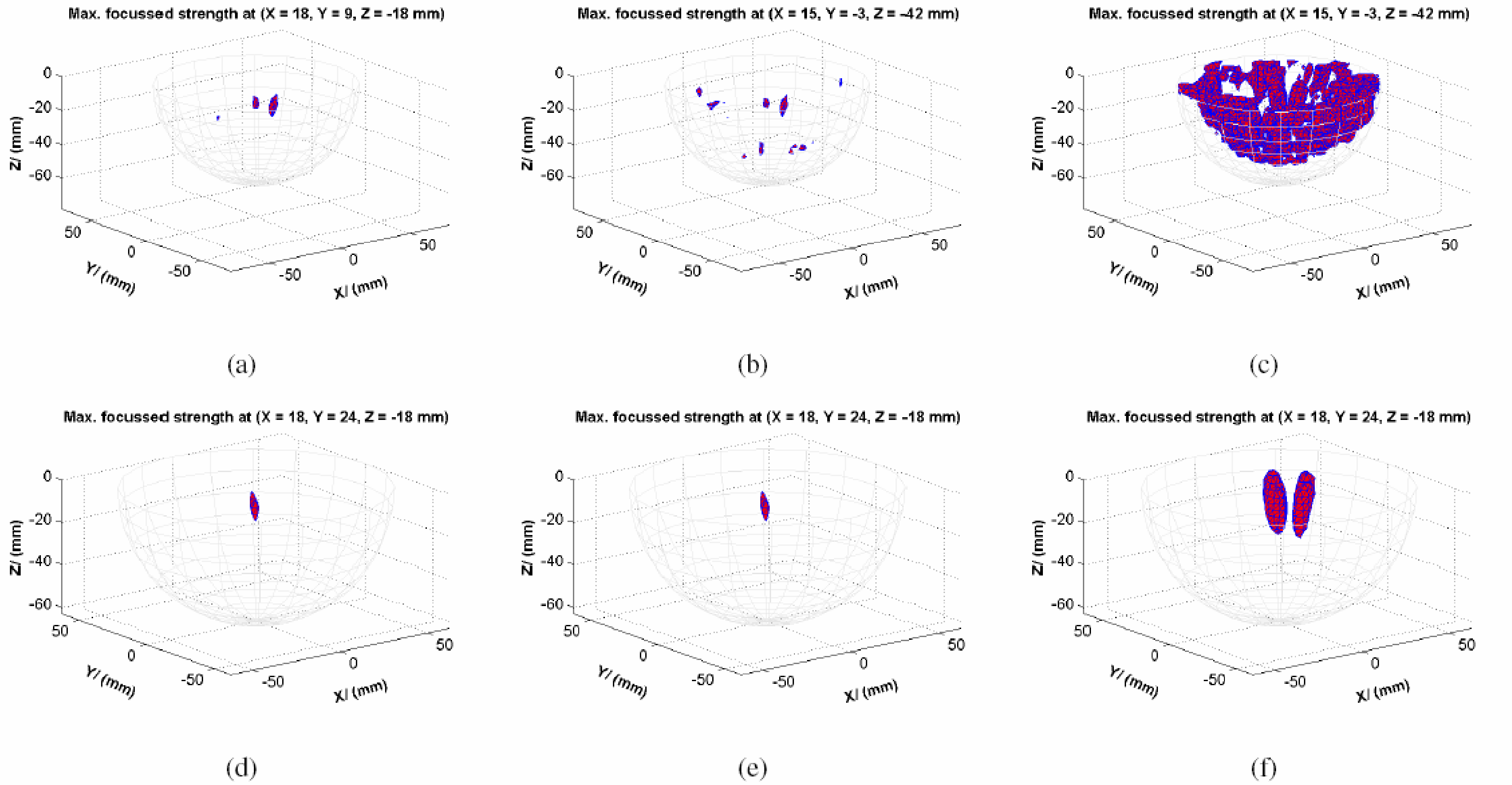


Fig. 4. Comparison of 3D imaging results: a) 16-element array, -1.5dB contour map for $\frac{1}{2}\theta_{max}$=25^o, b) 16-element array, -1.5dB contour map for $\frac{1}{2}\theta_{max}$=35^o, c) 16-element array, -7dB contour map for $\frac{1}{2}\theta_{max}$=35^o, d) 31-element array, -1.5dB contour map for $\frac{1}{2}\theta_{max}$=25^o, e) 31-element array, -1.5dB contour map for $\frac{1}{2}\theta_{max}$=35^o, f) 31-element array, -7dB contour map for $\frac{1}{2}\theta_{max}$=35^o.

Experimental imaging results

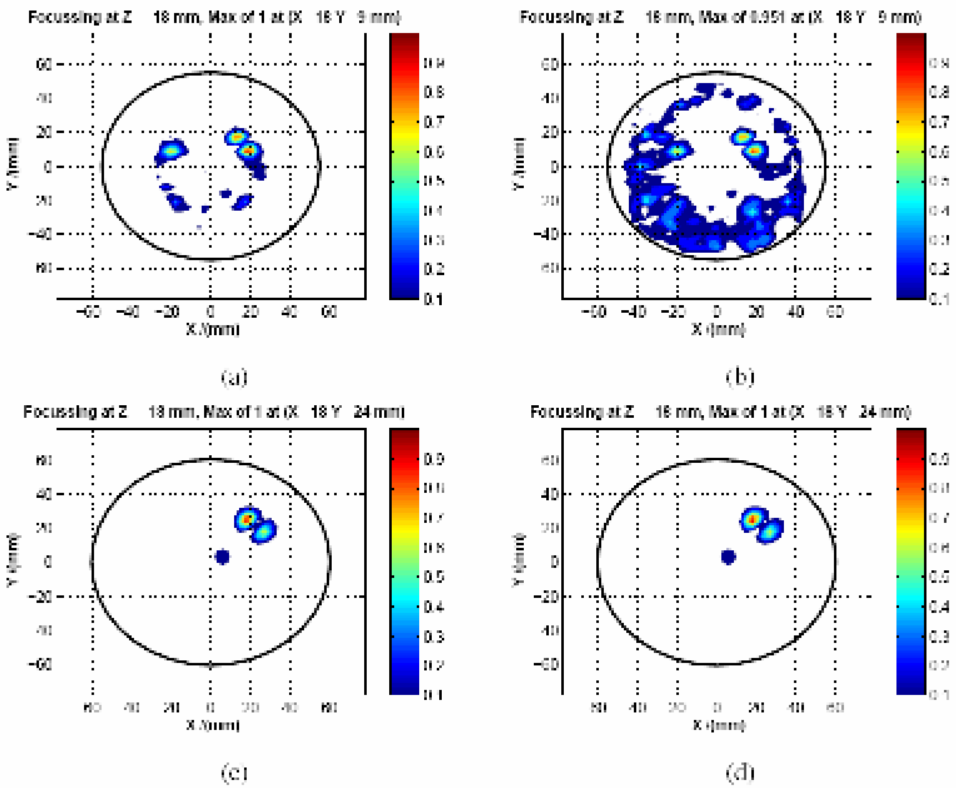
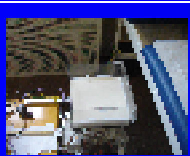


