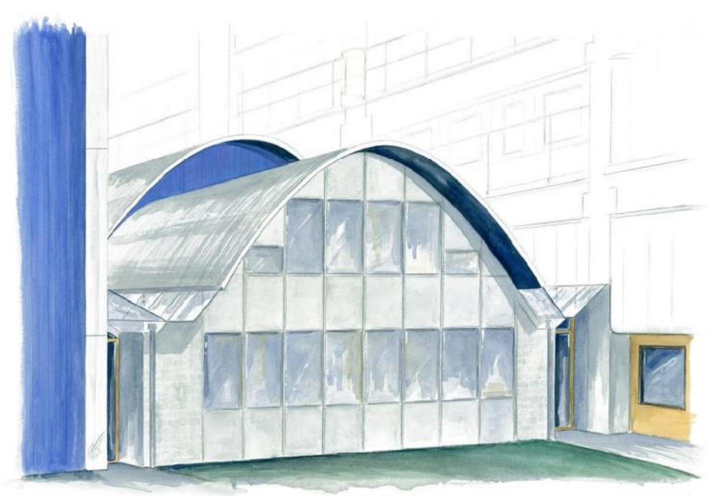
Leiden University Medical Center

New RF technologies for very high field and very low field magnetic resonance imaging

Andrew Webb

C.J. Gorter Center for High Field MRI

LEIDEN UNIVERSITY MEDICAL CENTER



Outline

1. How does RF technology fit into MRI?
   Similarities and differences to radar/antennas

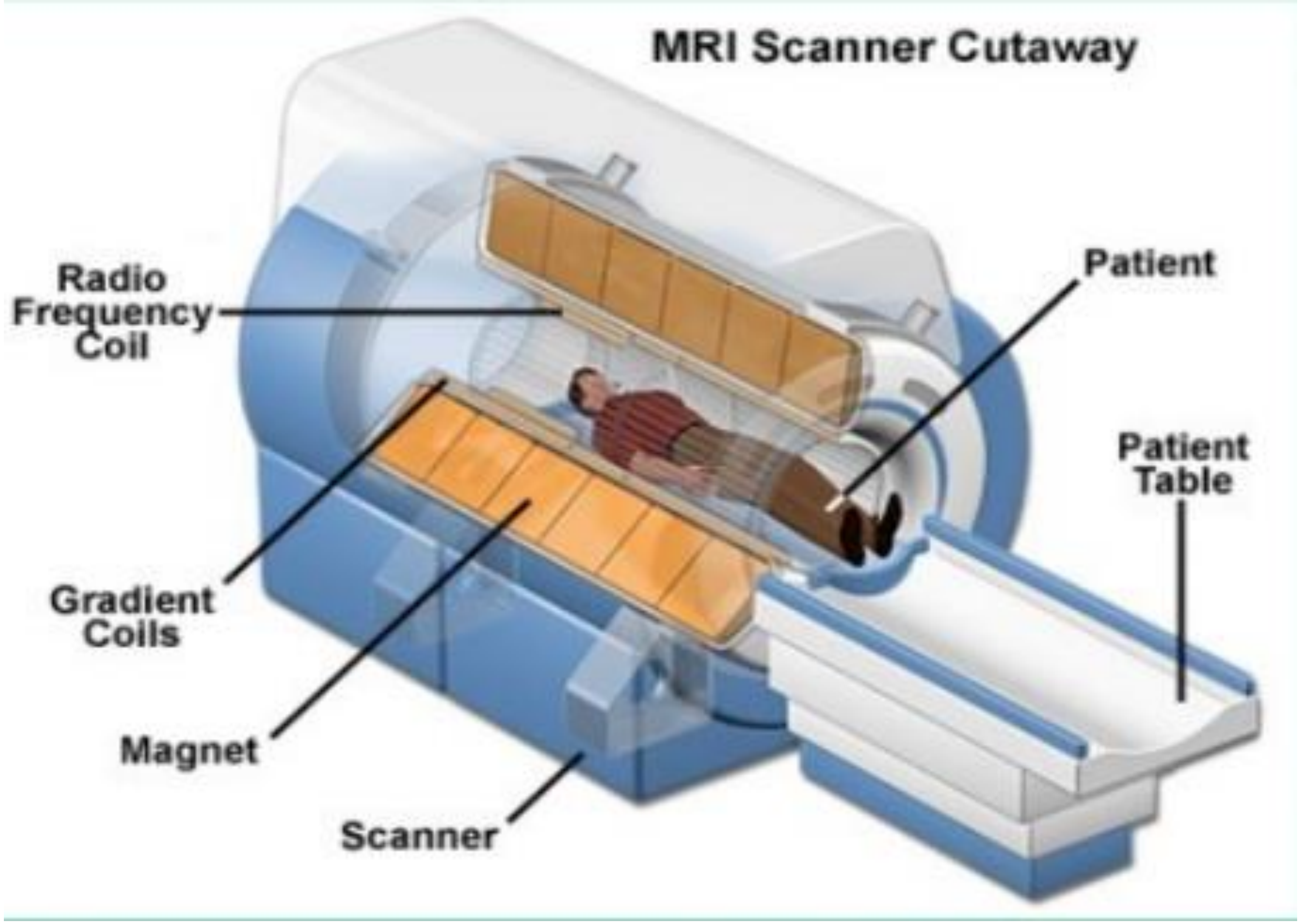
2. Advantages but also RF challenges of very high frequency MRI
   Interactions with the body

3. What do we use very high frequency MRI for in the hospital?

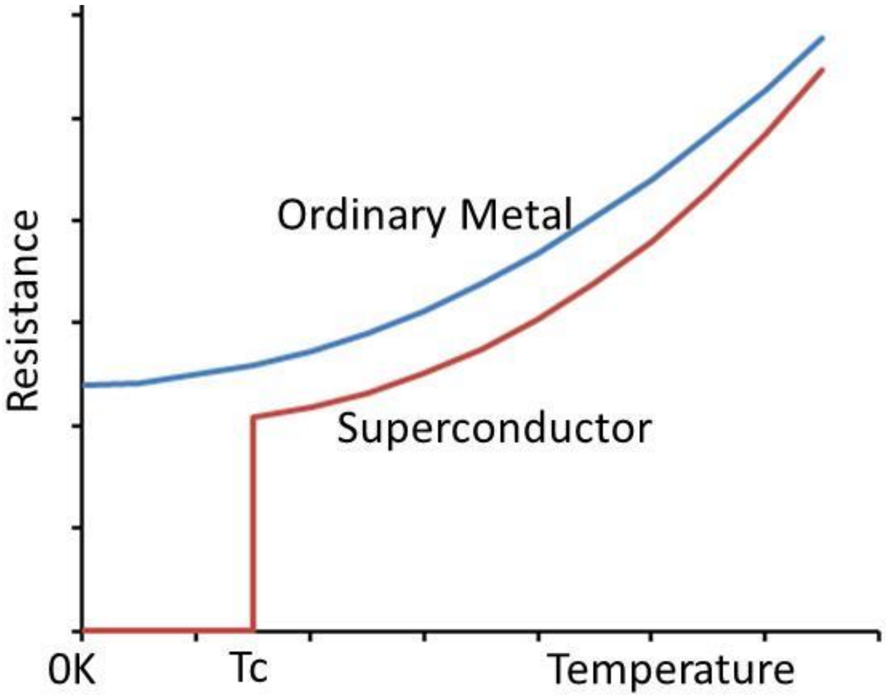
4. High frequency components, current and future….
   Expert advise welcome!

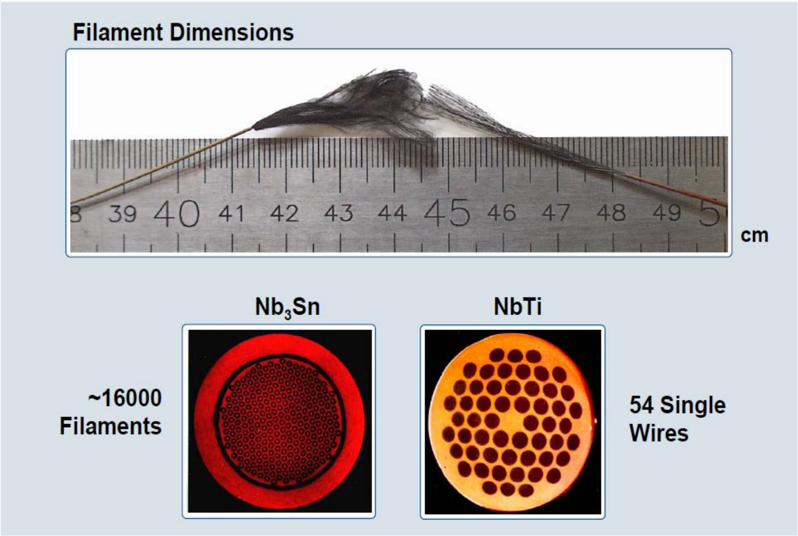
5. And now for something completely different….
   Ultra low field MRI, why and how

Magnet (DC), gradient coils (100s kHz), RF coil (100s MHz)



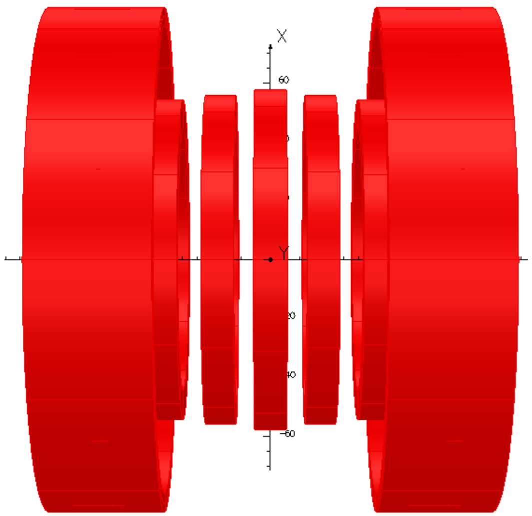
Superconducting wire (tens of km, cooled with liq He)

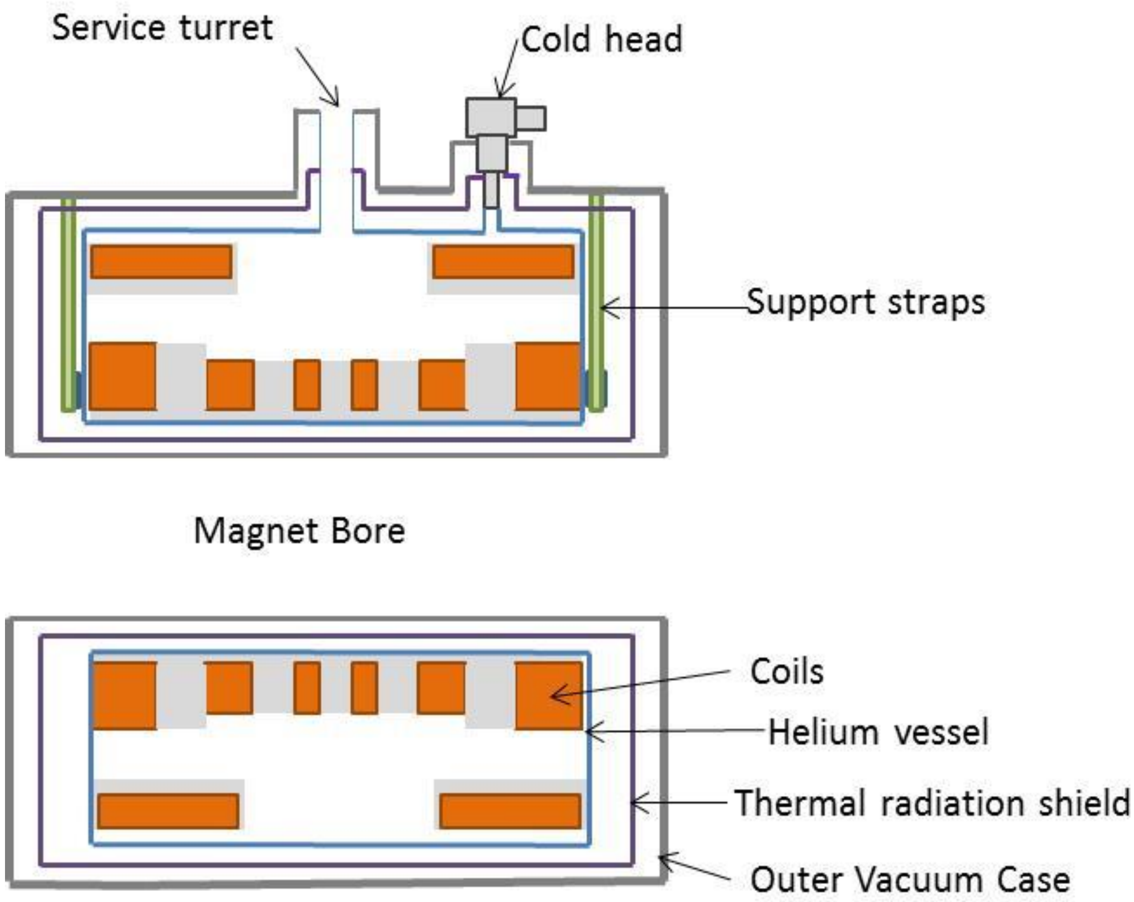




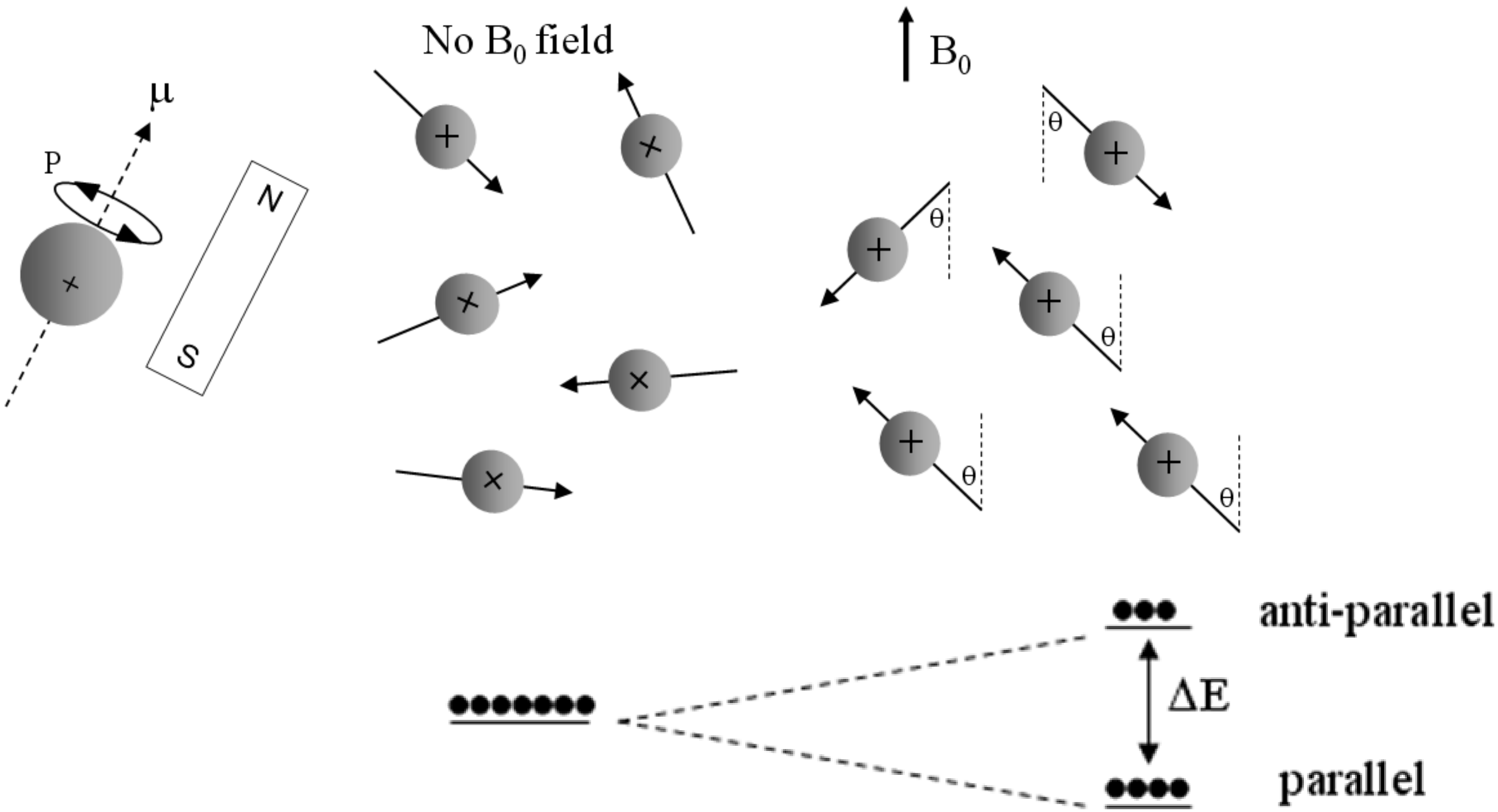
Earths magnetic field: 50 μTesla
Typical clinical scanner: 3 Tesla
Ultra high field human scanner: 10 Tesla
High field NMR spectrometer: 30 Tesla

Shielded superconducting magnet





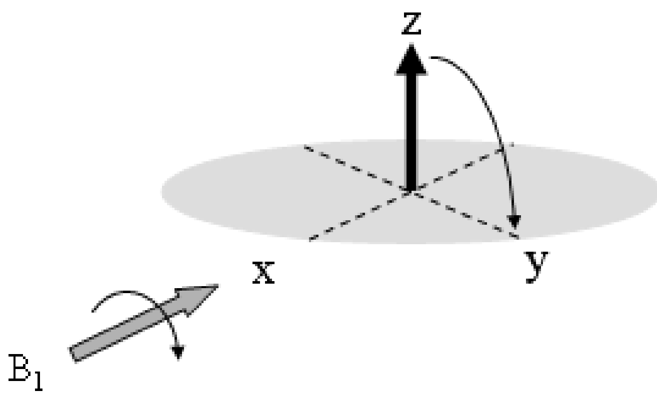
Why do we need a very strong magnet?

