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Hochschule Mannheim

## Bildgebende Systeme in der Medizin

### Magnetresonanztomographie IV:

#### Radiofrequenz Resonatoren

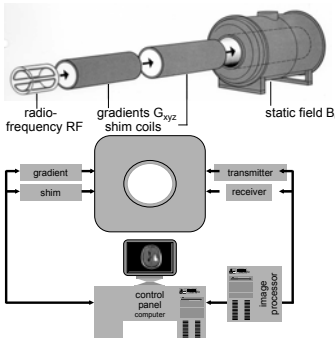
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## MRI Components: Physical Parameters



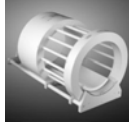
technical component	→	physical parameter
static field $B_0$	→	$M_0$
radiofreq. RF	→	signal
gradients $G_{xyz}$	→	image

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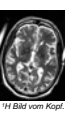
## MRT V:



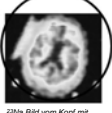
GANOKIPPER  $^{23}\text{Na}$  Bild des Menschen



Doppelresonanter  $^1\text{H}/^{23}\text{Na}$  Kopfresonator für Gehirntumorsuchungen.



$^1\text{H}$  Bild vom Kopf.



$^{23}\text{Na}$  Bild vom Kopf mit eingeschalteter Spule (schwarz).

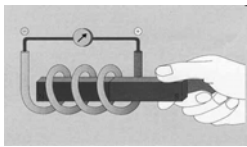
TIM TRIO mit  $^{23}\text{Na}$  Resonanzsystem für MRT bei ST.

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## Maxwellgleichungen 3 + 4 (Dynamische Felder)


3. Ein magnetisches Wechselfeld erzeugt ein elektrisches Feld (Induktionsgesetz)

$$\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$$

$$\oint_{\partial S} \vec{E} \cdot d\vec{l} = -\frac{\partial \Phi_{B,S}}{\partial t}$$


4. Magnetische Felder werden durch gerichtete Ladungsbewegung erzeugt (Bio-Savart)

$$\nabla \times \vec{H} = \vec{J}_f + \frac{\partial \vec{D}}{\partial t}$$

$$\oint_{\partial S} \vec{H} \cdot d\vec{l} = I_{f,S} + \frac{\partial \Phi_{D,S}}{\partial t}$$


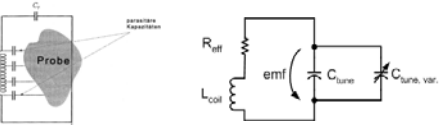
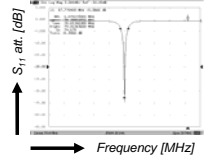
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## Resonanzschwingkreis

Impedanz einer Induktivität:  $Z_L = j\omega L$

Impedanz eines Kondensators:  $Z_C = 1/j\omega C$

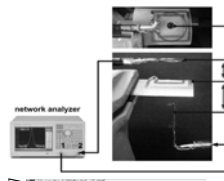
Resonanzfrequenz eines idealen Resonators:  $\omega = \frac{1}{\sqrt{LC}}$   $\omega = 2\pi f$