Fig. 5. Comparison of 2D imaging results: a) 16-elements array, $\frac{1}{2}\theta_{max}$=25°, b) 16-elements array, $\frac{1}{2}\theta_{max}$=35°, c) 31-elements array, $\frac{1}{2}\theta_{max}$=25°, d) 31-elements array, $\frac{1}{2}\theta_{max}$=35°. 2D contour plots show signal energy on a linear scale, normalized to maximum in the 3D volume, values below 0.1 rendered as white.

$$F_e(x_f,y_f,z_f) = \int_0^T \left(\sum_{i=1}^{M} C_{iTXant}(x_f,y_f,z_f)\cdot C_{iRXant}(x_f,y_f,z_f)\cdot w_i(x_f,y_f,z_f)\cdot y_i(t-T_i(x_f,y_f,z_f))\right)^2 dt \quad (1)$$

$$C(x_f,y_f,z_f) = \begin{cases} 1 & \text{if } \arccos\frac{\vec{v_1}\cdot\vec{v_2}}{\|\vec{v_1}\|\|\vec{v_2}\|} < \theta_{max}/2 \\ 0 & \text{otherwise} \end{cases}$$

Experimental imaging results



Location-independent performance

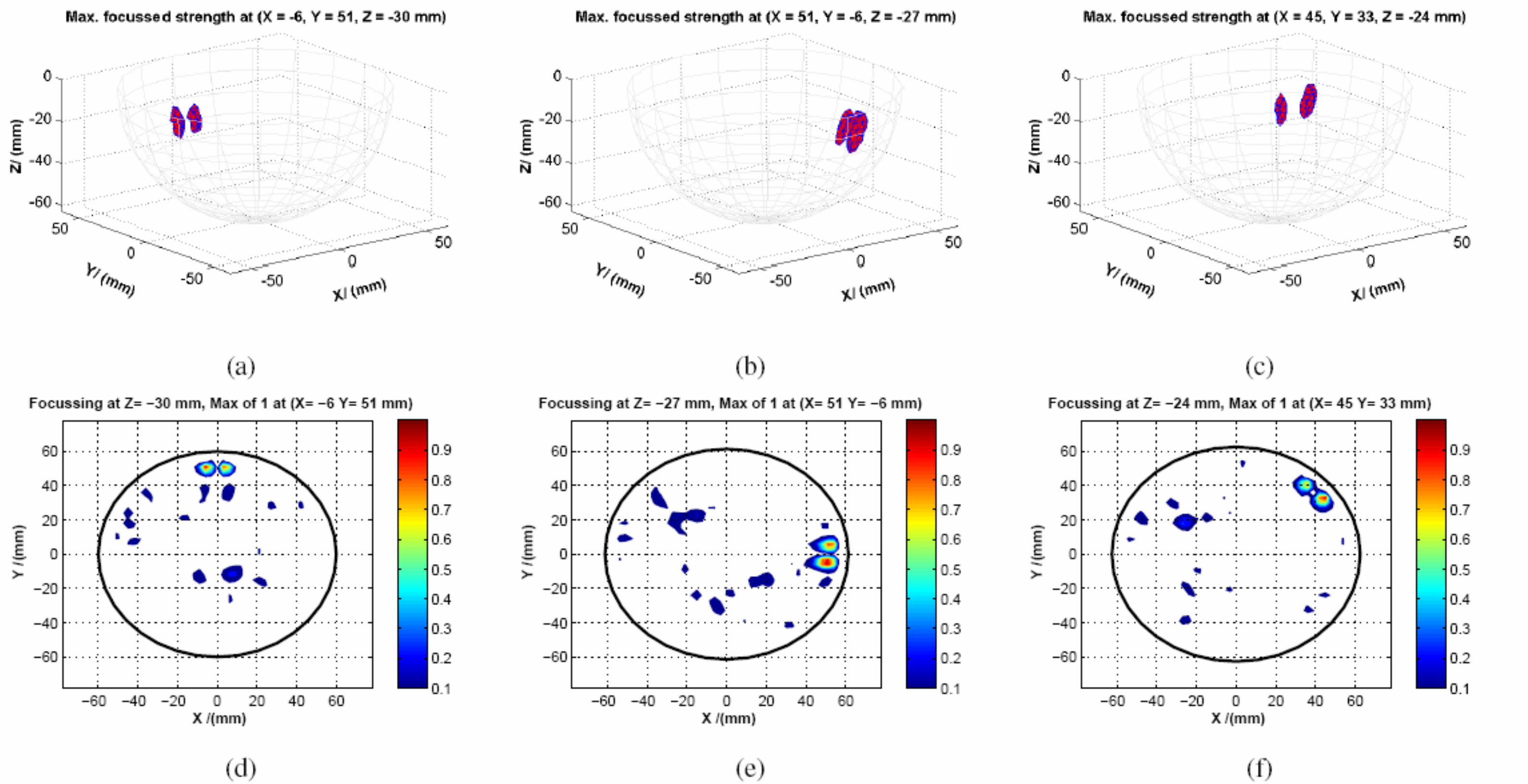


Fig. 6. 3D imaging of a 7-mm tumor phantom (ϵ_r=50) at three positions: P1(x=0,y=50,z=-30), P2(x=50,y=0,z=-30), P3(x=40,y=40,z=-30). a) 3D image for position P1, b) 3D image for position P2, c) 3D image for position P3, d) 2D image for position P1, e) 2D image for position P2, f) 2D image for position P3. $\frac{1}{2}\theta_{max}$=45^o has been used in DAS for all images. 3D images show -3dB contour maps. 2D contour plots show signal energy on a linear scale, normalized to maximum in the 3D volume, values below 0.1 rendered as white.