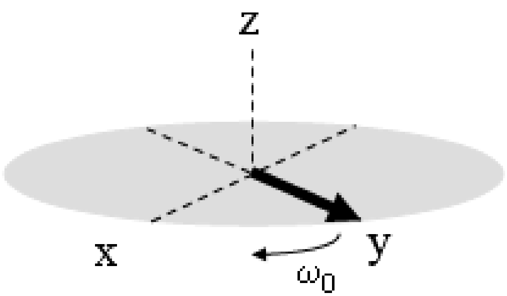


B_0=3 Tesla f=128 MHz

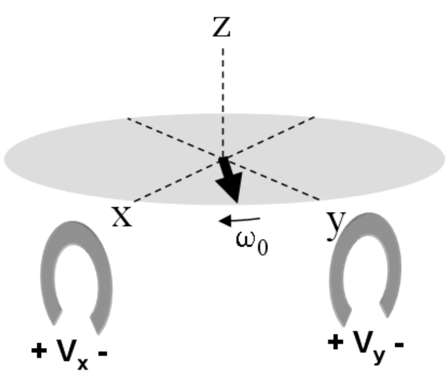
$$f = \frac{\gamma B_0}{2\pi}$$

Effects of a pulse of RF energy





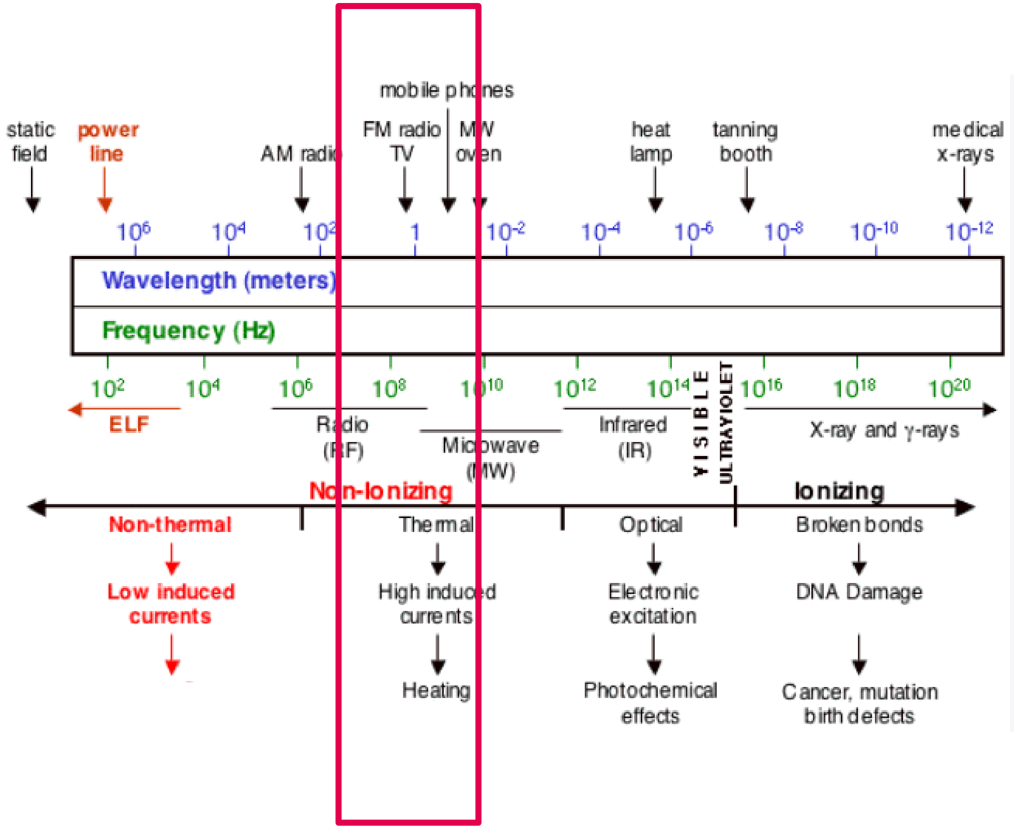
$$f = \frac{\gamma B_0}{2\pi}$$



Faradays'law

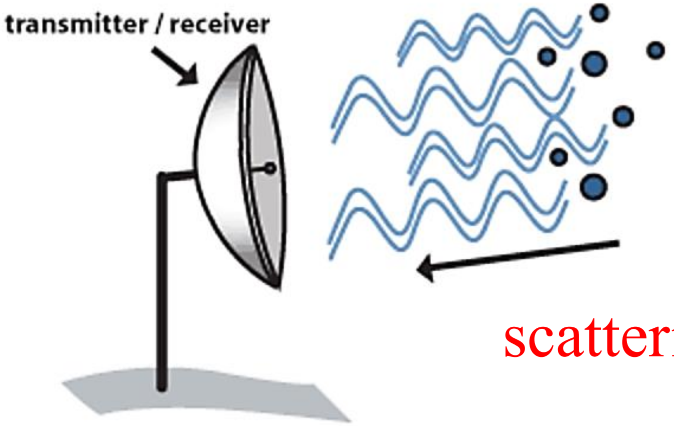
$$V \propto -\frac{d\phi}{dt}$$

What frequencies are we dealing with?



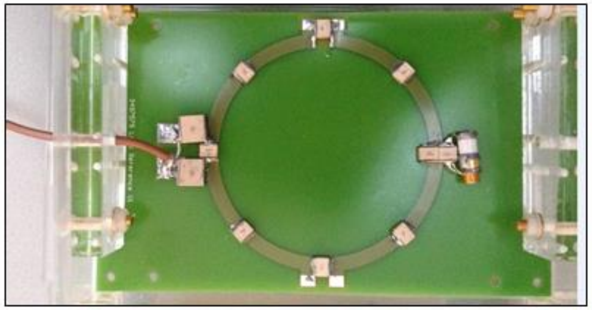
Similarities and differences with radar

FAR FIELD

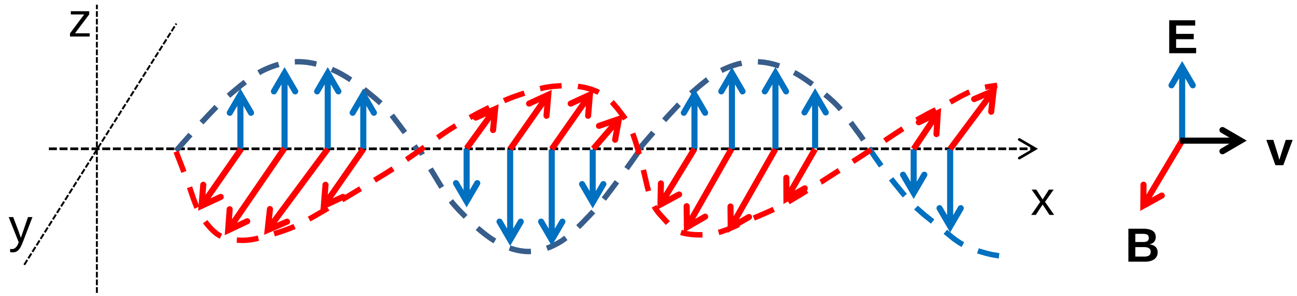


scattering

NEAR FIELD



dimensions <<λ

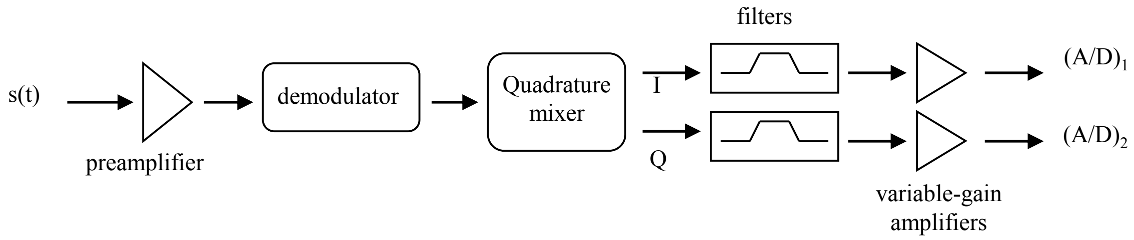


Multiple coil arrays

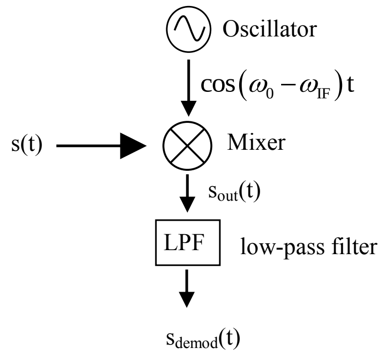
circularly polarized
transmit

multiple channel
receive

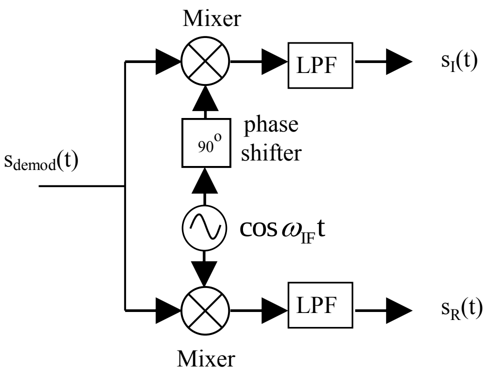
Superheterodyne detector



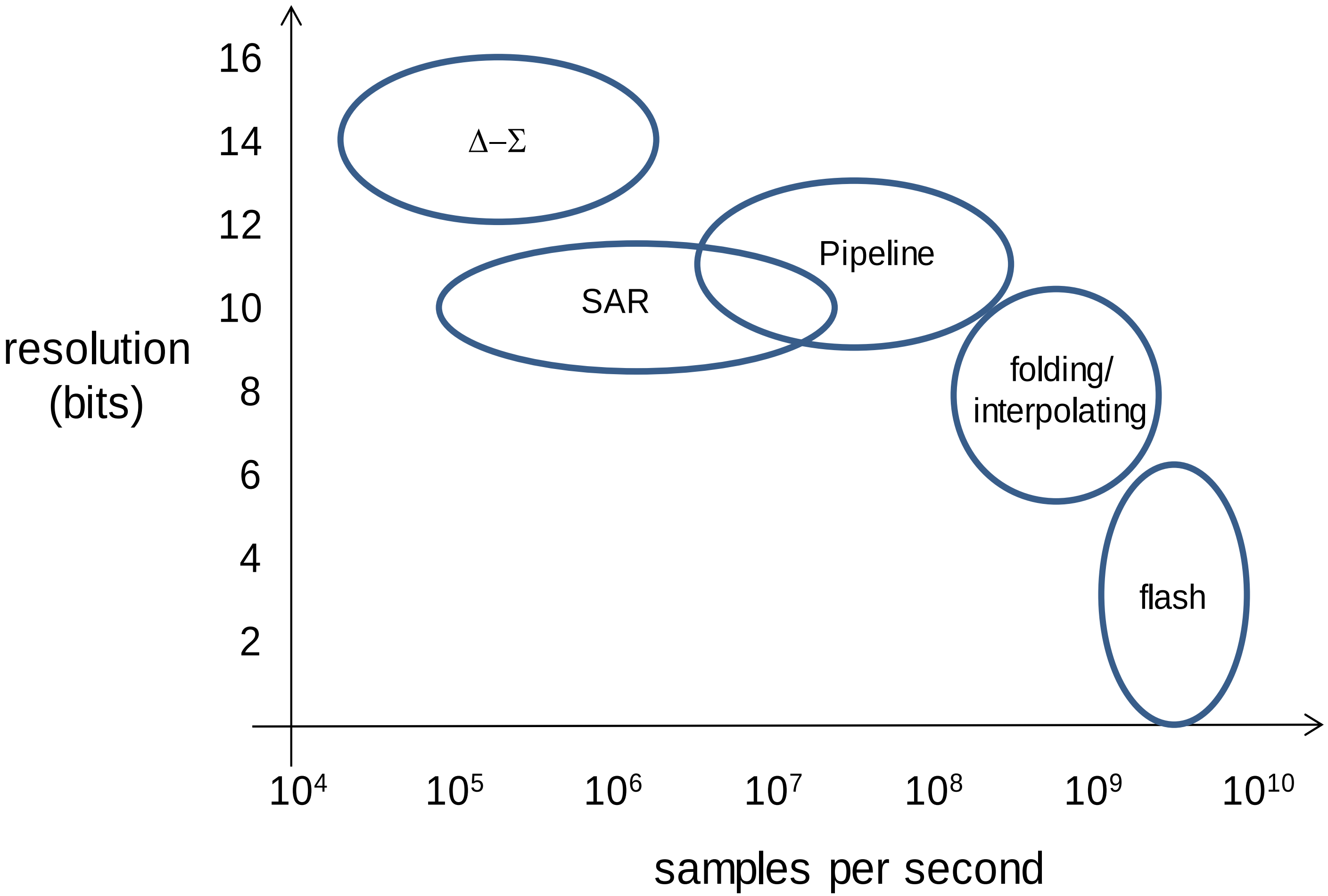
Demodulator



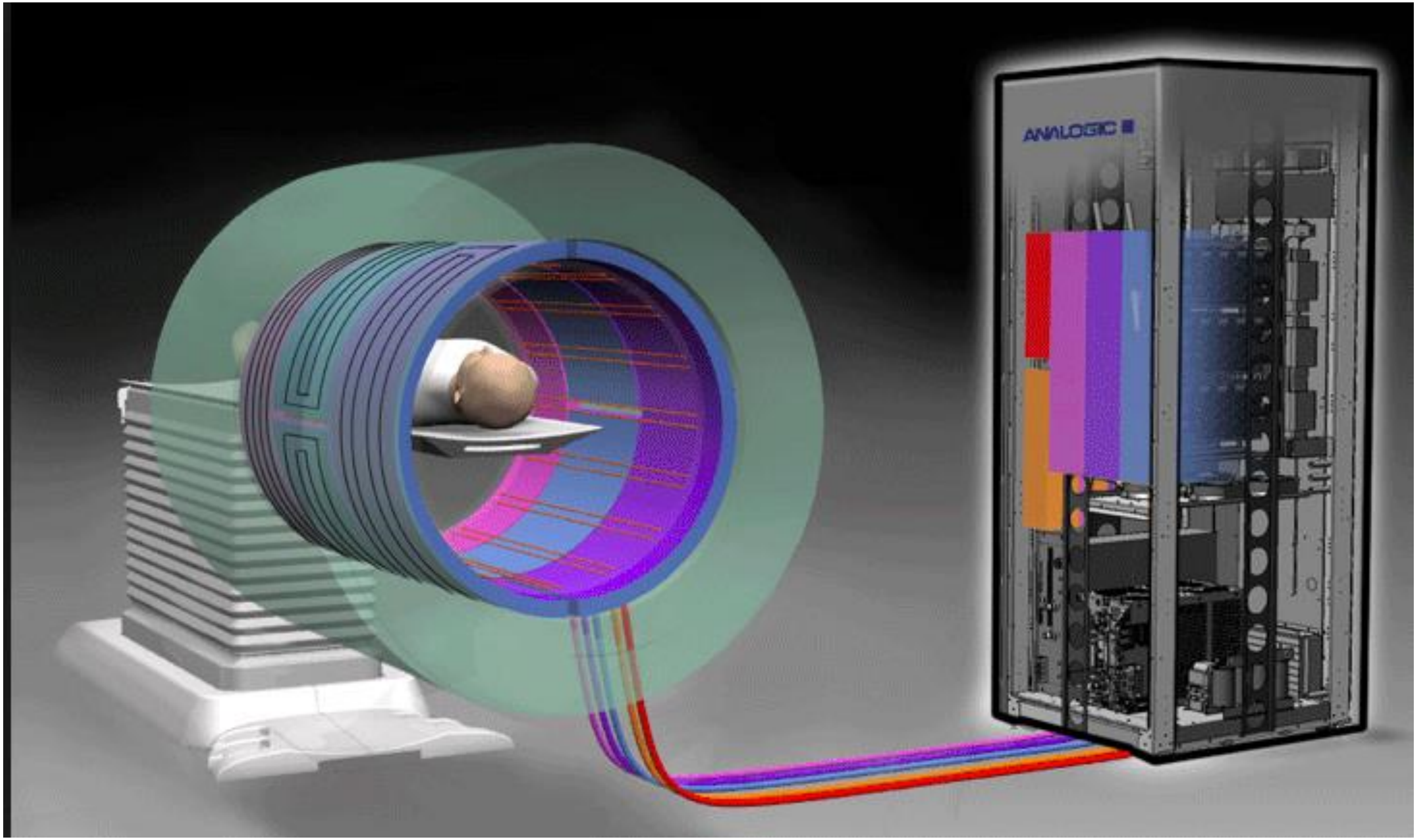
Quadrature mixer



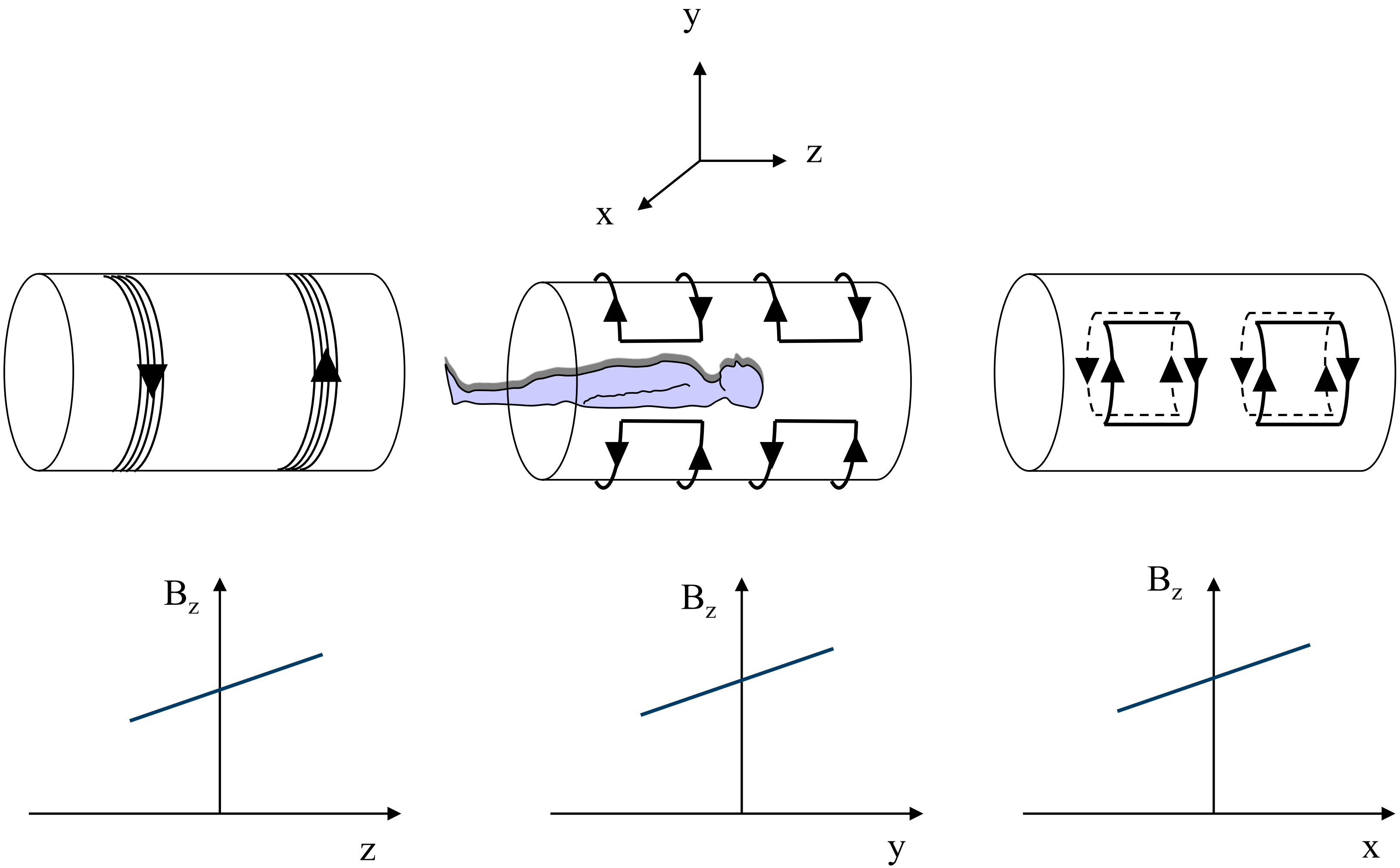
Analogue-to-digital converters



High current (400 Amps) gradient power supplies



Imposing spatial information on precessional frequency



$$\omega(x,y,z) = \gamma B(x,y,z)$$

What are the main differences to radar and antennas?