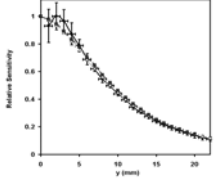
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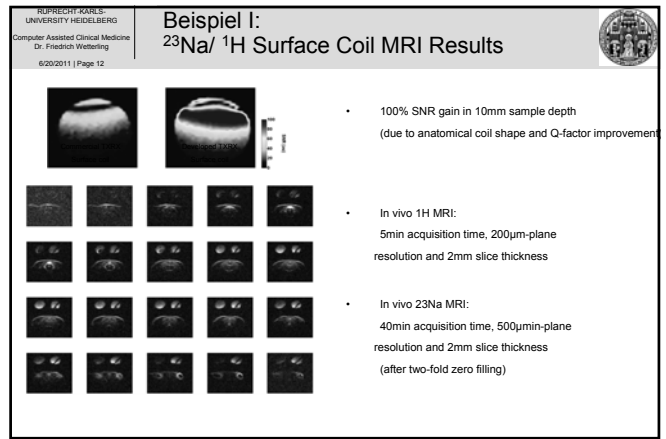
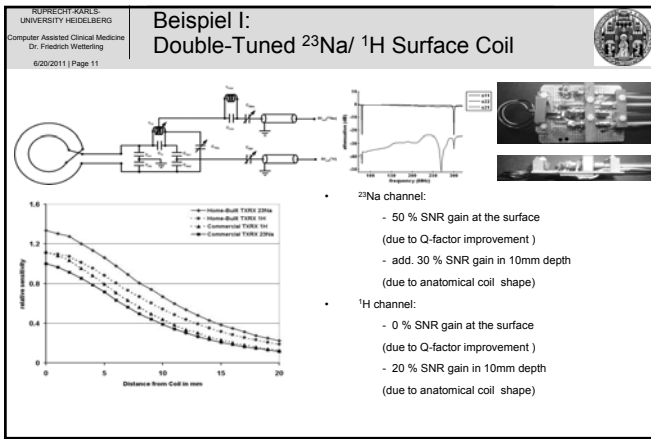
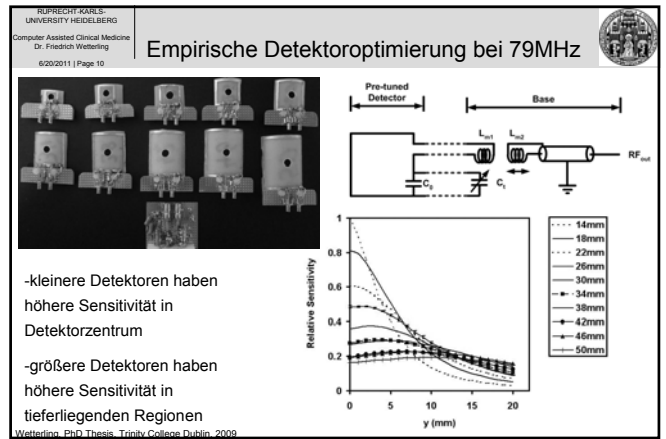
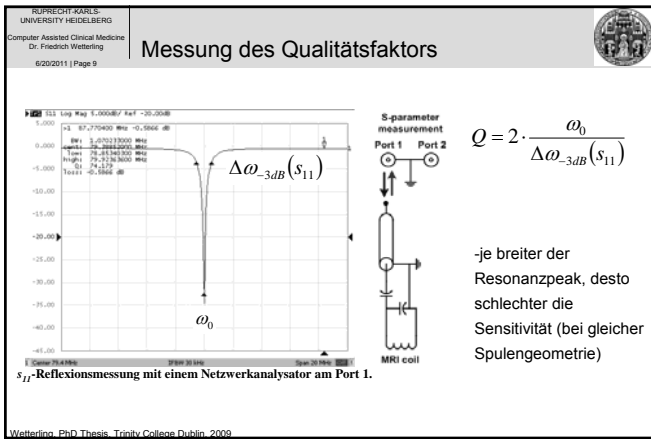
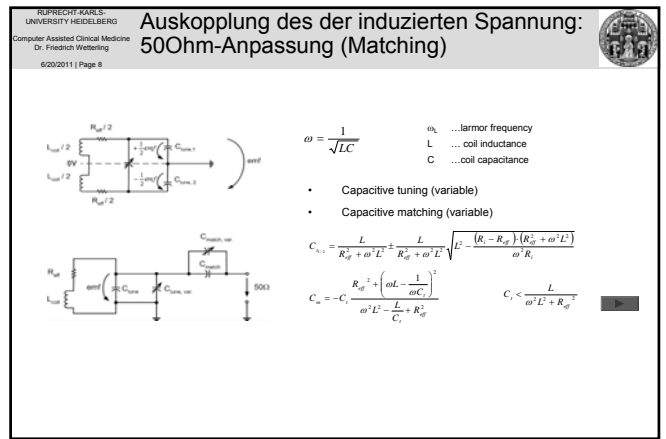
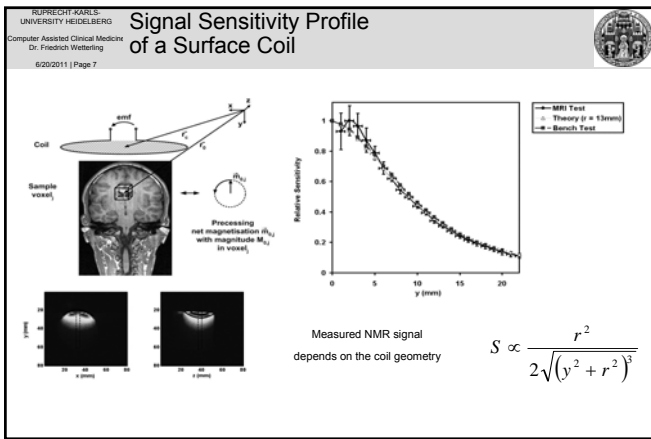
## Relative Signal Sensitivity of a Surface Coil