Experimental imaging results

Inhomogeneous phantom models with dense tissue

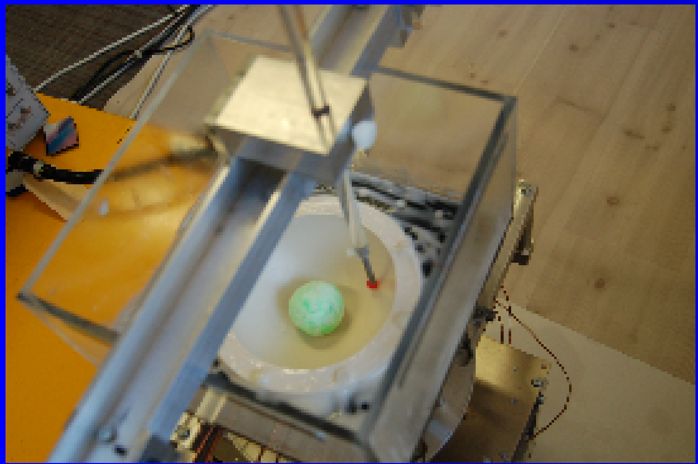
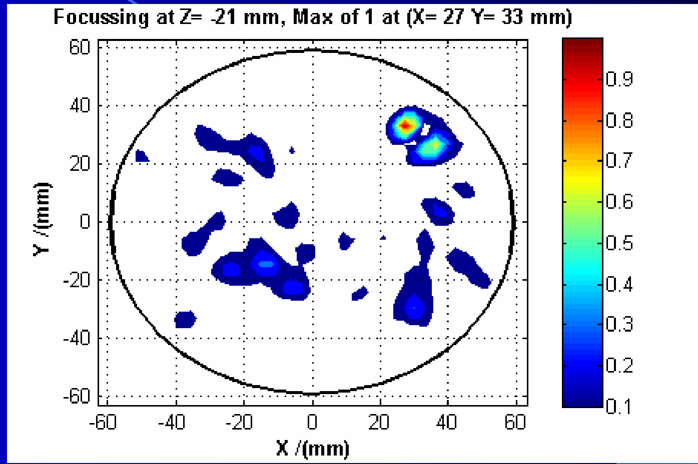
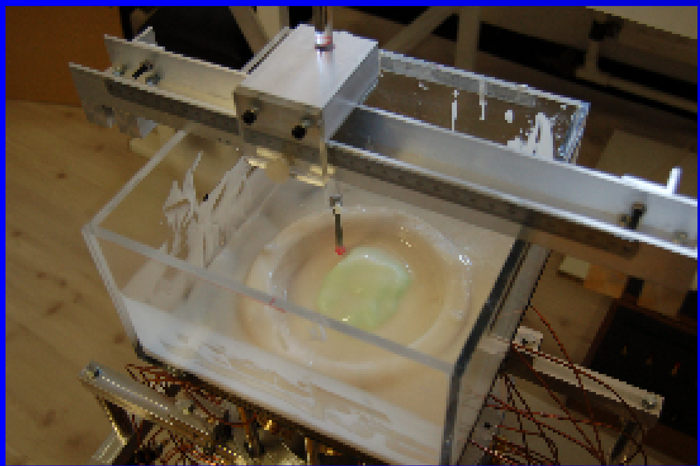
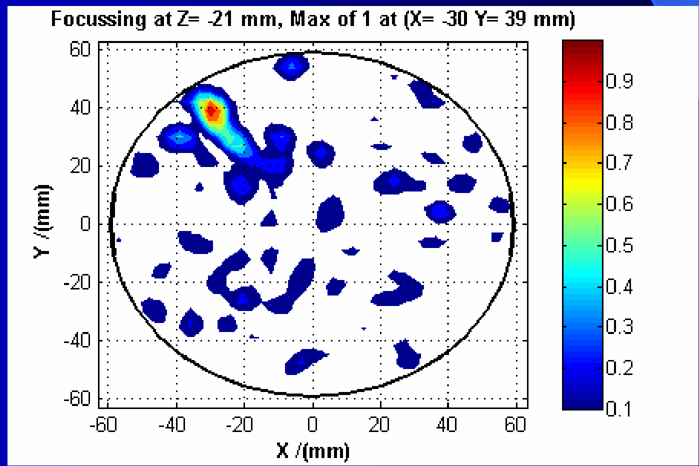


Fig. 4cm sphere with er=30 and 7mm tumour (er=50) at position x=30, y=30, z=-40. Tumour is about 5mm from the skin layer