Operate in the near field – so coils not antennas

Relatively low frequency so scattering is not relevant

Spatial resolution is not wavelength-related but depends upon the gradient strength, since we impose a frequency/phase difference onto the sample

Magnetic field produces the signal
Electric field produces heating!!

Part 2

Advantages and disadvantages of higher fields

The move to higher fields

Higher signal-to-noise

Higher spatial resolution

Higher spectral resolution

Increased image contrast

LUMC

LUMC

C.J.Gorter Center for High Field MRI (established 2008)

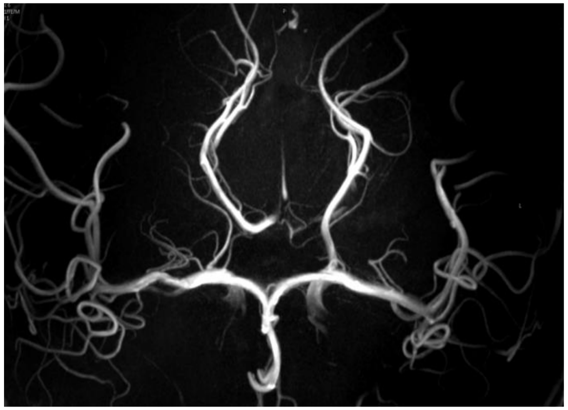
Mission: Develop new technology for clinical, medical research and biomedical research in MRI

Technique – application in volunteers – application in patients

Rapid translation of hardware and software – weeks not years

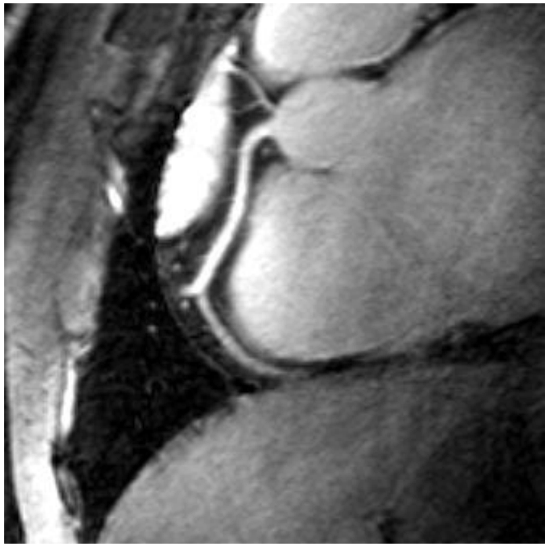
Most rapid – eye coil construction to first patient ~2 weeks

Examples of 7T MRI projects in Leiden



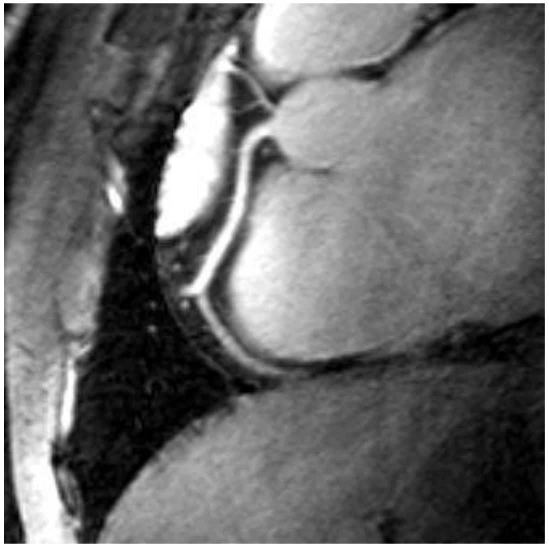
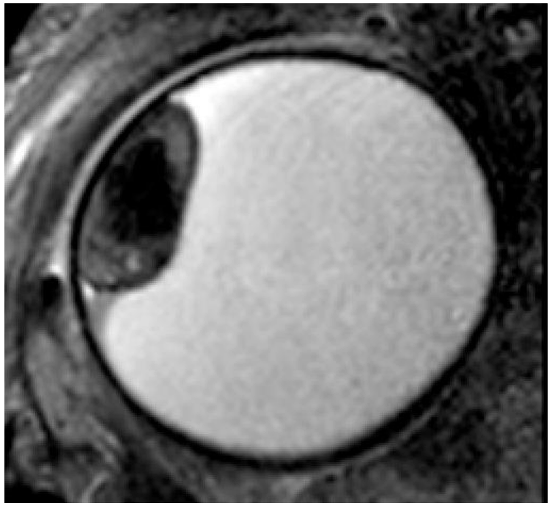
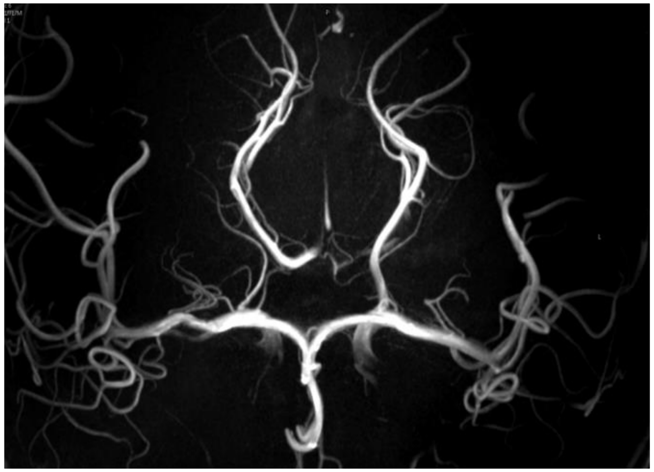
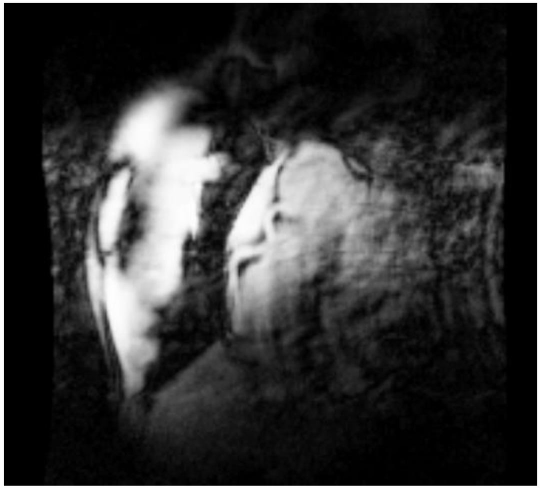
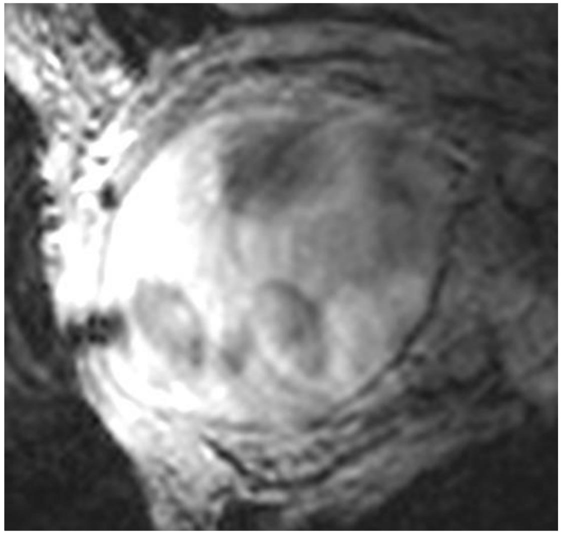
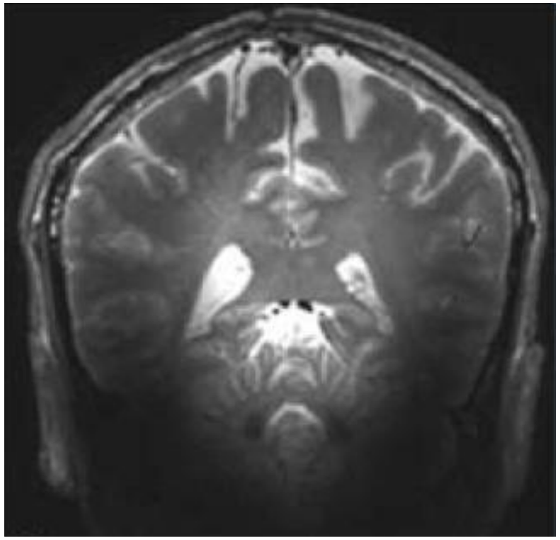
MR angiography
small vessel disease

Cartilage for early
stage osteoarthritis



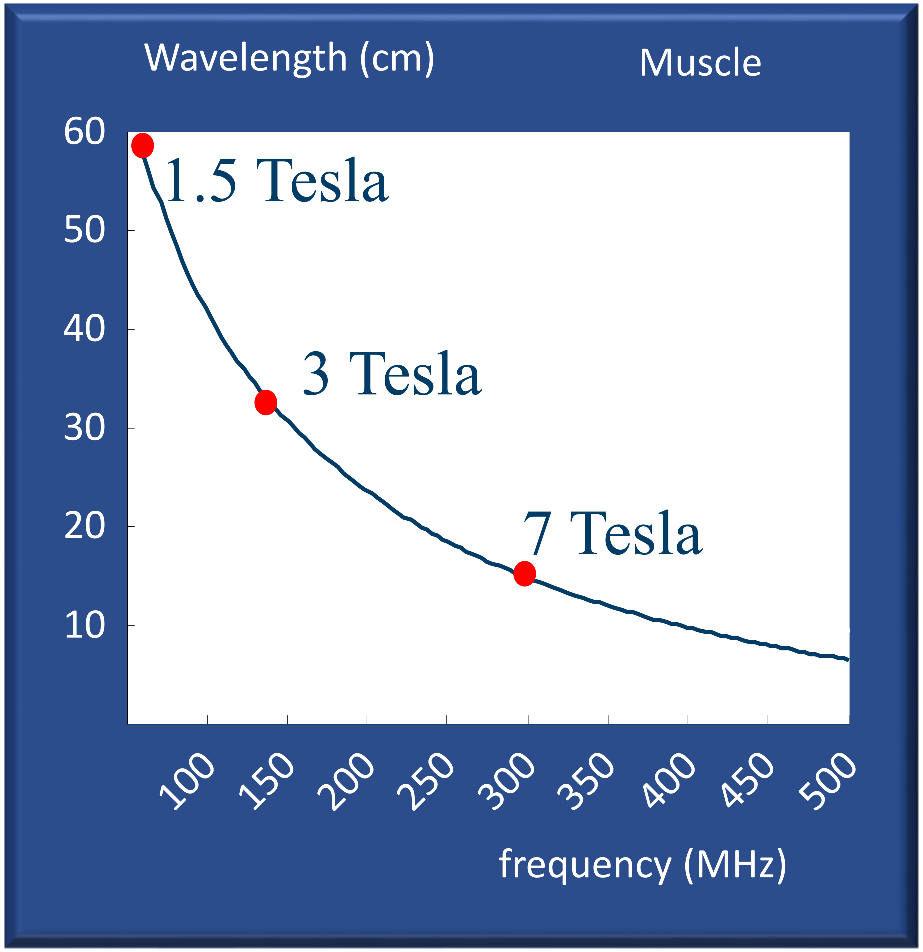
Coronary artery
early stenosis

Does it work first time?

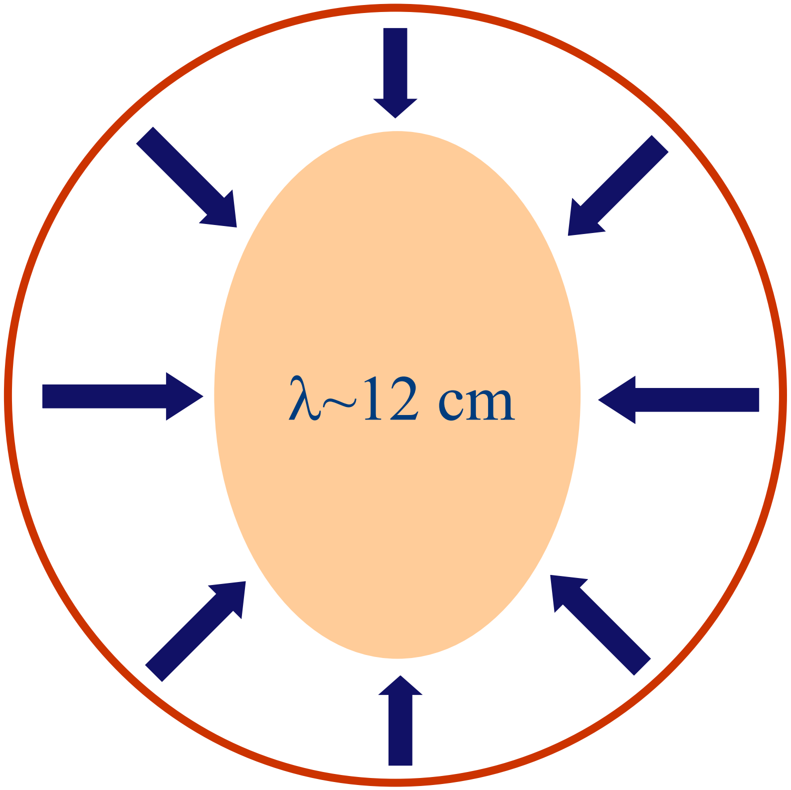
Effects of finite RF wavelength in tissue