$S_{rel} = 1V \cdot 10^{-\frac{A(z)}{20}}$



Measured relative sensitivity profile coincides well with measured MRI and theoretically calculated sensitivity profiles





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### Beispiel II: Double-Tuned $^{23}\text{Na}/^1\text{H}$ Volume Resonator

- $^{23}\text{Na}/^1\text{H}$  12-leg birdcage structure with RF-shielding
- Optimized for transmit homogeneity ( $\pm 7\%$ ; required for qNa- MRI)
- Variable balanced tuning/matching via two mechanically coupled trimmer capacitors
- Active decoupling

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### Beispiel II: Double-tuned $^{23}\text{Na}/^1\text{H}$ Volume Resonator/ MRI Results

- 200% SNR loss in 10mm depth  
BUT  $\pm 7\%$  signal homogeneity across the entire sample
- In vivo  $^1\text{H}$  MRI:  
5min acquisition time,  $300\mu\text{m}$ -plane resolution and 2mm slice thickness

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### Beispiel III: Receive-Only $^{23}\text{Na}$ Surface Resonator

- Receive-only surface coil
- Optimised for SNR
- Active decoupling
- 200 % SNR gain in 10 mm sample depth

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### Beispiel III: $^{23}\text{Na}$ Surface Resonator/ MRI Results

- 0% SNR gain in 10mm depth
- Homogeneous sample excitation (doubled penetration depth)
- In vivo  $^{23}\text{Na}$  MRI:  
40min acquisition time,  $500\mu\text{m}$  in-plane resolution and 2 mm slice thickness (after two-fold zero-filling)

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### Coil System Comparison

Acquisition Parameter:  
2D FLASH,  
Taq = 10min, TE = 3ms, TR = 250ms  
1.25mm in plane res., 1mm ST,  
non-physiological 4M NaCl solution

10mm

Surface Coil      Surface Coil      Birdcage Coil

SNR in au

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### Beispiel IV: Vorverstärkerkoppelte Detektoren

- Preamplifier Matching
- Active Decoupling

25mm x 25mm square loop, 2mm wide, 0.5mm thick silver foil ( $f_R=79\text{MHz}$ )

79 MHz      40 dB

[A. Reykowski et al, Magnetic Resonance in Medicine, 1995. 33(6): p. 848-852]

Preamp Matching Loop ( $f_R=79\text{MHz}$ )      Low Input Impedance Preamplifier

(+) limited current flow in the coil  $\rightarrow$  no interaction with adjacent coils  
 (+) limited dielectric losses in object: Non-resonant  $\rightarrow$  no-tune no-match  
 (-) complex circuit diagram  
 (-) receive-only (!)  $\rightarrow$  separate transmit resonator necessary

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### Beispiel V: Multi-element Detektoren

Figure 1: The schematic circuit diagram for one element of the two-element phased array coil with both preamplifier and active decoupling.