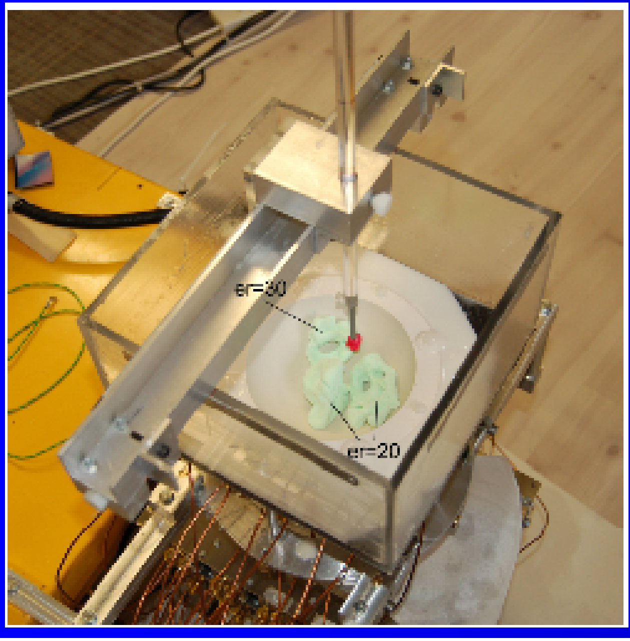


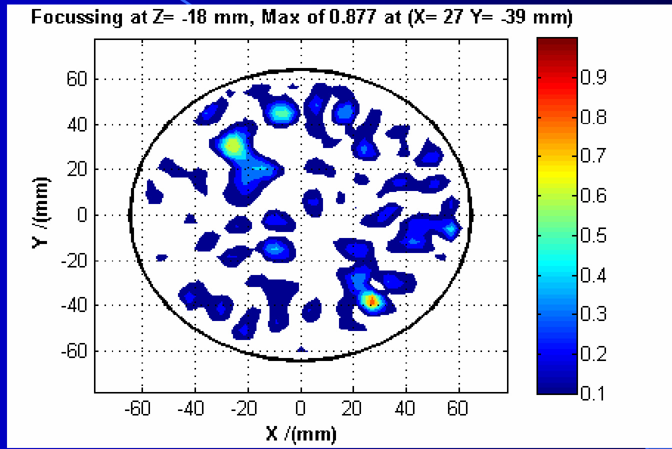


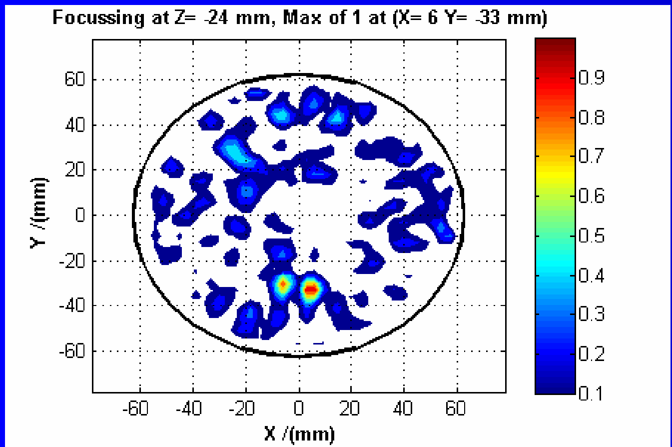


Experimental imaging results

Inhomogeneous phantom models with dense tissue





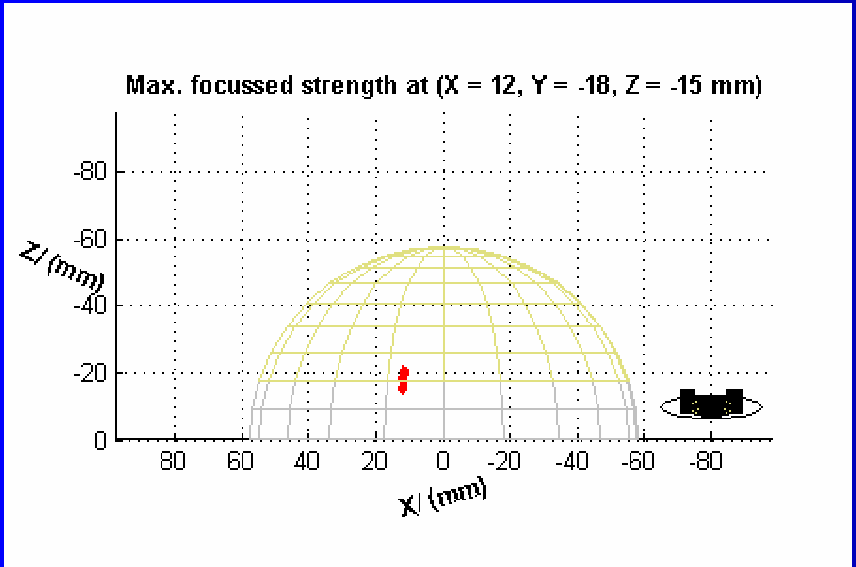


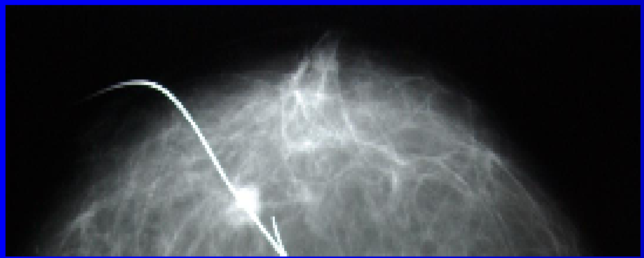
- Mixed results
- Complex scenario
- Results depend on e.g. tumour position, distance to skin, etc.

Clinical imaging results

Clinical imaging results

Clinical setup at Bristol Oncology Centre (Summer 2007)





Mk2

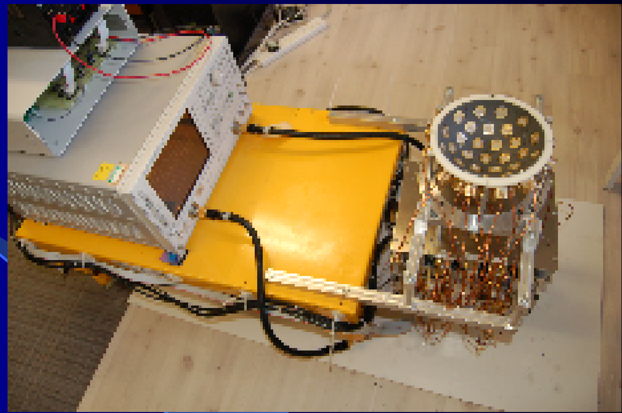
- Very small sample (only 5 patients)
- Promising results

Clinical imaging results

Clinical setup at Bristol's Frenchay Hospital

(since Aug.2008; ongoing)

Mk3



- World's first clinical trial of the microwave **radar** imaging system
- Large-scale clinical trial
- 250 patients (about 25% with cancers)

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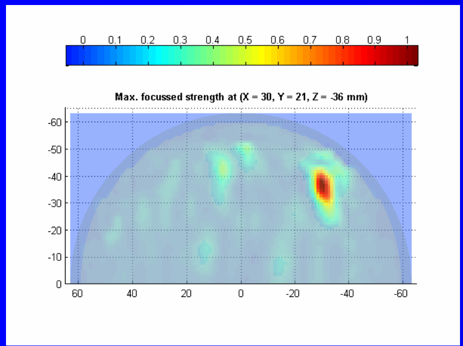
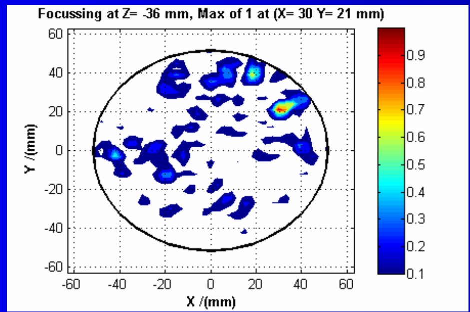
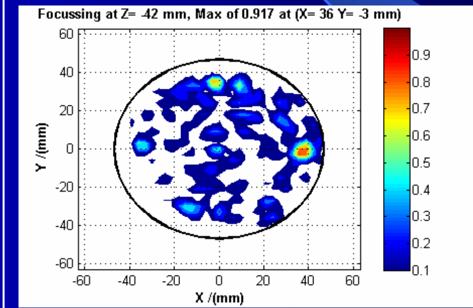
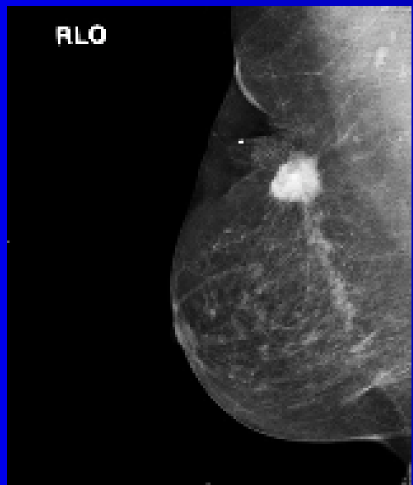
Clinical imaging results

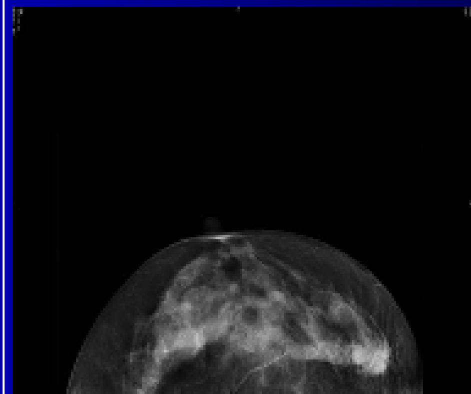
- Detection rate worse than expected: 20% (initial goal 65%)
- Several practical problems (e.g. variation of breast sizes)
- Proved that simple phantoms are not realistic

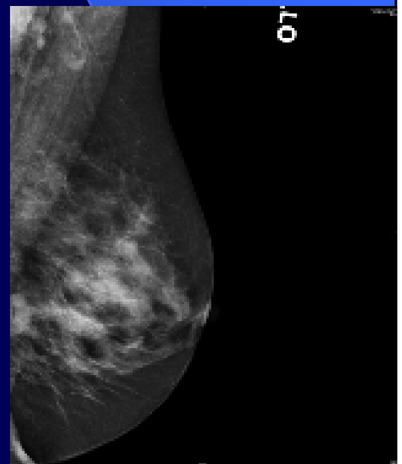












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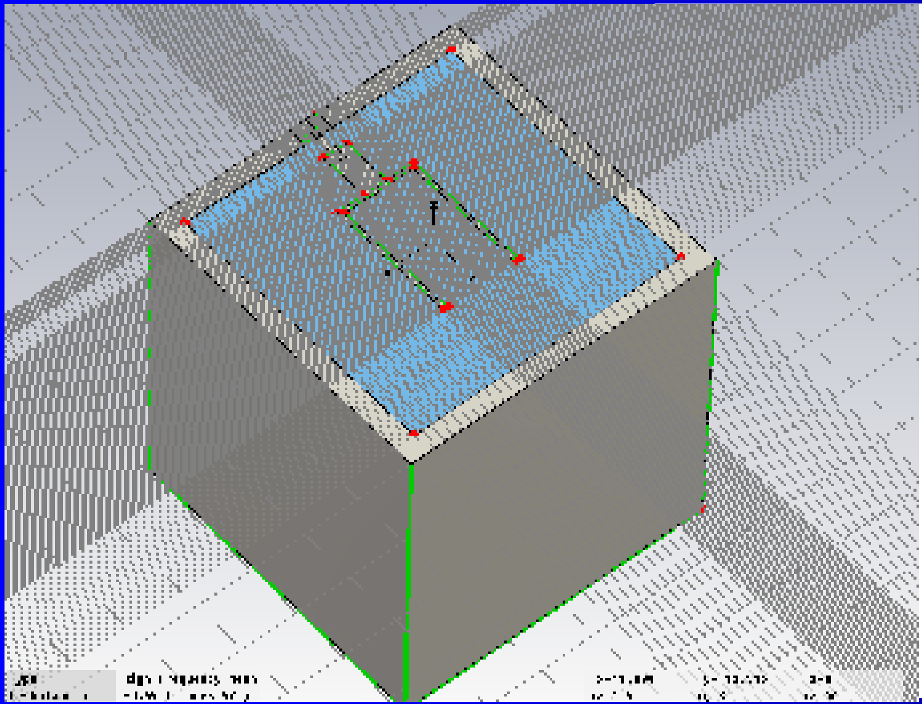
Electromagnetic modelling