$$\lambda_{tissue} \propto \frac{1}{f\sqrt{\varepsilon_r}}$$



$\varepsilon_r \sim 60$

RF inhomogeneity
constructive/destructive interference



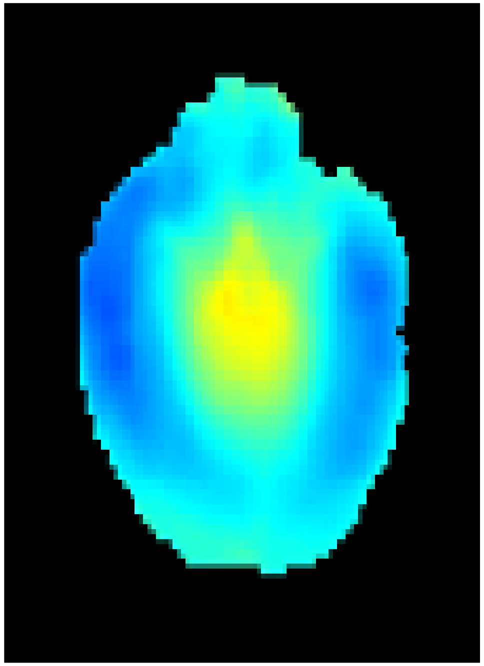
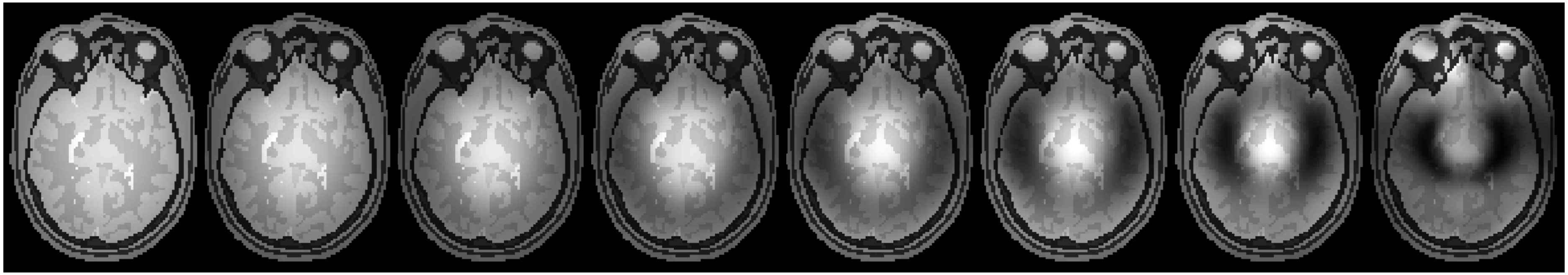
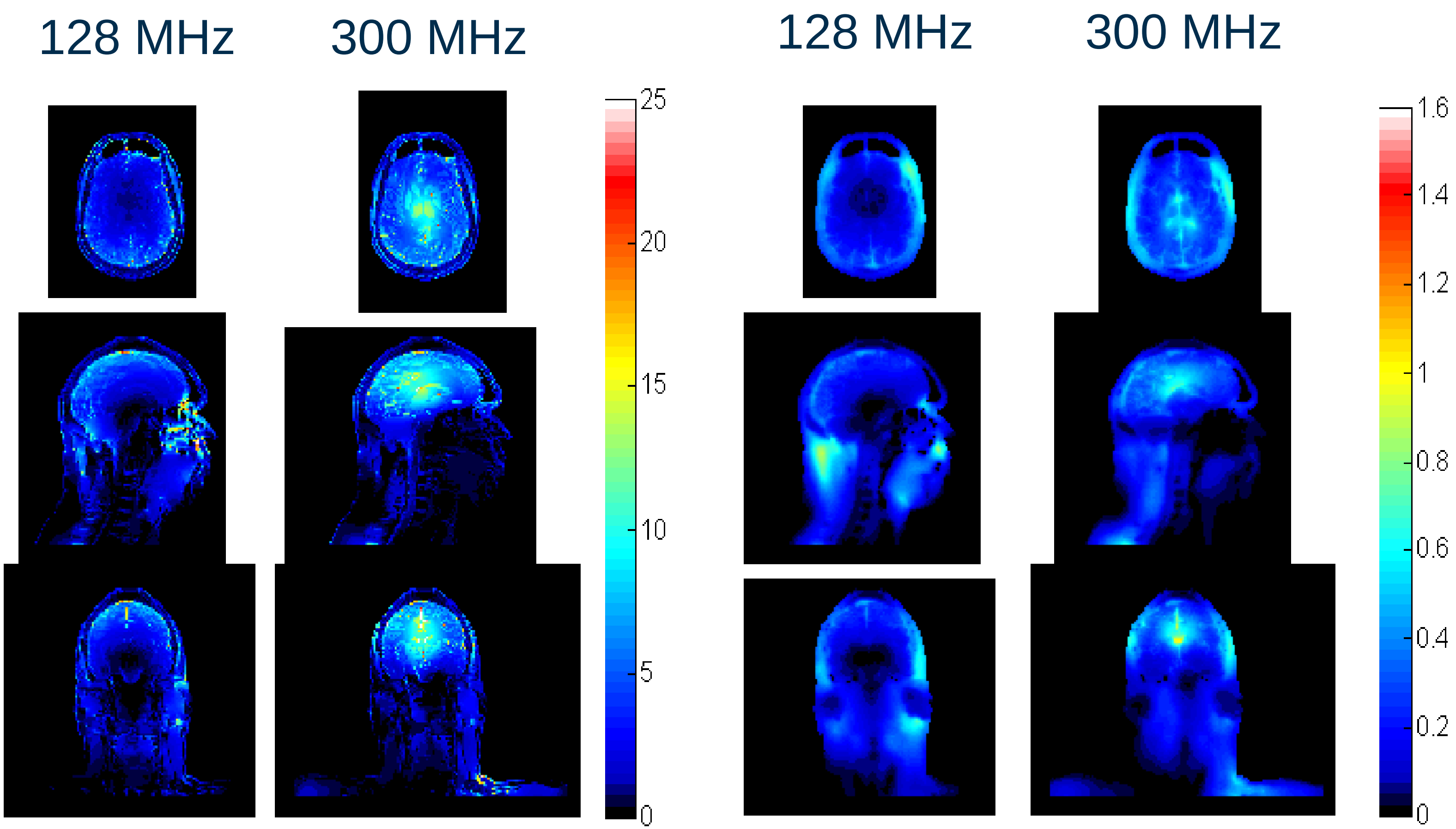


Image non-uniformities at high field

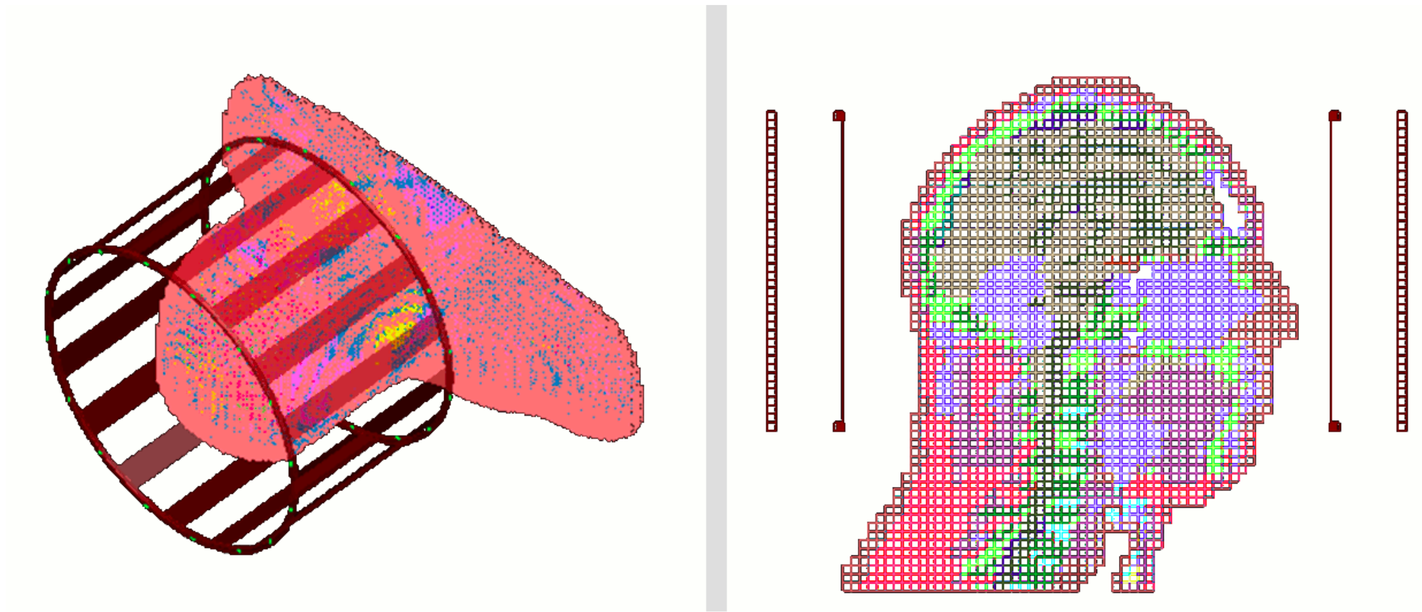


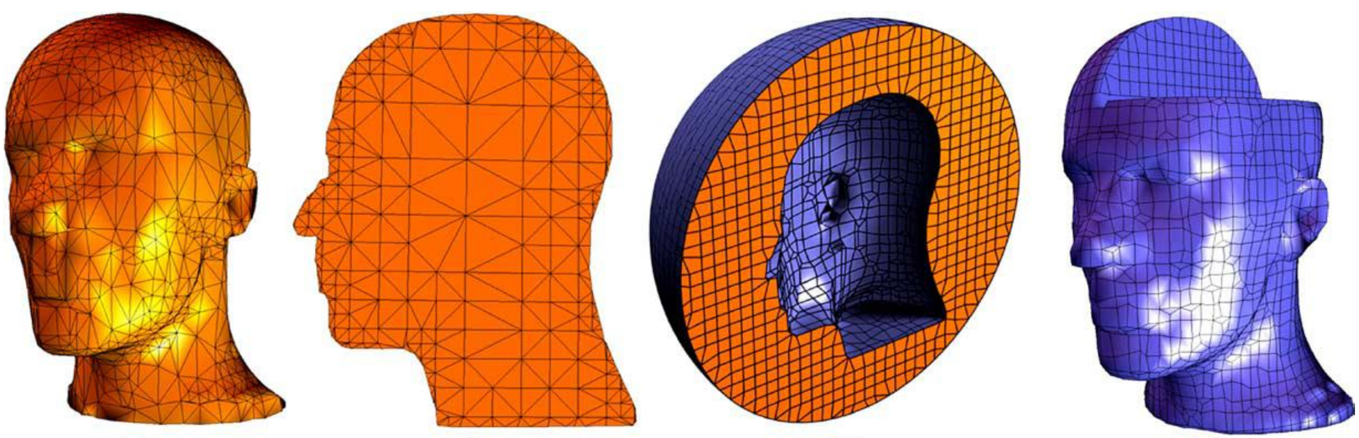
3T 4T 5T 6T 7T 8T 10T 12T

Increased SAR and heating at 7T



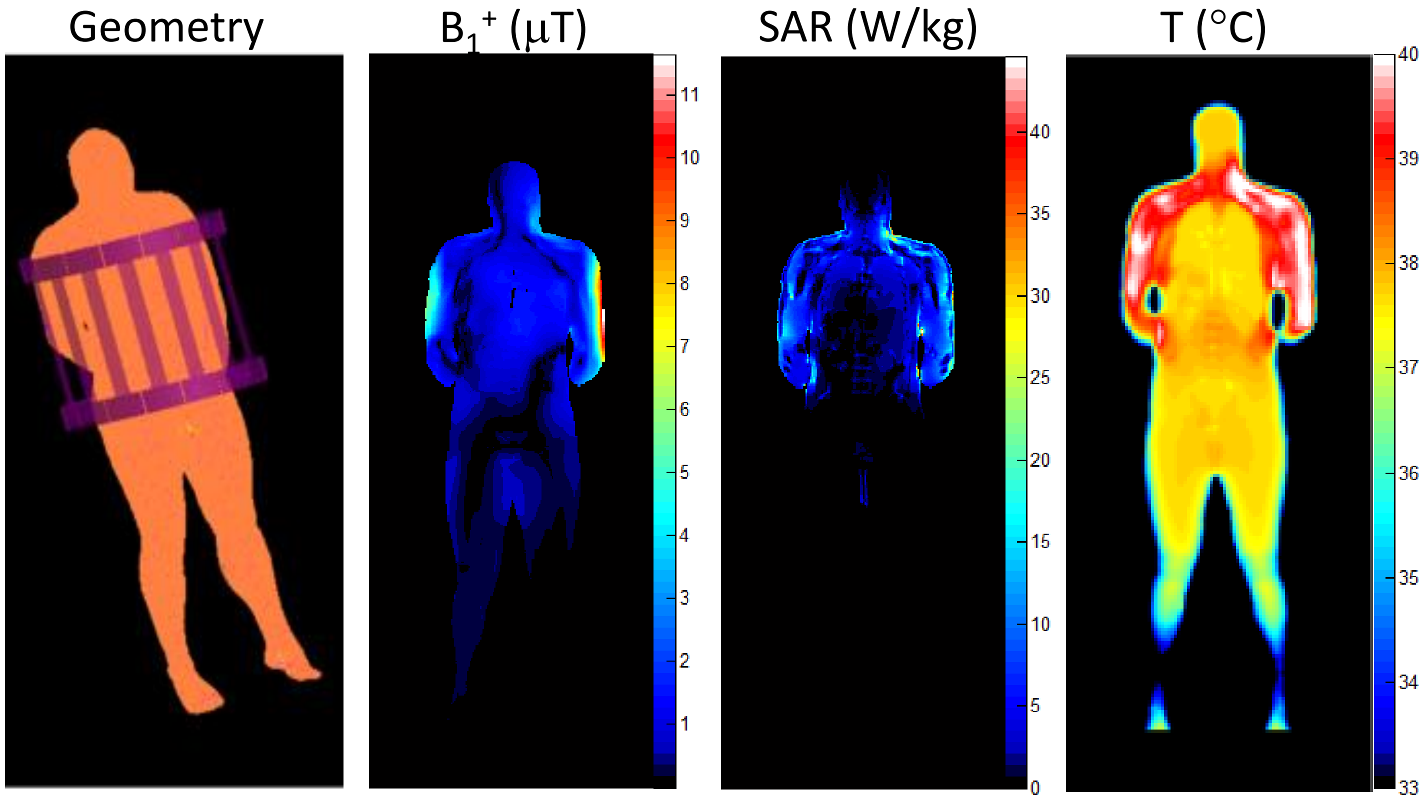
EM modelling





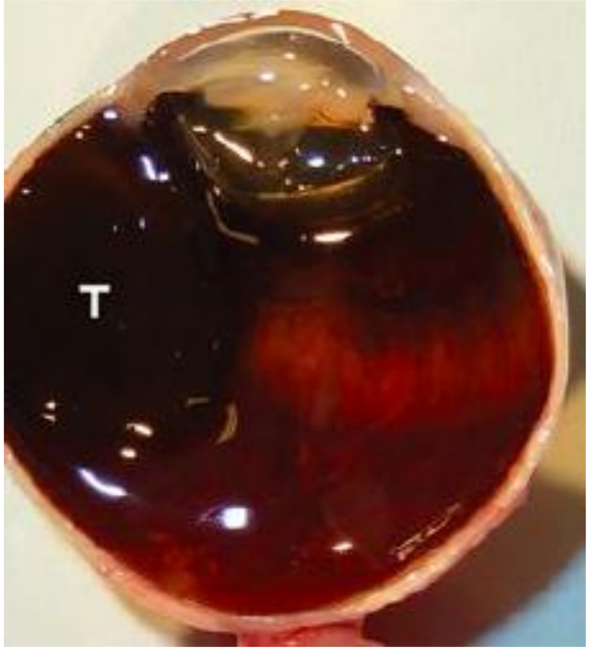
(a) (b) (c) (d)

EM modelling



Uveal melanoma and treatment planning

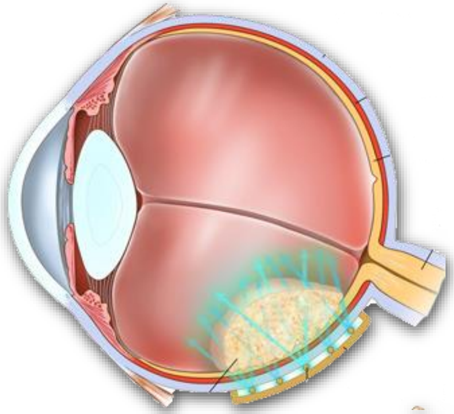
LUMC is Netherlands Center for uveal melanoma
200-300 patients per year