Figure 2: Newly-developed <sup>23</sup>Na receive-only two-element phased array coil in (left) bottom, and (right) side view.

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### Multi-element Detektoren: Summation mittels Sum-of-Squares Methode

$$\text{SQRT}(\text{Signal}_1 + \text{Signal}_2) = \text{Summed Signal}$$

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### Parallel Imaging: Coil Sensitivity

- surface coils
- inhomogeneity correction
- phased array coils
- image combination
- parallel imaging: SMASH / SENSE

array combination

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### Parallel Imaging: Receive Coils

102 seamlessly integrated coil elements at 32 receiving channels

matrix coils:

- head
- neck
- stem
- leg

courtesy: Siemens AG, Erlangen

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### Parallel Imaging: Receive SENSE

- SENSE (sensitive encoding) works in the image domain  
- use sensitivity and location information of coils to unfold image  
- 32 receiving channels standard at modern MRI scanners

128 channel prototype, MGH Boston

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### Parallel Imaging: Receive SMASH I

- SMASH (simultaneous acquisition of spatial harmonics) works in the k-space  
- use sensitivity and location information of coils to reconstruct missing lines (harmonics) of the k-space  
- 32 receiving channels standard at modern MRI scanners

Sodickson and Manning, MRM 1997

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### Parallel Imaging: Receive SMASH II

Sodickson and Manning, MRM 1997

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### Parallel Imaging: Receive SMASH III

- speed  
cMRA: 18 s

- resolution  
 $0.4 \times 0.4 \times 1 \text{ mm}^3$

T2 SPACE, PAT 2 with GRAPPA

Ce-MRA, PAT 3, GRAPPA, TA 18 s

courtesy: Siemens AG, Erlangen

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### Whole Body MRI

areas of applications:  
Oncology ✓  
Cardiovascular ✓  
Inflammatory/ Rheumatism -  
Infection/ Immunology  
Health Care Screening

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### Whole Body MRI: Metastasis Screening

- complex, multiparametric classification with local and global parameters
- training systems
- computer aided diagnosis vs. automated diagnosis

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### Whole Body Moving Table Angiography

courtesy: Siemens AG, Erlangen

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### Whole-body $^{23}\text{Na}$ MRI (12 000 times less signal compared to $^1\text{H}$ -MRI)

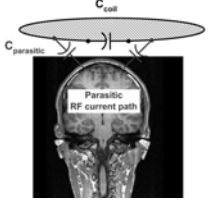
$^{23}\text{Na}$ -birdcage on patient bed (outside 3T magnet)

Split  $^{23}\text{Na}$ -birdcage

Wieteling et al., ISMRM 2011

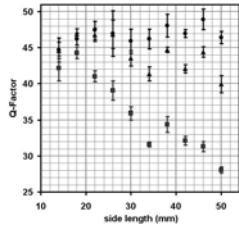
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## Radiofrequenz-Verluste



$C_{coil}$   
 $C_{parasitic}$   
Parasitic RF current path

-Q-Faktoren der parasitischen Kapazität dominieren Verluste, wenn die Impedanz einen Stromfluß durch das Objekt erlaubt (Z klein, Abhängig von Frequenz, Geometrie und Leitfähigkeit des Objekts)



Q-Factor

side length (mm)

- Unloaded
- Loaded (145mm NaCl)
- Loaded (1M NaCl)

$$Z_c = \frac{1}{j\omega C}$$

$$C \propto \frac{A(\text{Fläche})}{d(\text{Durchmesser})}$$

$$Q_{unloaded} \propto \sqrt{\frac{L}{C}} \frac{1}{R_{Ohm}}$$

$$Q_{loaded} \propto \sqrt{\frac{L}{C}} \frac{1}{R_{Ohm} + R_{parasitisch}}$$

Wetterling, PhD Thesis, Trinity College Dublin, 2009

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## Detektorkühlung lohnt sich, wenn ohmsche Verluste überwiegen

-Überwiegen die ohmschen Verluste in der Spule, kann ein signifikanter Sensitivitätsanstieg durch Kühlung der Spule erzielt werden (Kühlung lebender Subjekts bei MRT ist unmöglich).