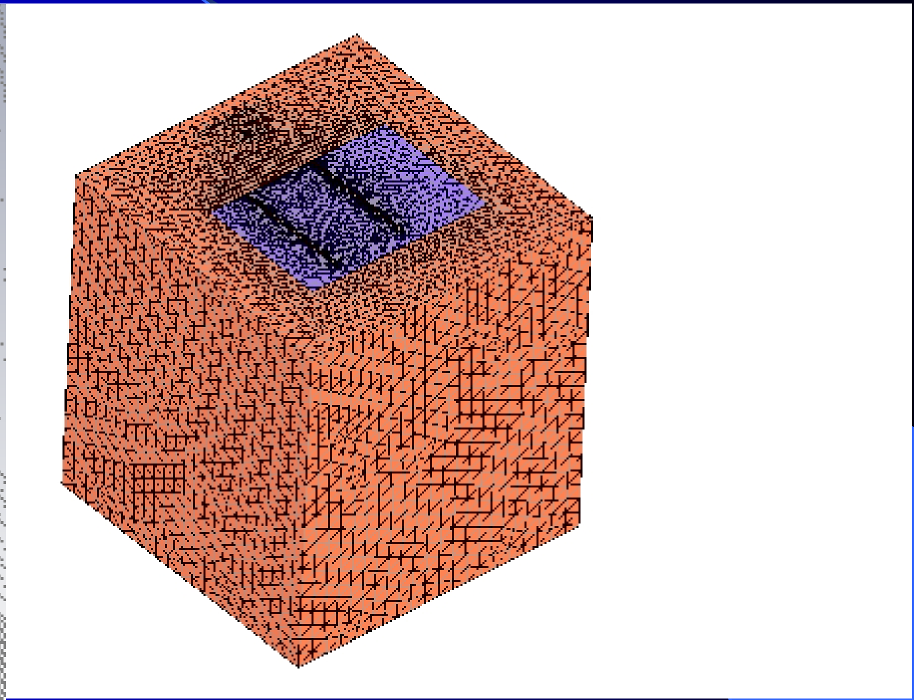
Centre for Communications Research CCR

Electromagnetic modelling

Antenna modelling



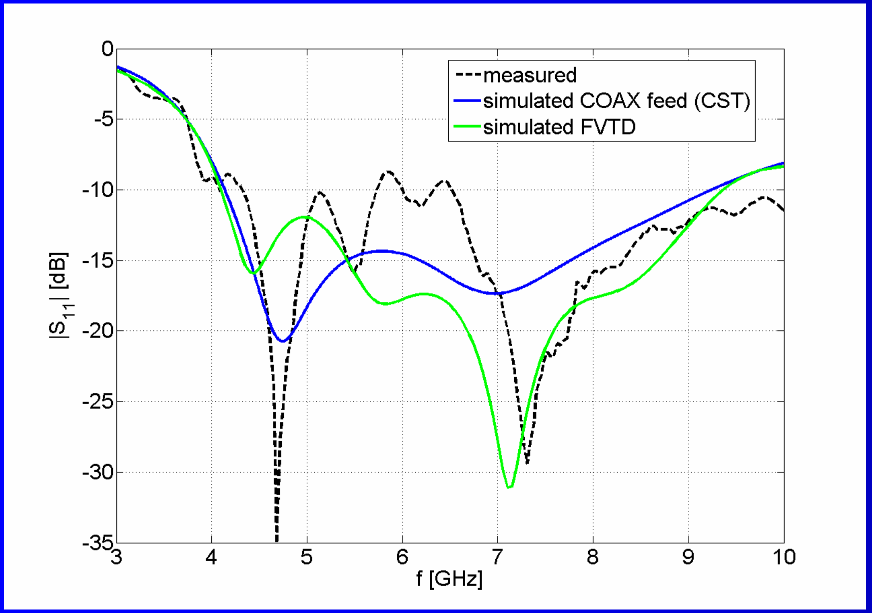
FDTD

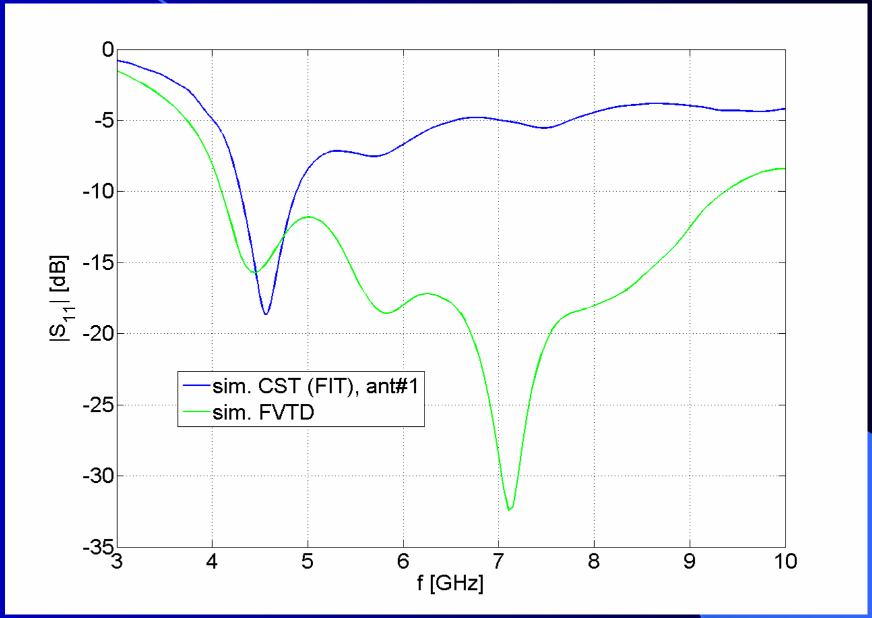


FVTD*
(C. Fumeaux, Uni.of Adelaide)