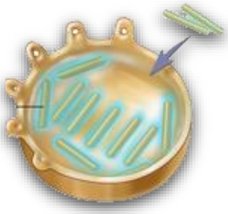


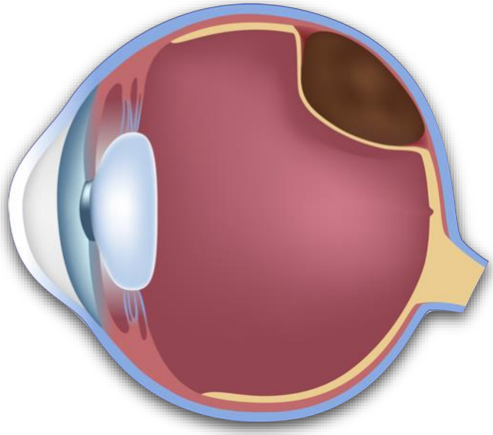
Treatment options

Enucleation

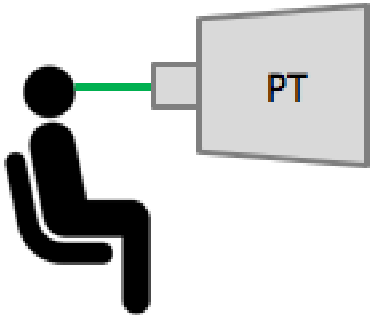
Radiotherapy







External beam therapy

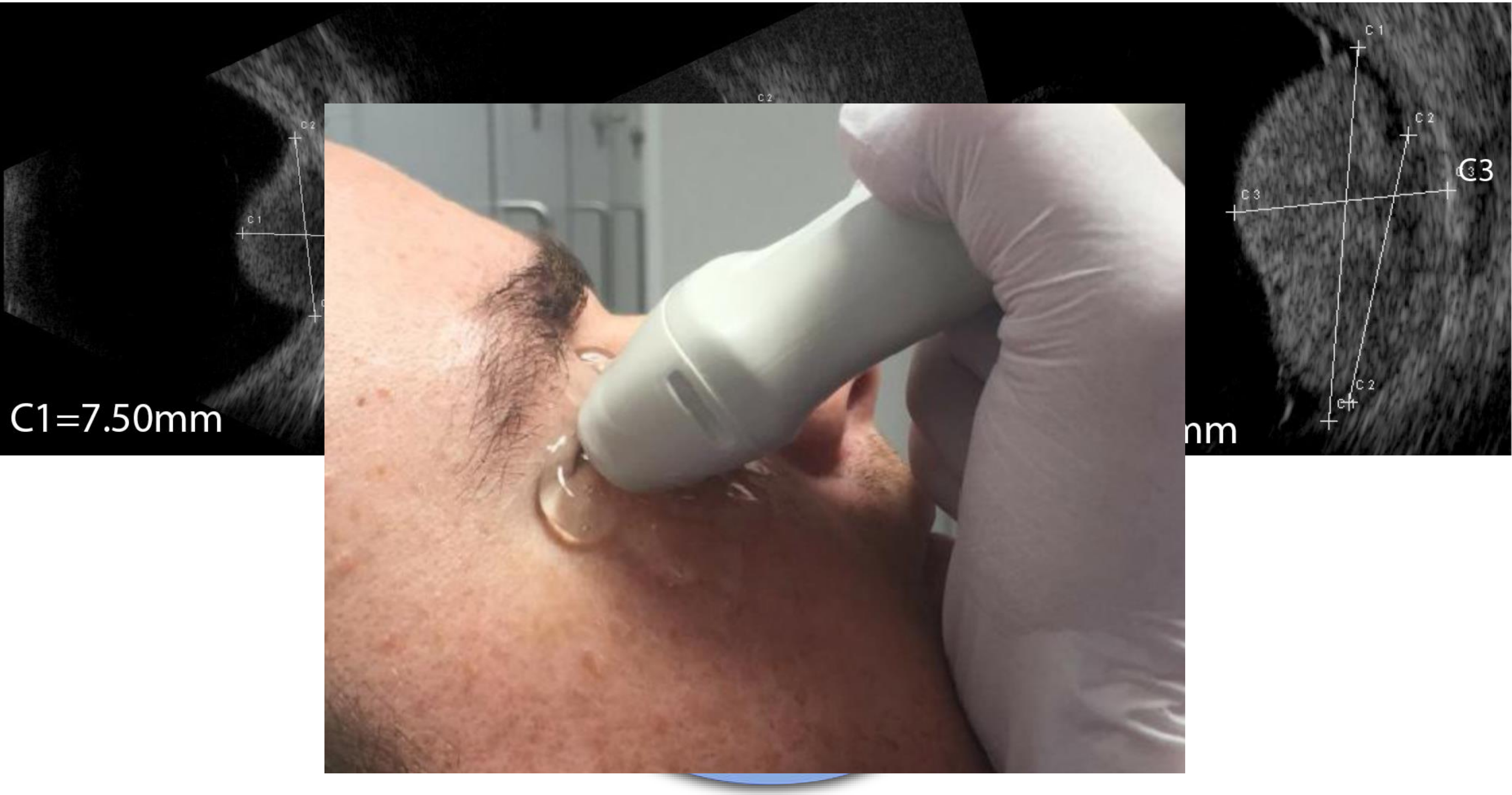


Ruthenium plaque therapy

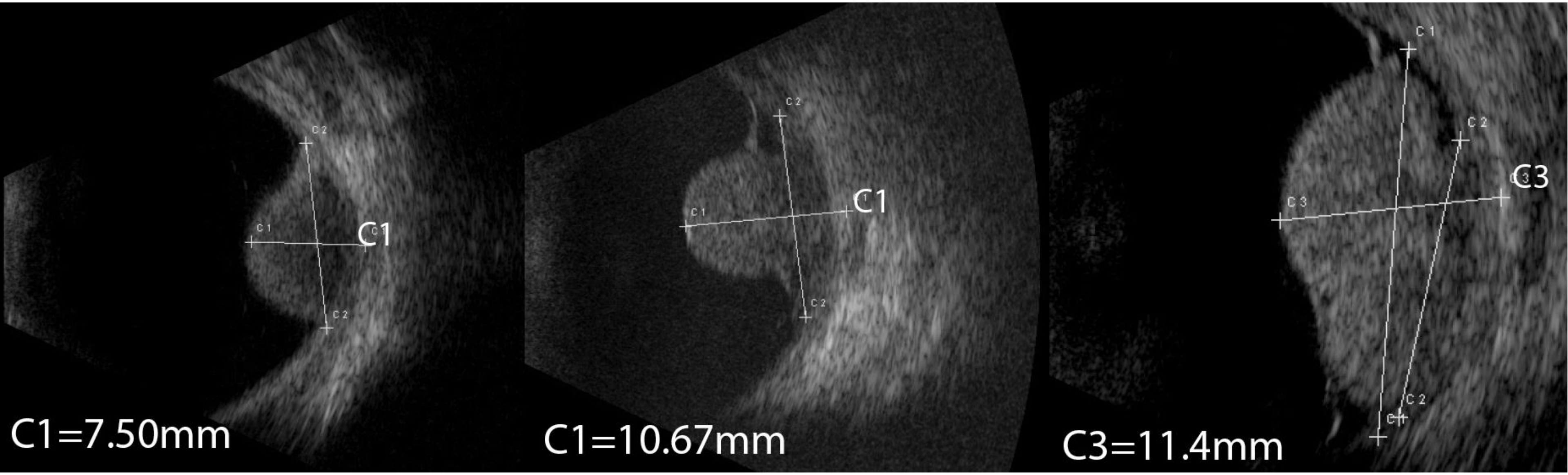
For a patient to be eligible for ruthenium plaque brachytherapy the maximum tumour prominence is 7 mm.

For tumour prominences greater than 7 mm the eye is removed.

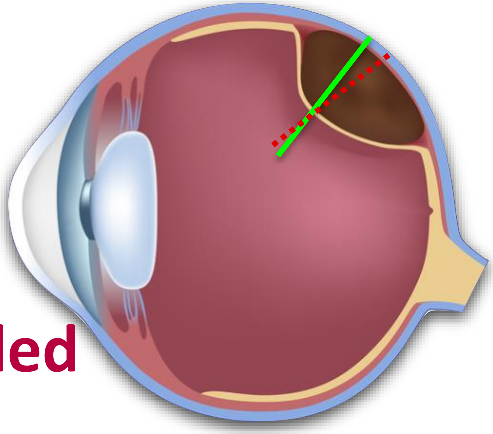
Ultrasound



Ultrasound

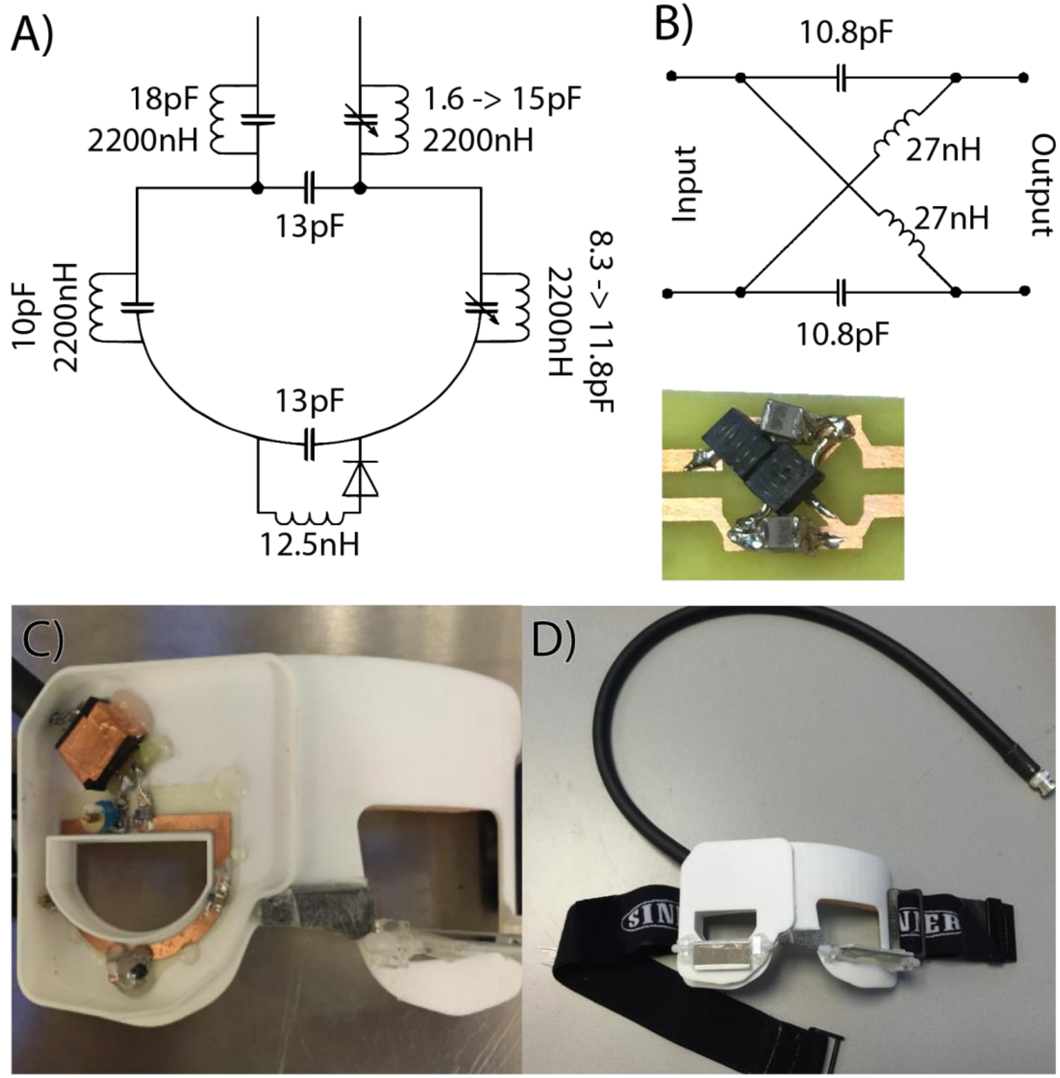


- Only 2D cross-sections
  - Oblique cross-sections typically overestimate tumour size
  - Inadequate for large, complexly, shaped tumours
- Low contrast between tumour and sclera

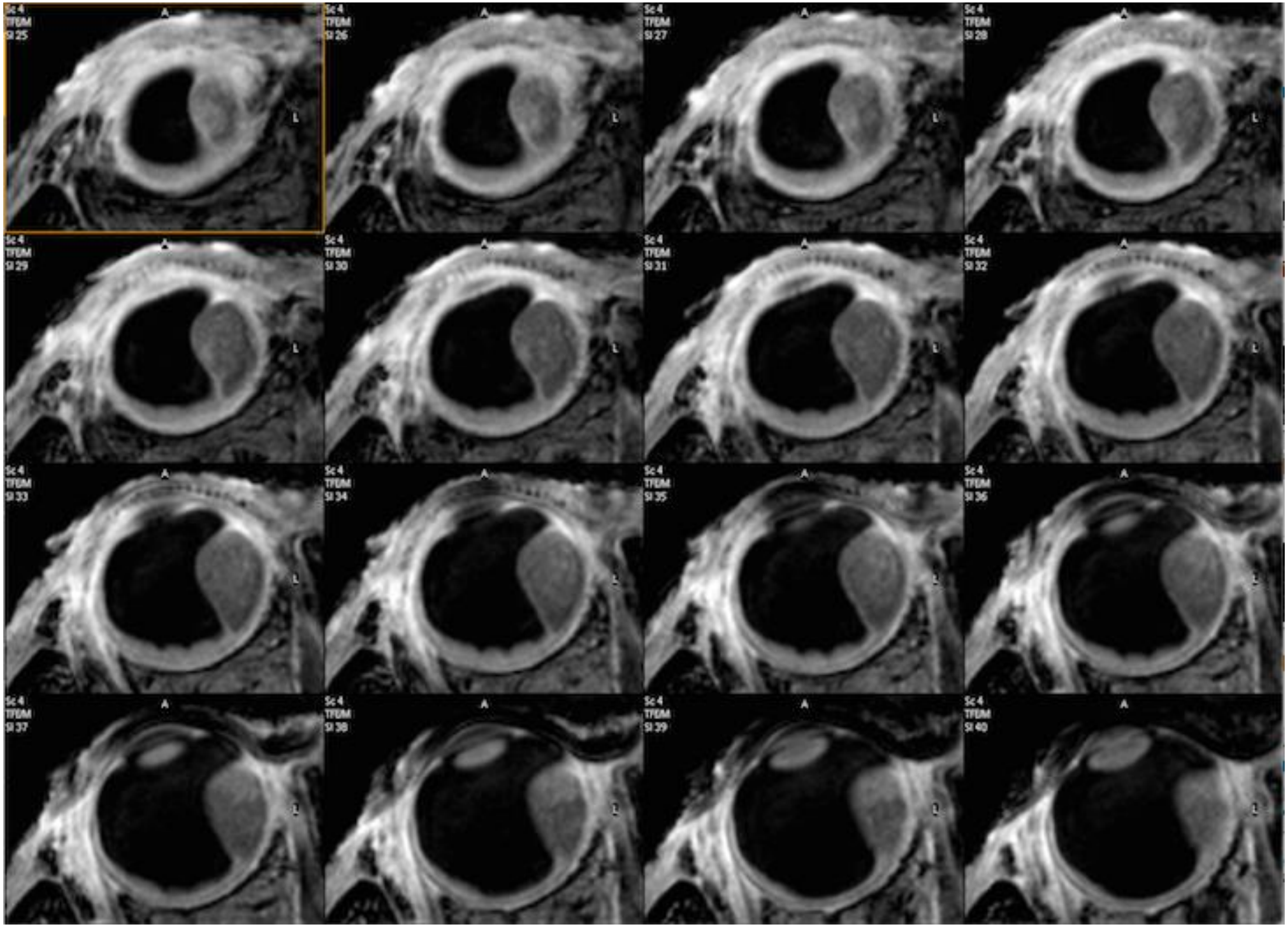


3D imaging technique with better contrast needed

High resolution imaging of the eye

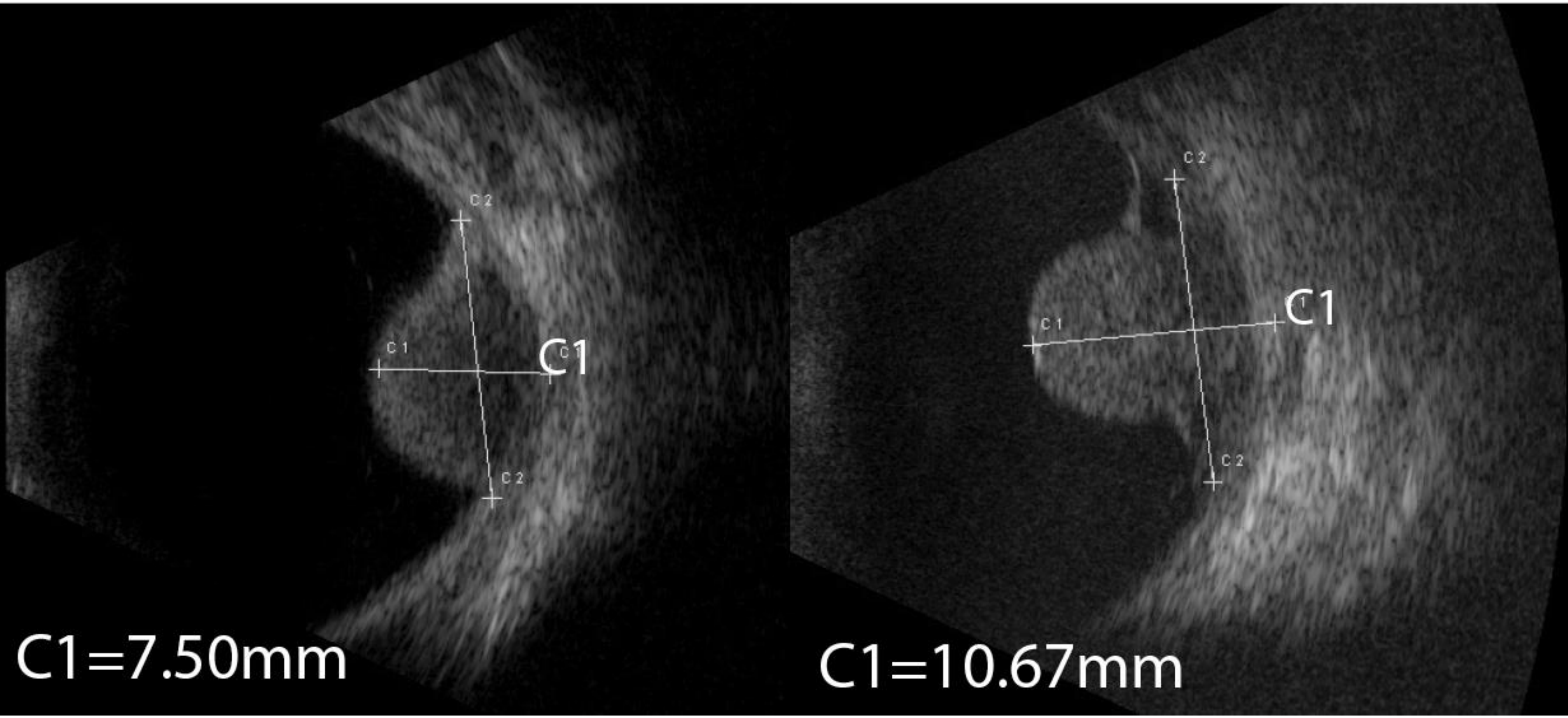


Uveal melanoma patients



Two patients

Patient 1 Patient 2



Two patients

Patient 1 – MRI-estimated tumour prominence was 6.2 mm
Patient 2 - MRI-estimated tumour prominence was 9.2 mm

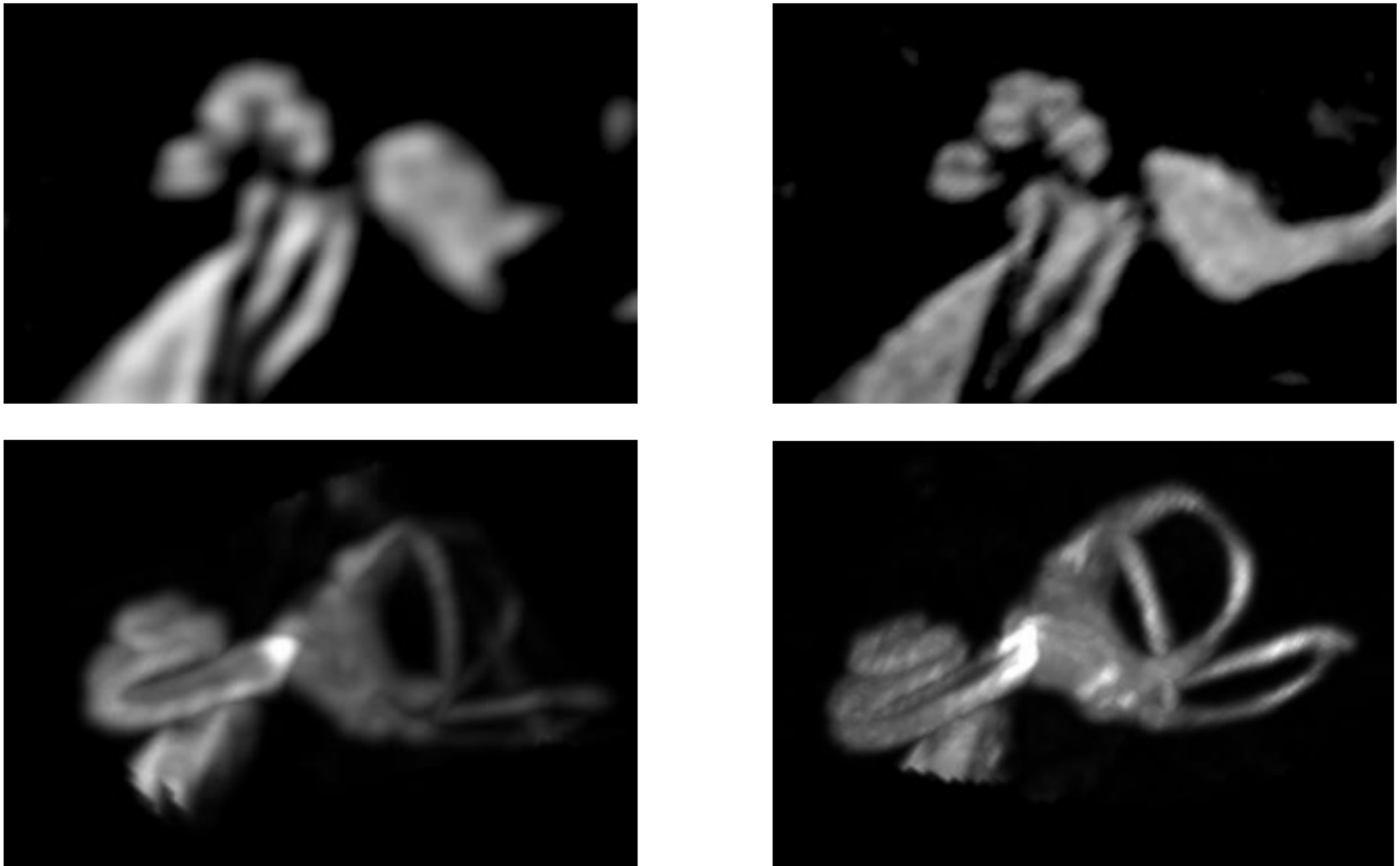
For patient 1, this resulted a substantial change in treatment plan from eye removal (based on the UBM scan) to treatment with ruthenium plaque therapy

A combined evaluation of all the different sequences showed no extra-scleral extension for either patient.