- Test, ob sich Kühlung lohnt: Q-Faktormessung mit gewählter Spulengeometrie und Beladung

$$Rauschen = \sqrt{4 \cdot (R_{Ohm} + R_{parasitisch}) \cdot k_B \cdot T \cdot \Delta f}$$

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## Spulenvergleich bei 100MHz und ~15mm Durchmesser

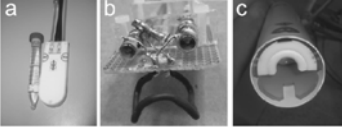


Fig. 1: a) Image of the standard surface coil and the phantom containing DMSO. b) Home-built <sup>13</sup>C transceiver surface coil with anatomically-shaped square element. c) <sup>13</sup>C-cryo-probe; anatomically shaped and additional <sup>1</sup>H saddle coil

	SNR
c) Cryo:	92
b) Eigenbau:	14.9
a) Commercial:	7.9

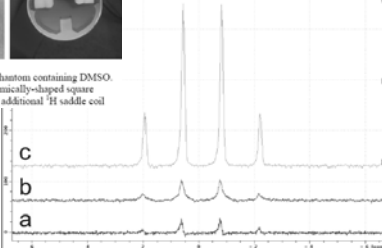


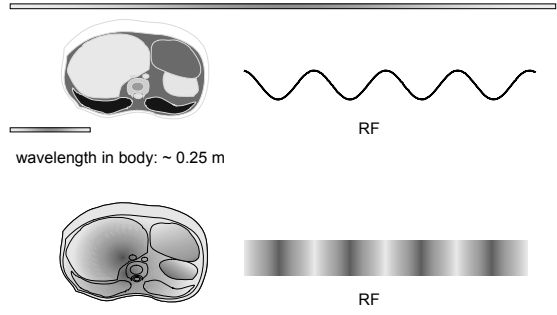
Fig. 2: <sup>13</sup>C spectra of the DMSO phantom obtained by a single pulse sequence. a) Standard surface coil, b) home-built transceiver coil and c) <sup>13</sup>C-cryo-probe.

Sack, Wetterling et al., ISMRM 2011

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## High Field MRI: RF Problems

wavelength at 130 MHz in air: 2.3 m

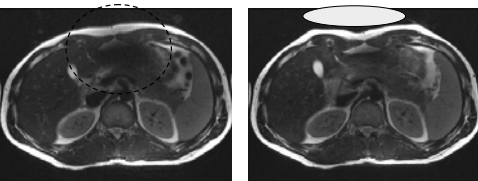


wavelength in body: ~ 0.25 m

problem: dielectric resonances

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## High Field MRI: RF Problems 3 Tesla



darkening can be avoided by dielectric pad

- wavelength has the same dimension as organs in the body → reflections at organ borders create interference called "dielectric resonance"
- RF absorption increases
- B<sub>1</sub> - field is inhomogeneous
- dielectric resonances appear at transmitting and receiving

courtesy: Hennig, Department of Diagnostic Radiology, University Freiburg

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## Zusammenfassung

1. Abstimmen und Anpassen von Resonanzschwingkreis für MRT
2. Charakterisierung von MRT Resonatoren
3. Optimierung der Detektorsensitivitäten
4. Oberflächenspulen (Leistungsangepasst/ Rauschangepasst)
5. Volumenresonator
6. Transmit-Only Receive-Only (TORO) Systeme
7. Multi-element (Phased-Array) Detektorsysteme (Ganzkörperbildgebung)
8. Vorteil durch Detektorkühlung
9. Probleme bei hohen Feldstärken → Sende-Arrays notwendig