Electromagnetic modelling

Antenna modelling: results



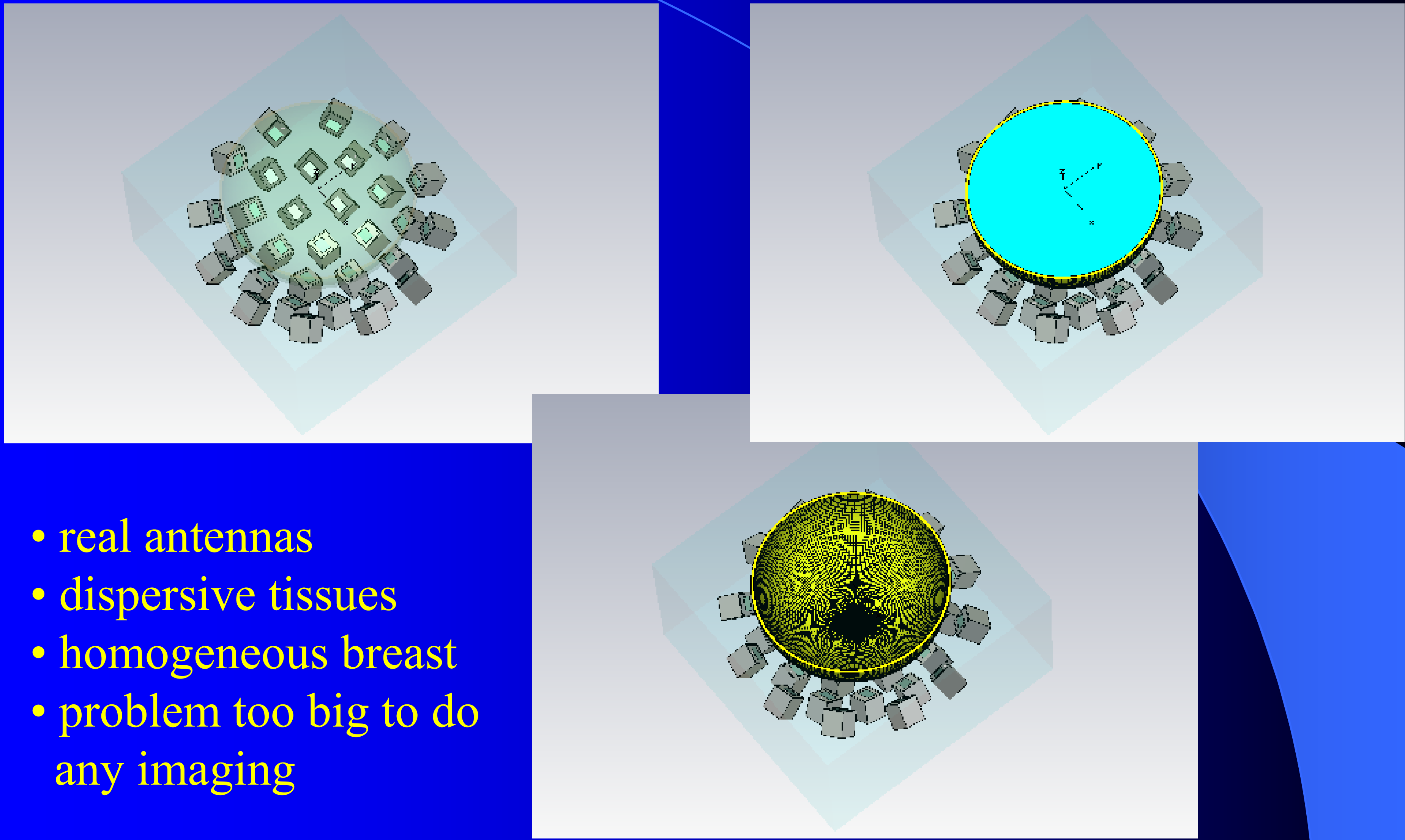


- grid-aligned FDTD
- coax port (mode excitation)

- not grid-aligned FDTD
- voltage gap excitation

the same excitation in FVTD!
not dependent on antenna orientation

Electromagnetic modelling



- real antennas
- dispersive tissues
- homogeneous breast
- problem too big to do any imaging

Electromagnetic modelling

Numerical model details:

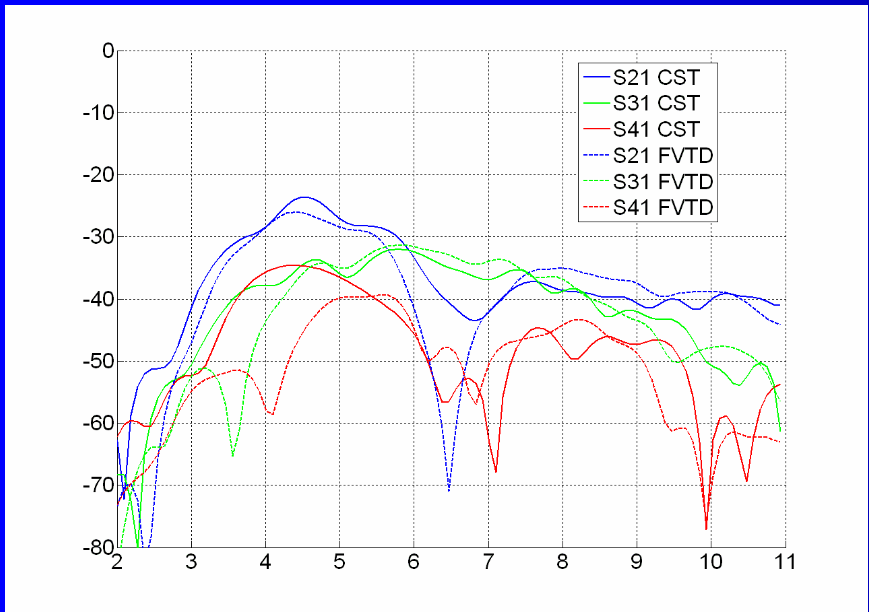
FDTD (FIT-CST)

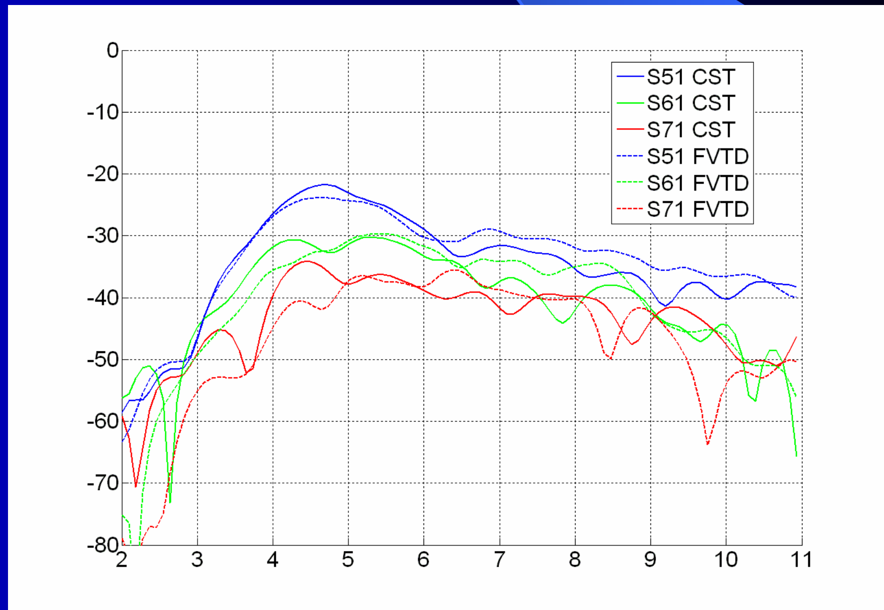
- 854M cells (!)
- can not be run (yet)

- 411M cells – only 14 antennas (!) 48Gb RAM, 270h CPU (8 cores!)