1-2 patients per week are now being referred to the 7T scanner for treatment planning

Imaging patient before cochlear implant

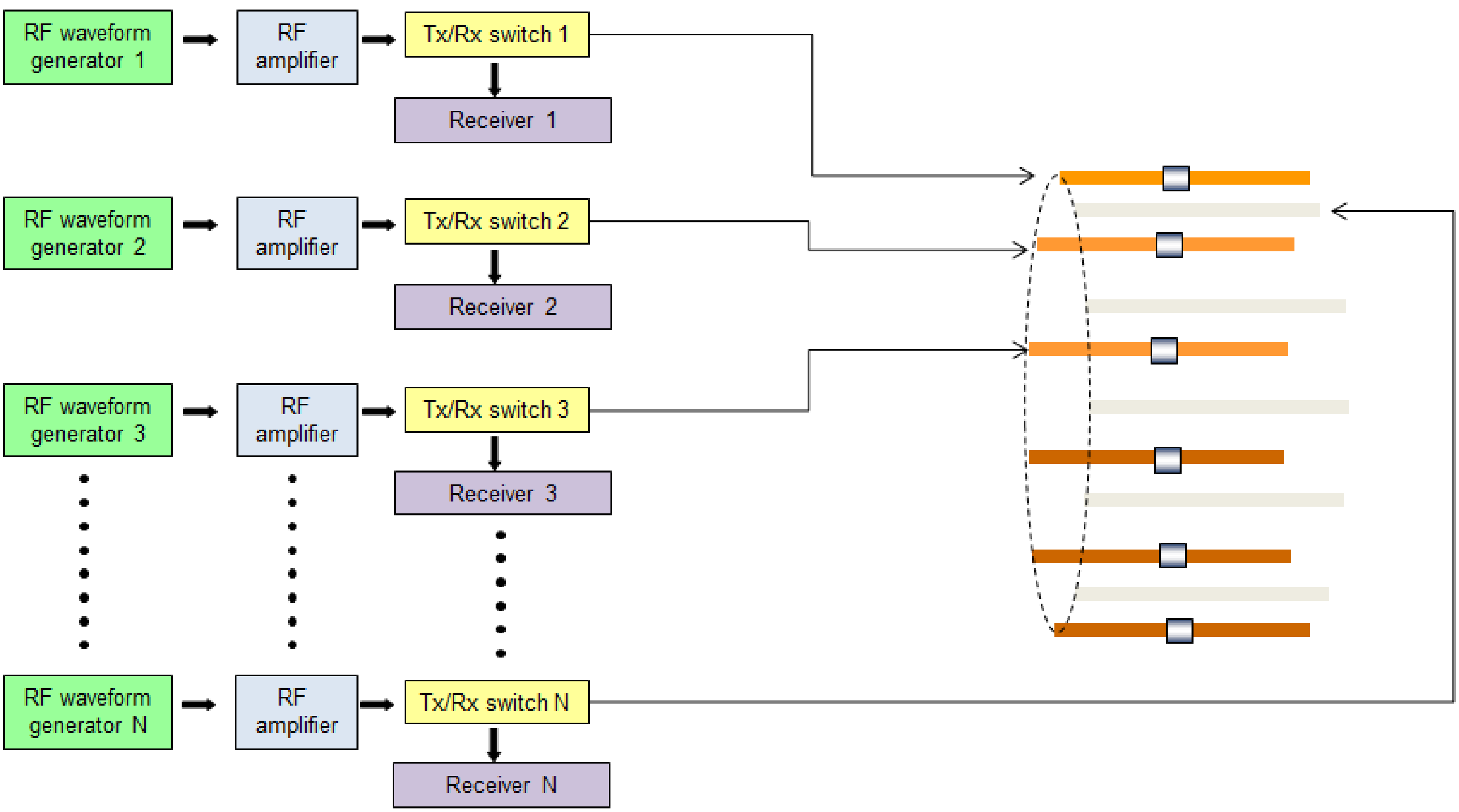
3T | 7T



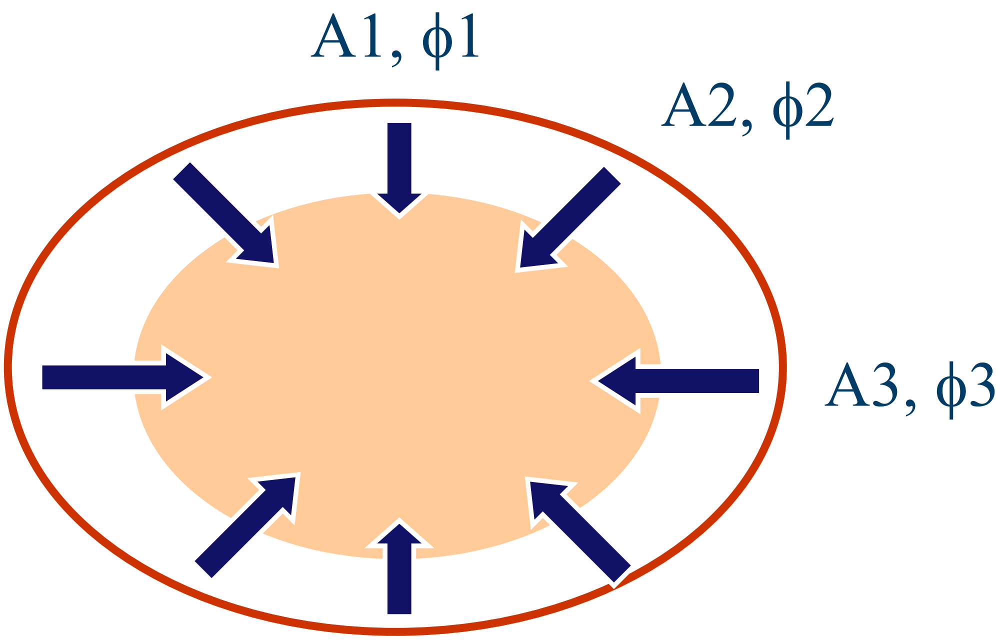
Part 4

RF and image inhomogeneities

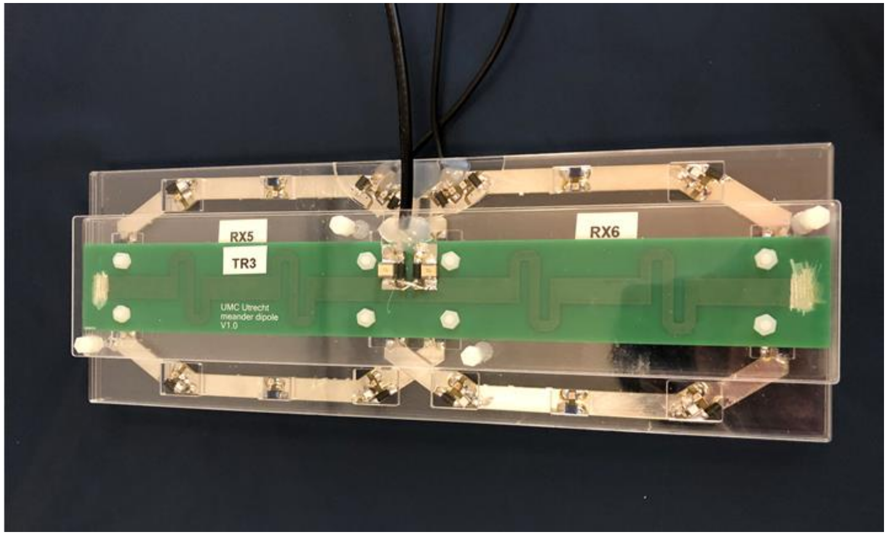
B1 inhomogeneity – parallel transmit approach



Parallel transmit approach



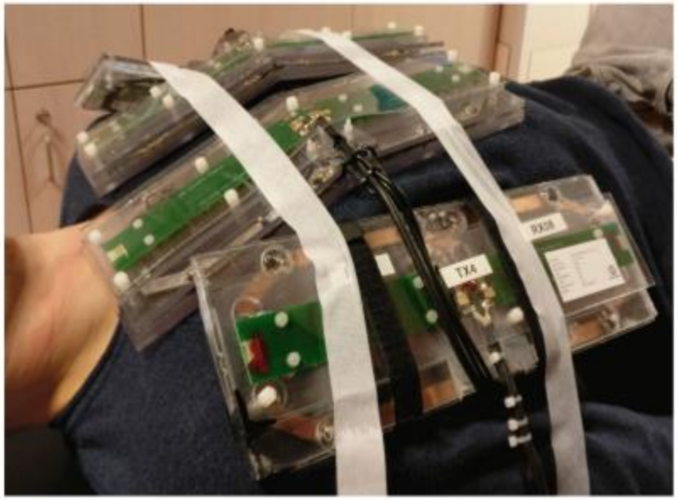
Multi-element dipole antennas



a

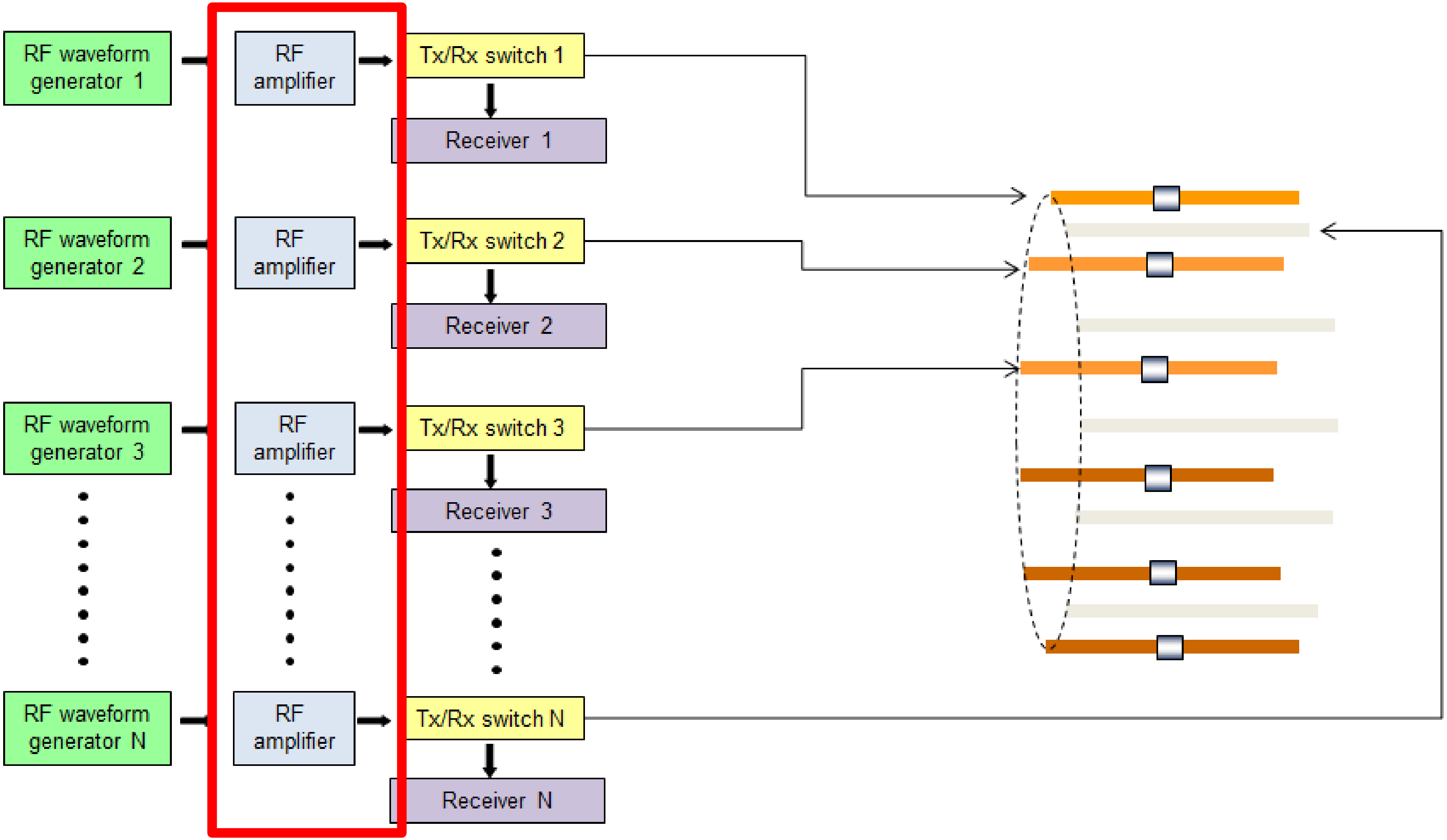
b

c



First attempts in vivo on the 7 Tesla

Parallel transmit approach



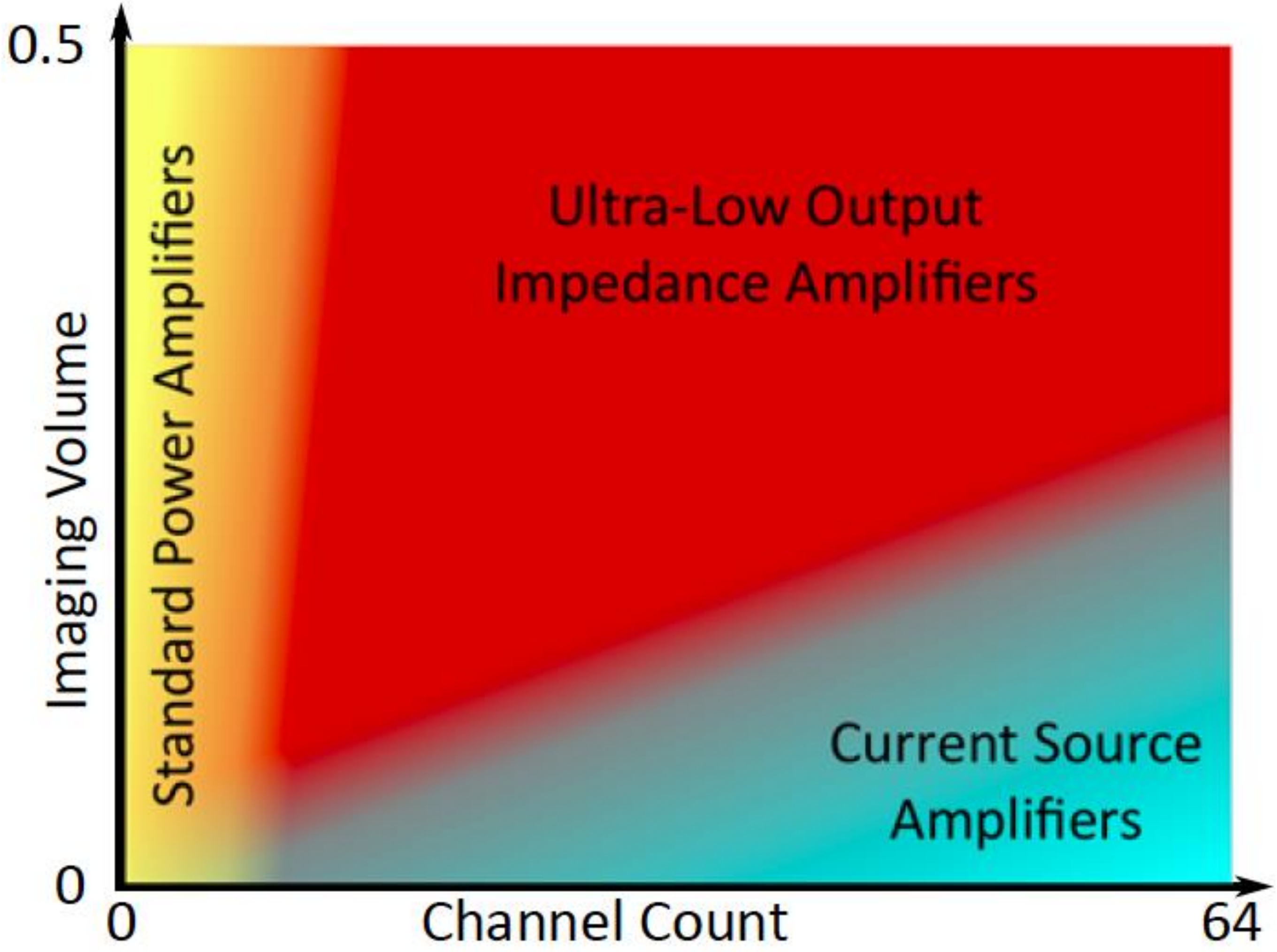
Improving the RF amplifiers?

Class A/B amplifiers
Broadband

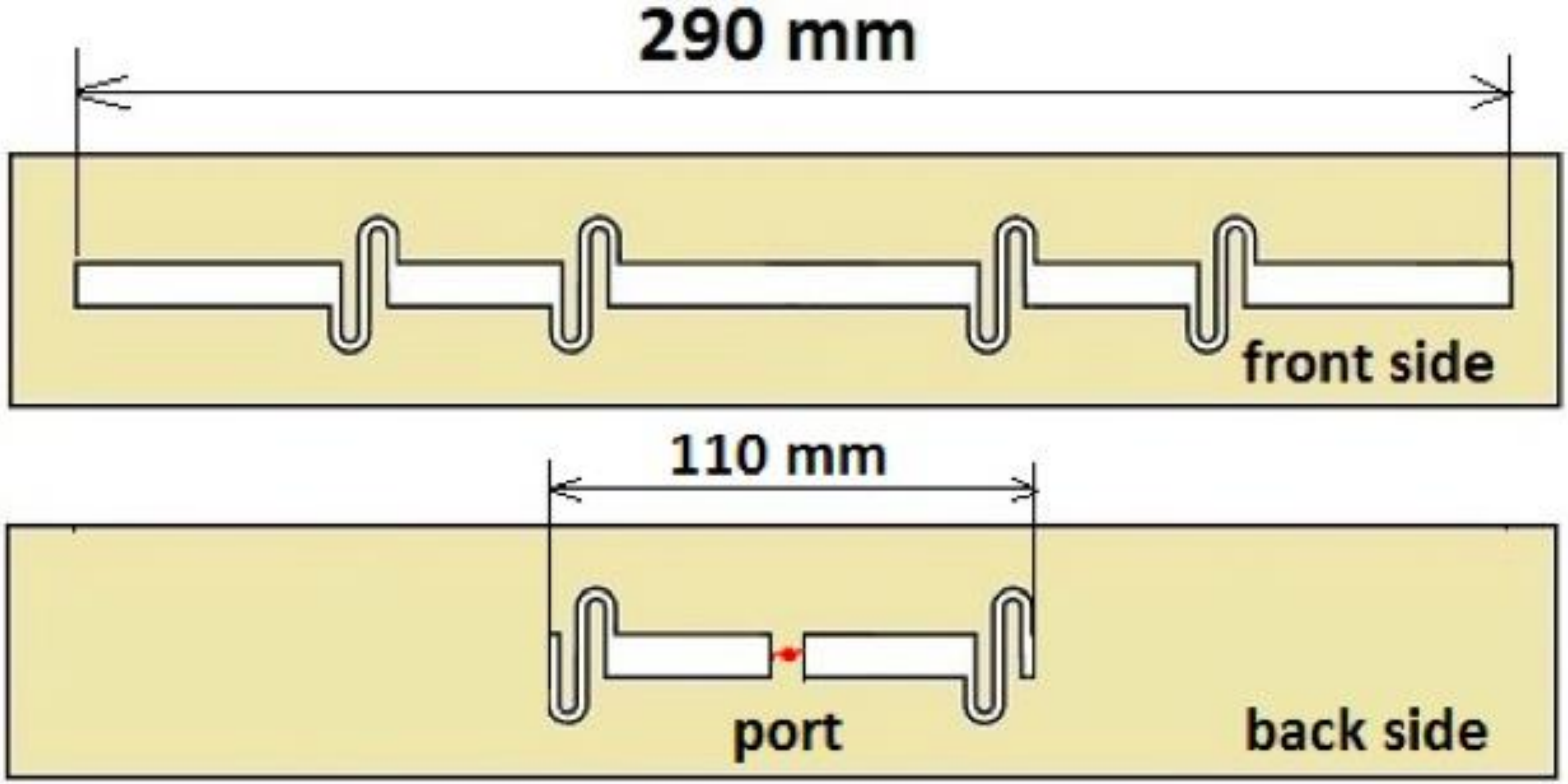
Class D?
Class E?
Class H?

On coil amplifiers to avoid enormous power losses in cables

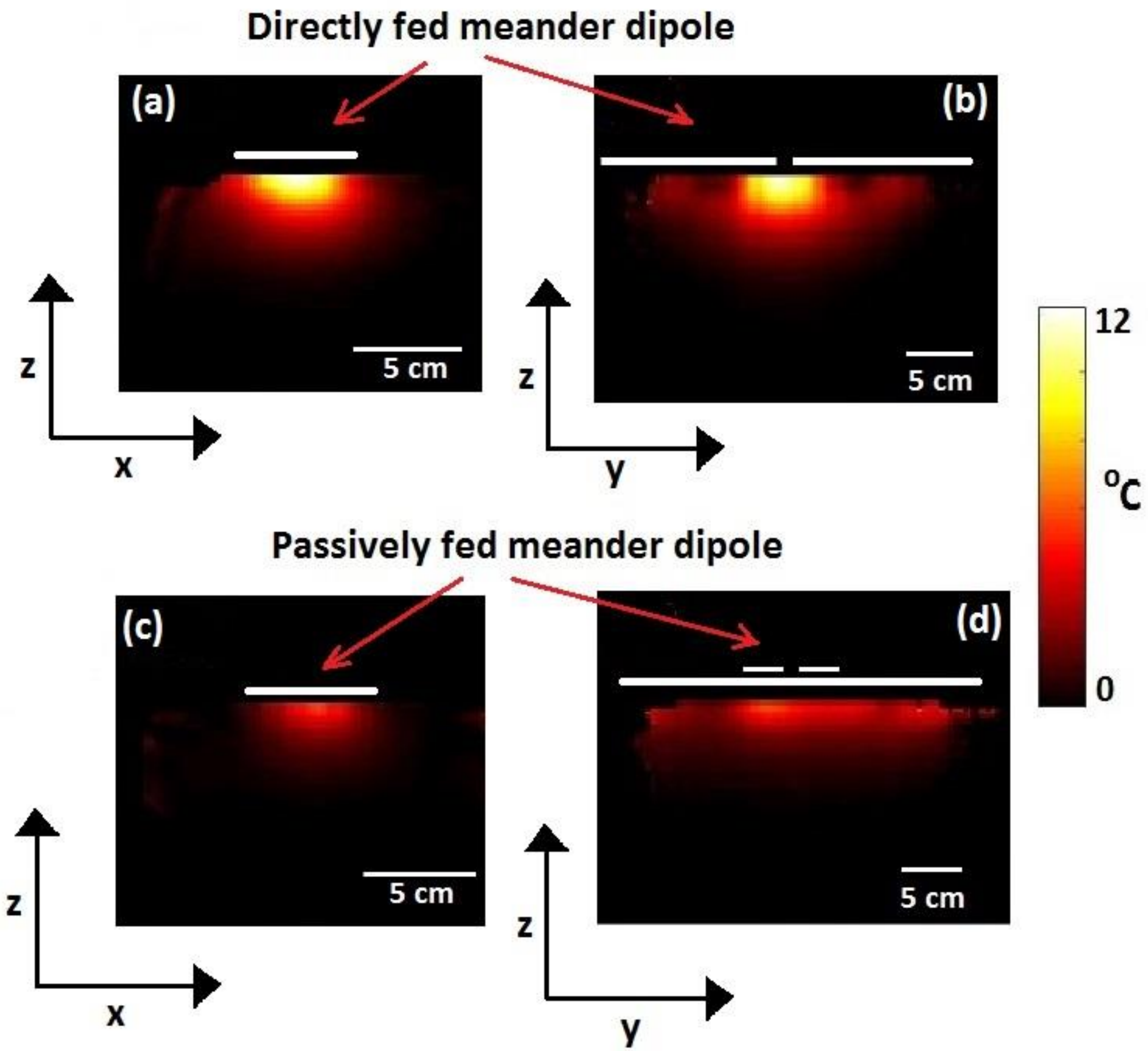
Different types of amplifiers



Passively vs. actively fed dipoles



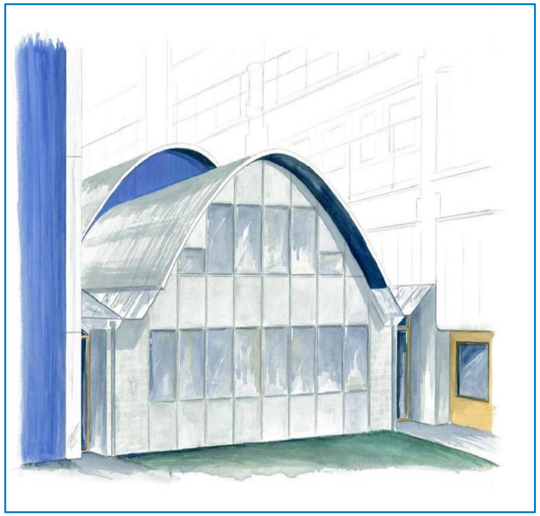
Passively vs. actively fed dipoles



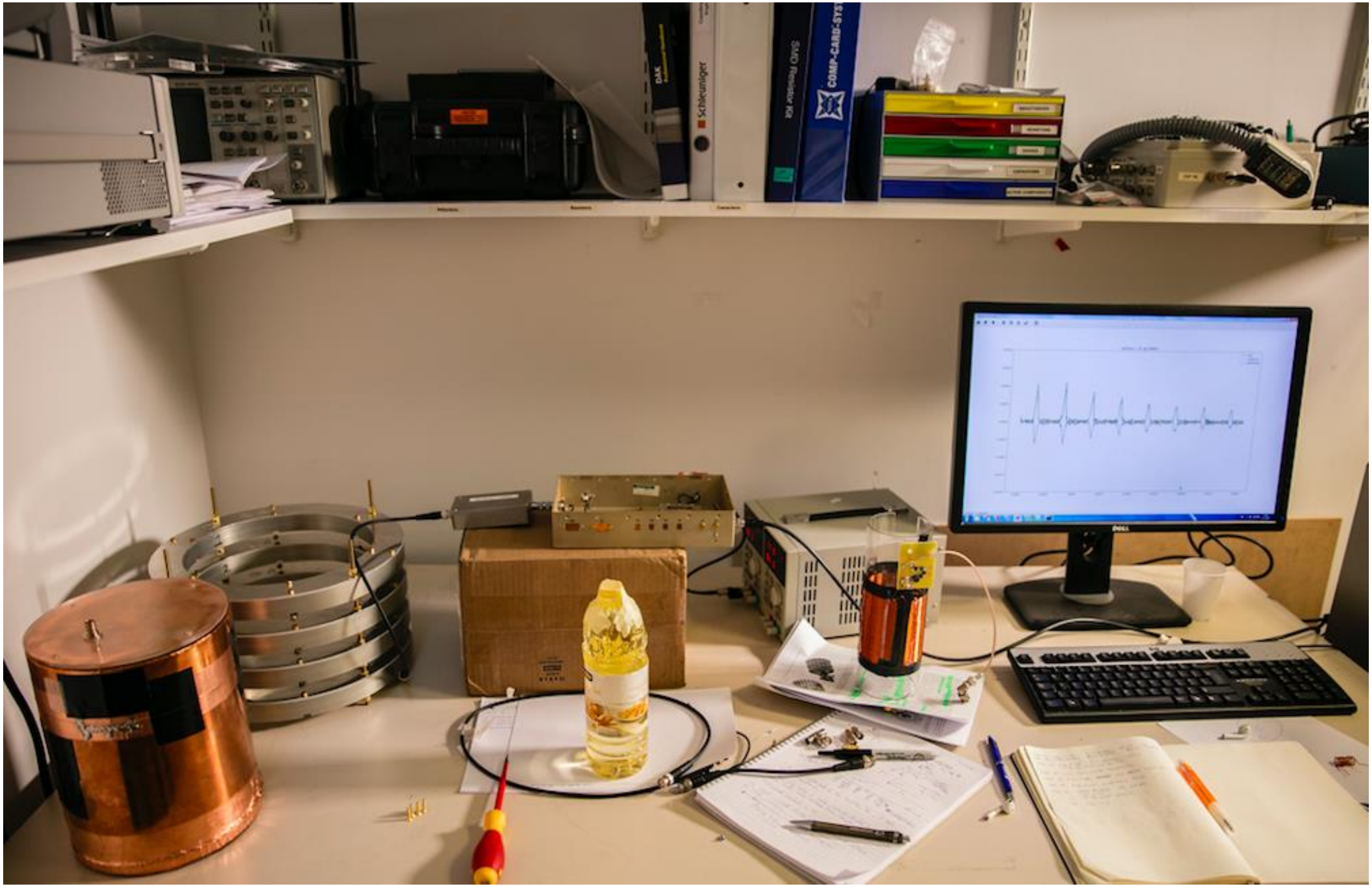
Leiden University Medical Center

TU Delft

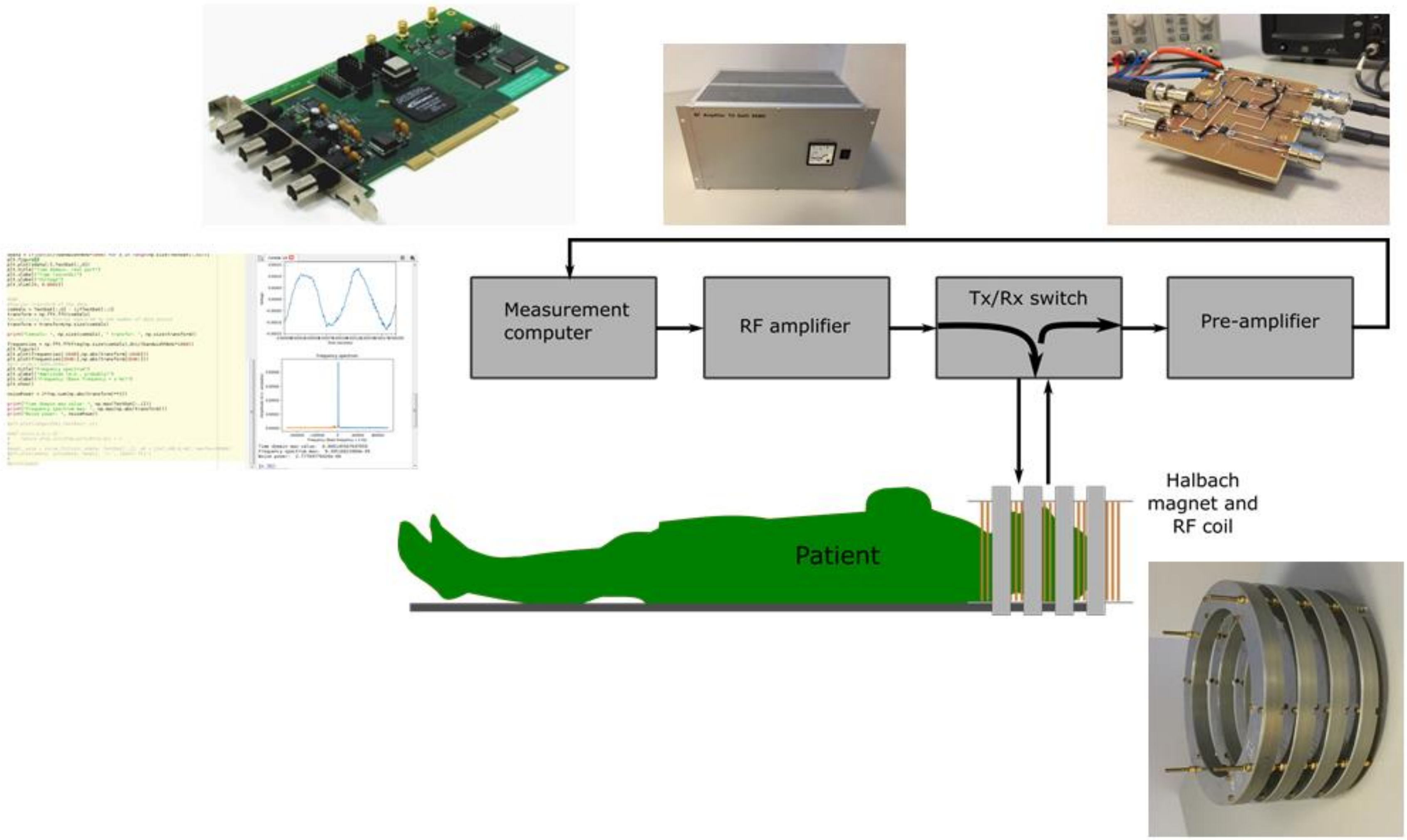
5. Ultra-low field sustainable MRI for developing countries