FVTD

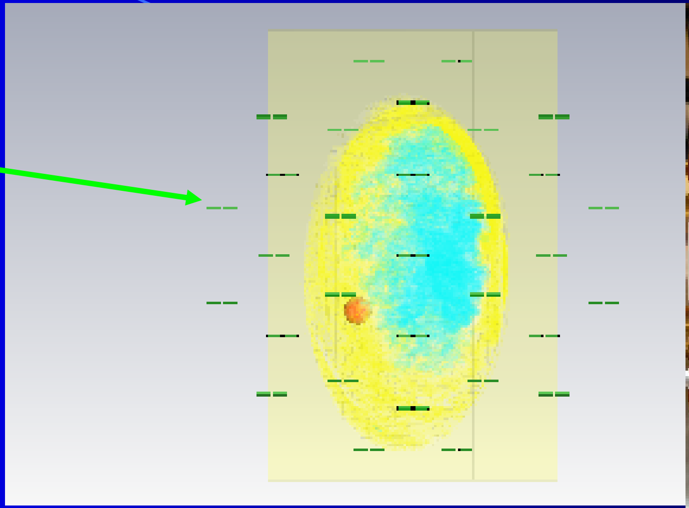
- 21M cells
- can be run at once (!)
- 22Gb RAM, 330h CPU (1 core)

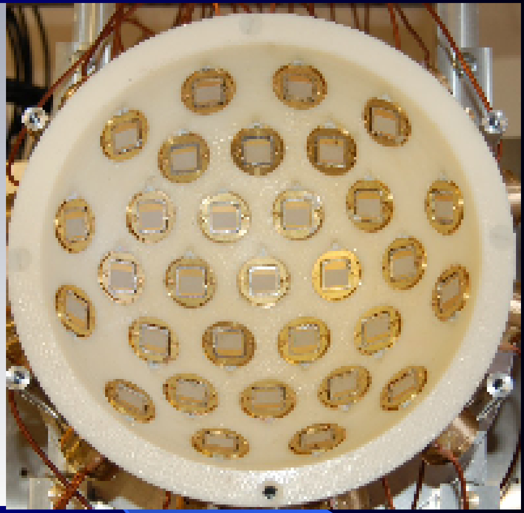


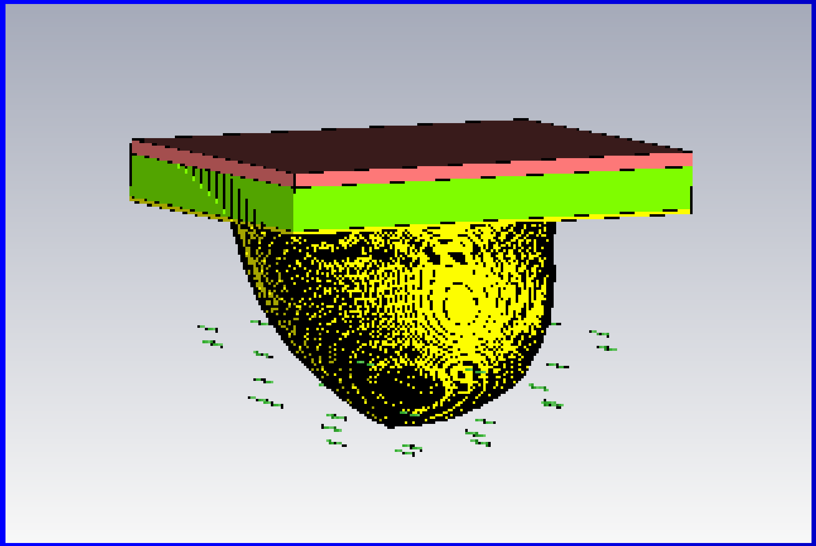


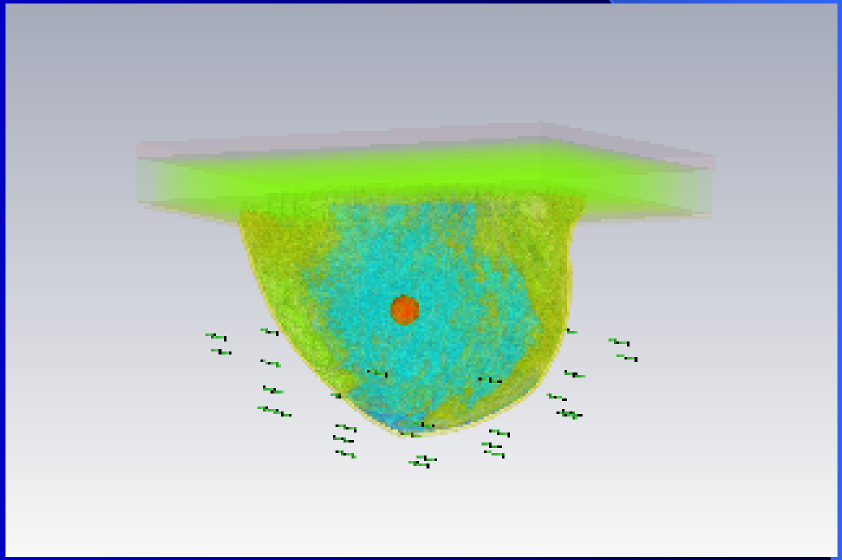
Electromagnetic modelling

- dipole antennas
- dispersive tissues
- inhomogeneous breast !
- model 30-40M cells
- full imaging (30 simulations) takes about 10h (hardware accelerated; 4 GPU cards)