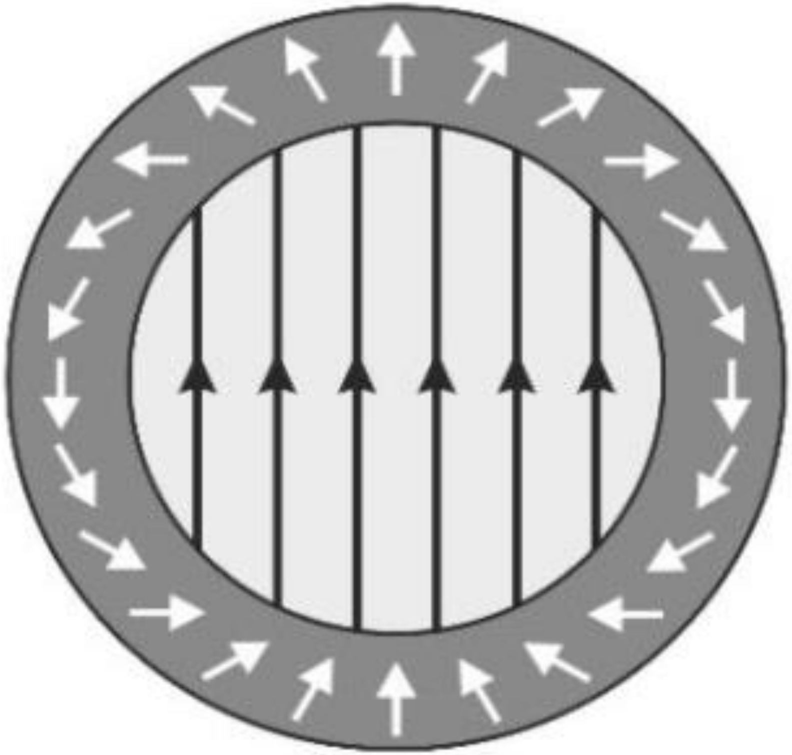
First prototype system 2018

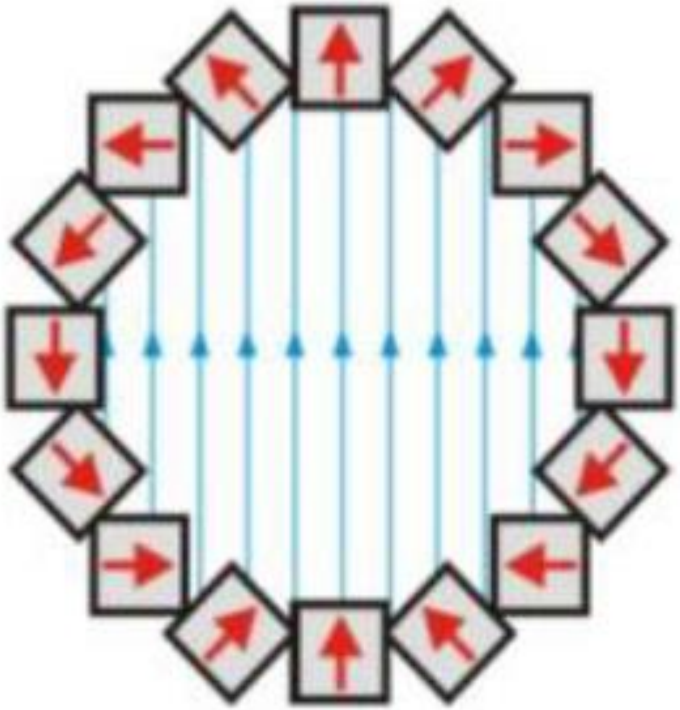


The system

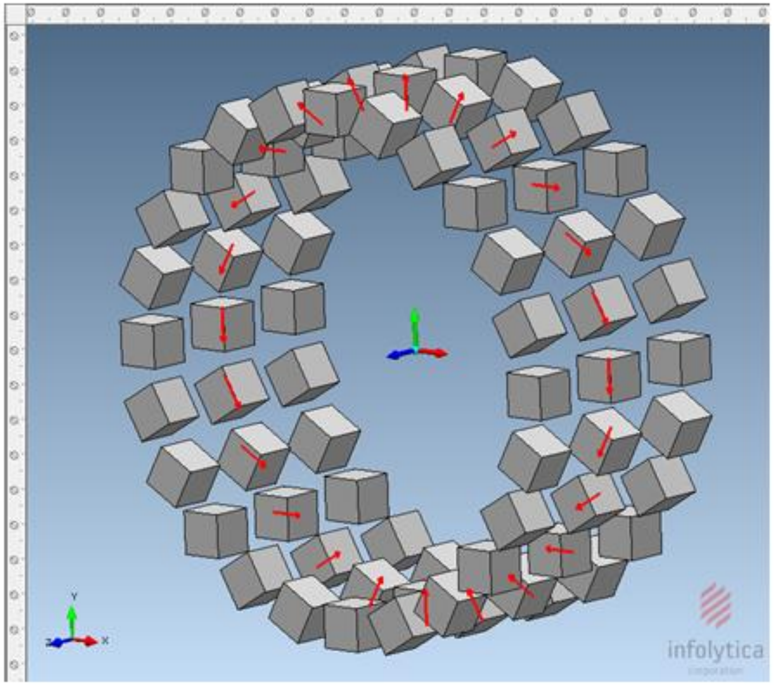

Measurement computer
RF amplifier
Tx/Rx switch
Pre-amplifier
Halbach magnet and RF coil
Patient

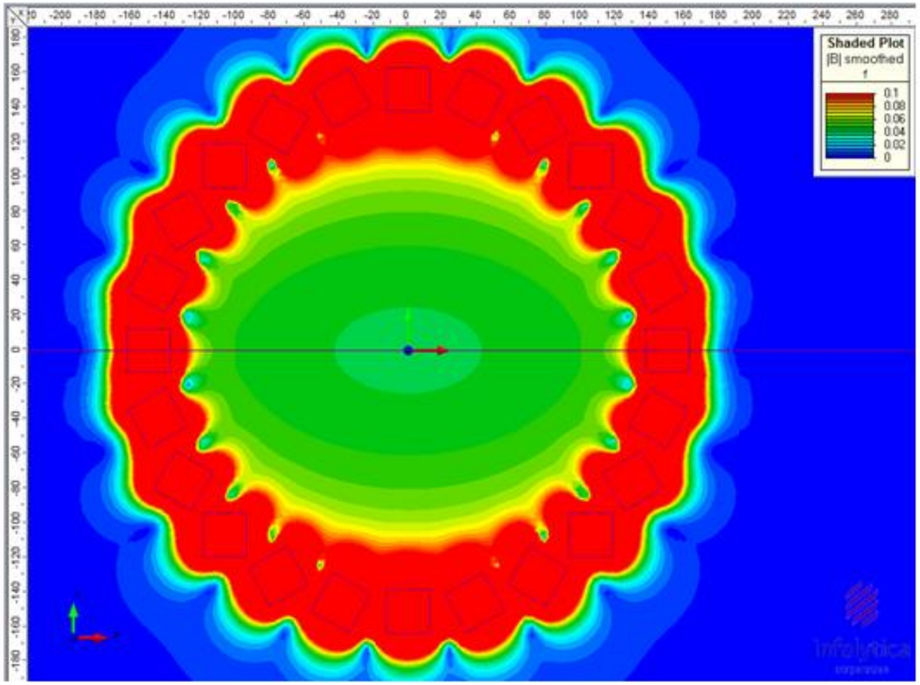
A Halbach magnet – NdBFe material





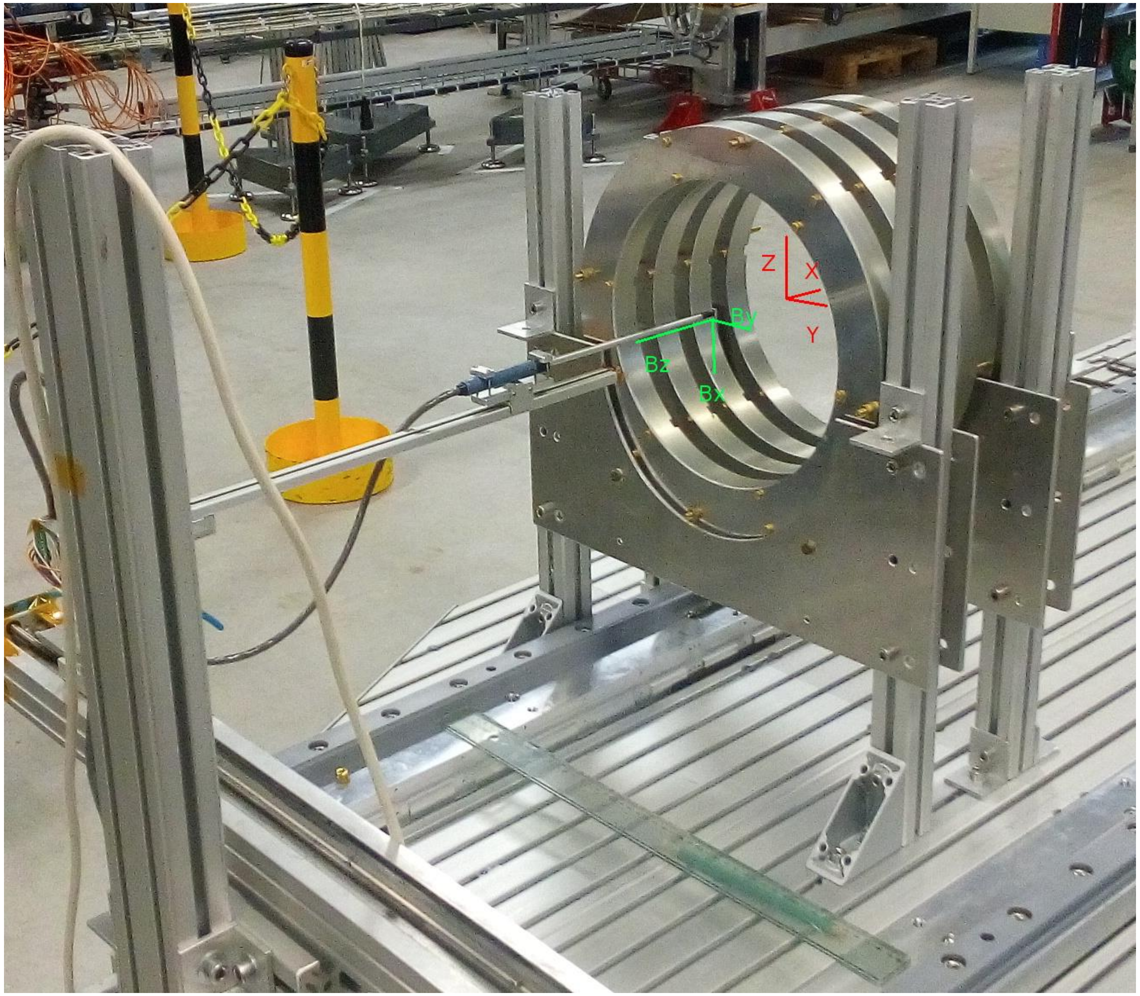
First iteration modelled



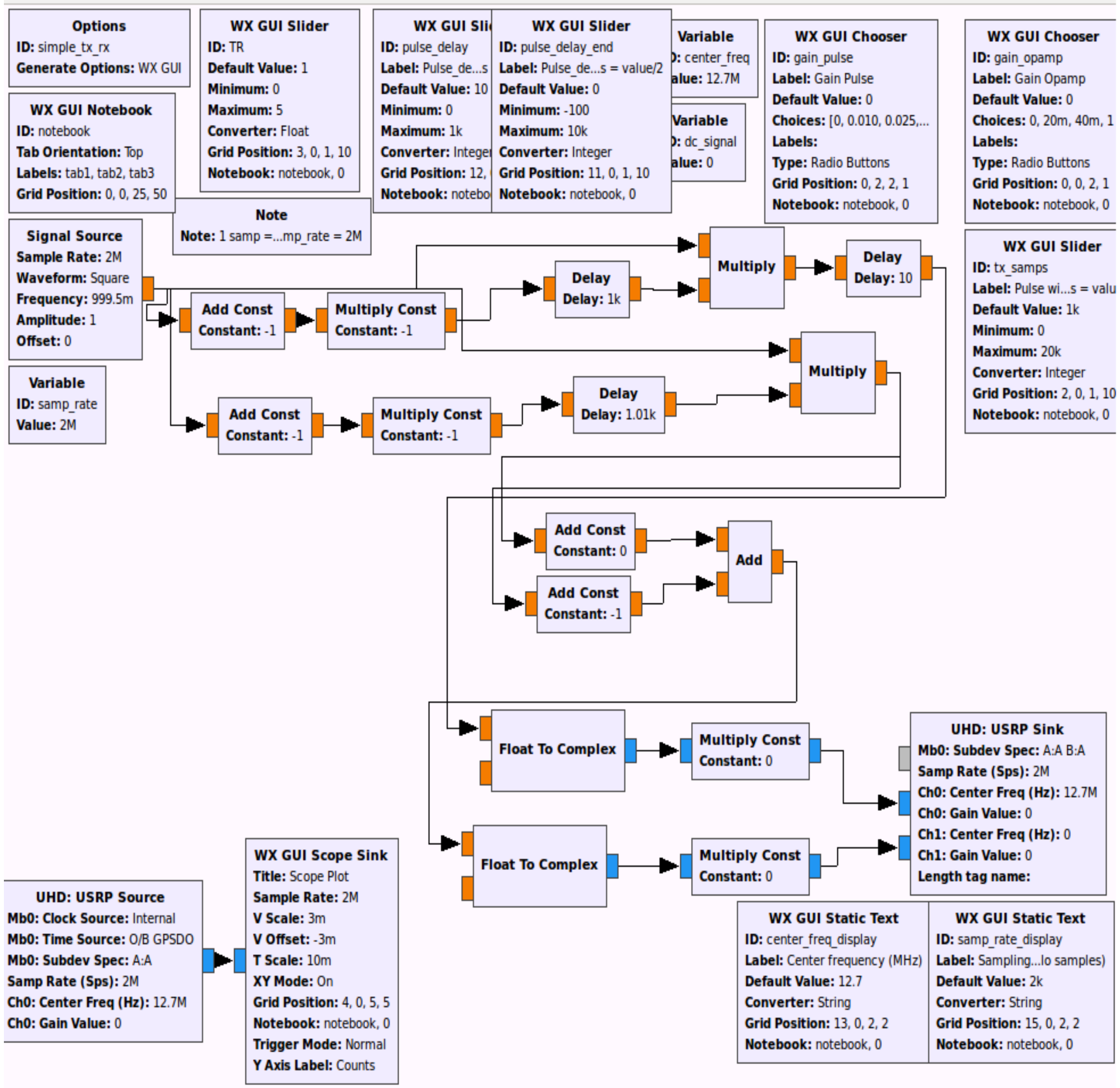


Central frequency 2.5 MHz

And built

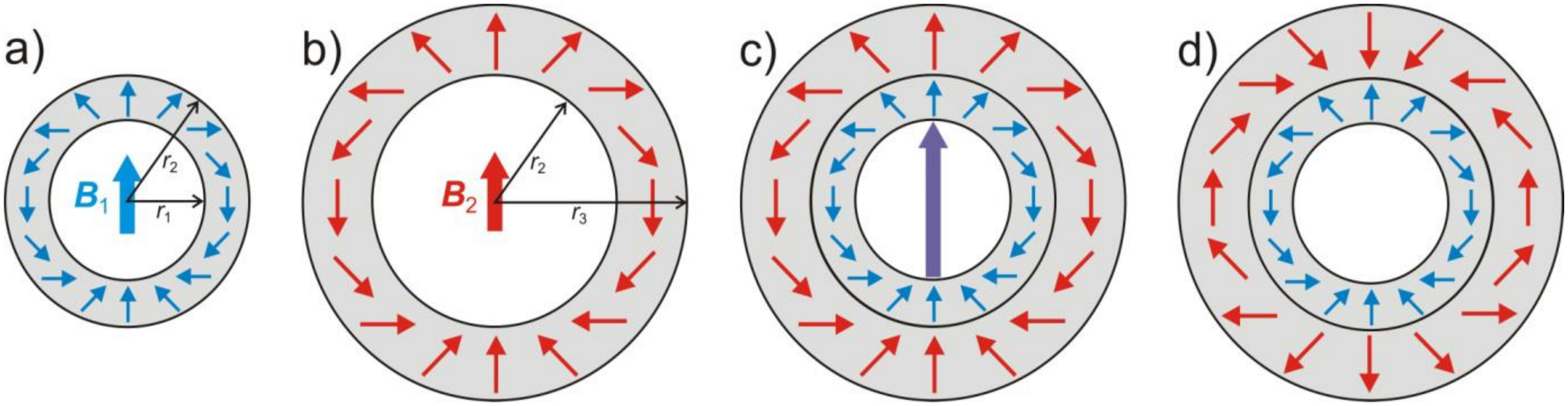


First software written – open source platform



How to spatially encode i.e. get an image

Two ring magnet and rotate the outside one



Collaboration with signal processing from TU Delft

Image reconstruction

The MR physics in a Halbach array are simulated. Different SNRs are investigated. Due to the inhomogeneity of the field, we use model-based image reconstruction, which leads to a linear least-squares system

$$\mathbf{s} = A\mathbf{x} + \mathbf{n}, \qquad (1)$$

in which $\mathbf{s}$ is the measured signal, A is a known matrix that represents the model, $\mathbf{s}$ is the initial magnetisation (the unknown image) and $\mathbf{n}$ is the noise vector. The noise is assumed to be Johnson noise. In order to suppress the noise, total variation regularisation is used, leading to the minimisation problem

$$\min_{\mathbf{x}} ||\mathbf{s} - A\mathbf{x}||_2^2 + \lambda||F\mathbf{x}||_1, \qquad (2)$$

where λ is the regularisation parameter and F is an operator that calculates the value of the jumps between neighbouring pixels. The alternating directions method of multipliers is used in conjunction with conjugate gradient to solve the minimisation problem.

Steps to improve performance in next 5 years


Figure 4.7: Boost rev2.0, 85 mmX36 mmX18 mm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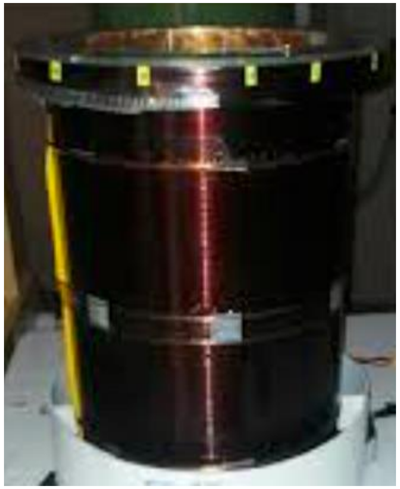
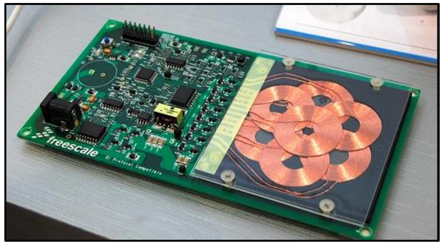
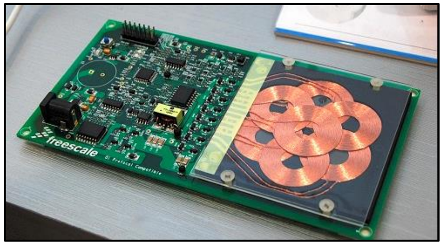
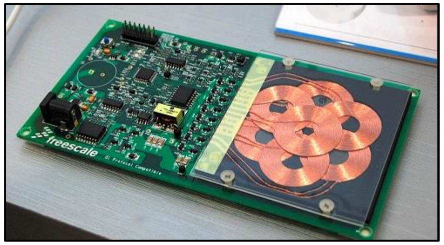
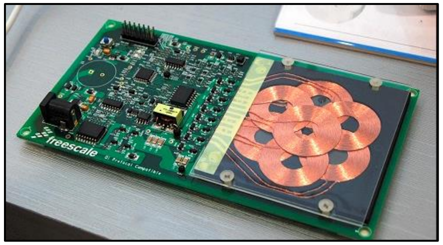
Steps to improve performance in next 5 years











Acknowledgements

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