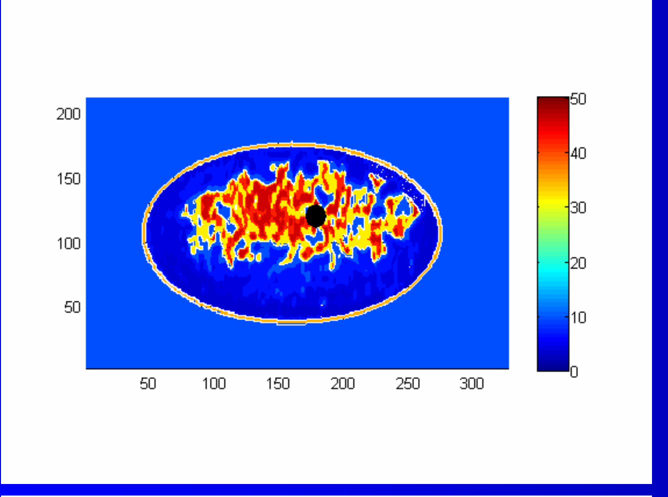


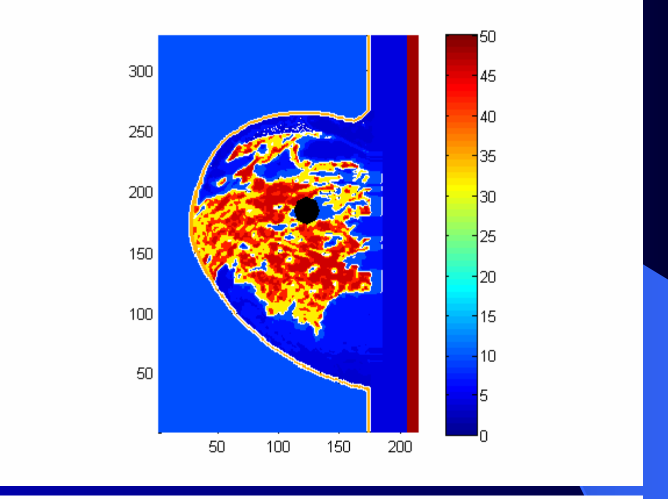


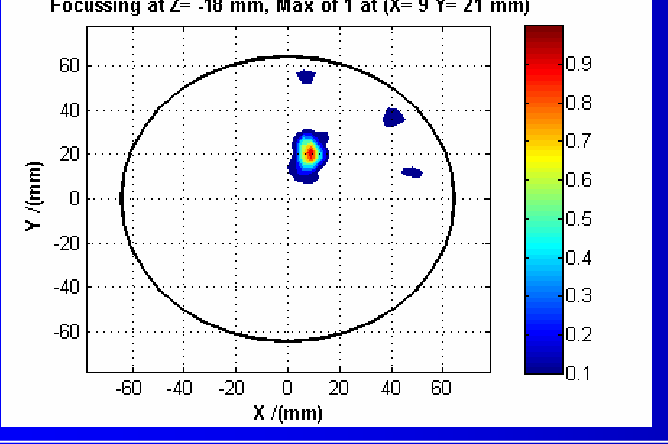
Electromagnetic modelling

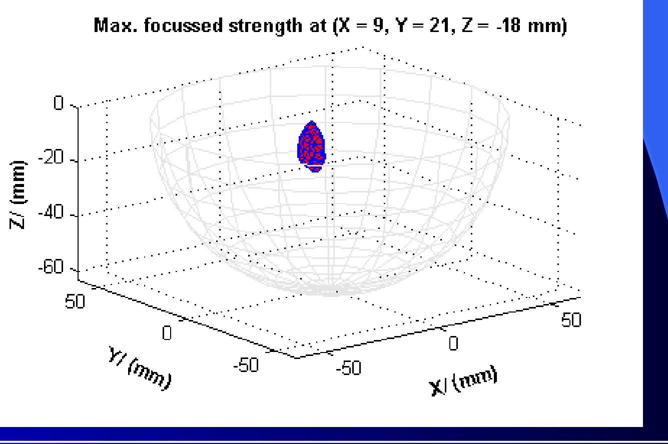
New concept: contrast-enhanced imaging

- differential imaging (subtraction of two full scans)
- example below: scan1: **tumour *er=50***; scan2: tumour ***er=48***



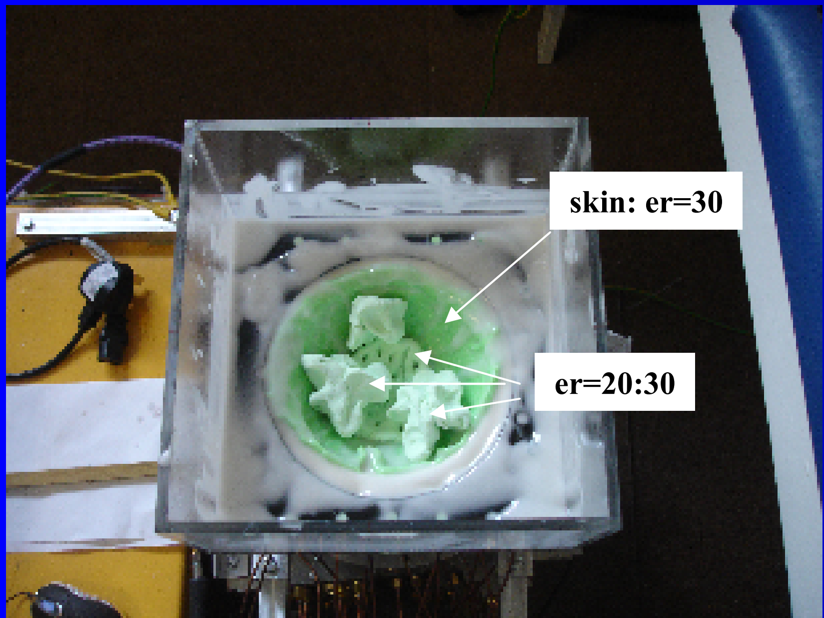




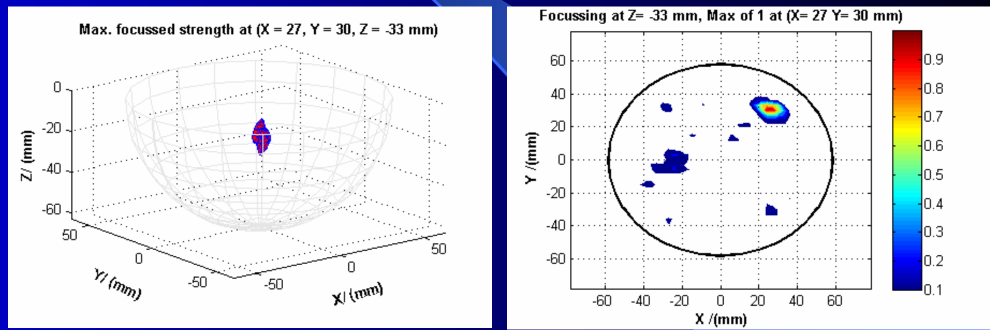


New concept: contrast-enhanced imaging

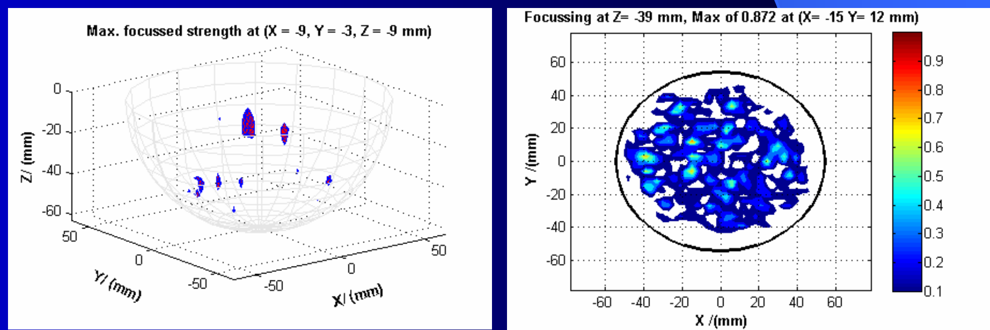
- numerical results confirmed by measurements !!!
- example below: scan1: **tumour *er=58***; scan2: tumour ***er=51***



Contrast-enhanced



Without contrast



Conclusions

- We have developed the microwave radar imaging system for breast cancer detection
- System performs very well in homogeneous breast phantoms
- For inhomogeneous phantoms results can still be good in specific scenarios; generally detection is challenging
- The first large-scale clinical trial is still under way at Bristol Frenchay hospital; results so far worse than expected
- So far we were able 'to build', rather than 'to design' the system; the problem was too big for numerical EM tools
- EM numerical simulations were limited to antenna designs
- However, we are starting to be able 'to design' imaging system using EM numerical solvers
- We have shown so far, that standard FDTD is not efficient in our scenario; alternative numerical solutions (e.g. FVTD, DGTD, meshless) should be developed

Thank you for the attention