Travelling-wave excitation in MRI

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   - Working principle
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Motivation

Figure: brain image 7 Tesla - source: CEA neuroimaging centre
Motivation

Figure: brain image 9.4 Tesla - source: German Center for Neurodegenerative Diseases (DZNE)
RF Transmitting and Receiving

Transmitting:
- usually in MRI an RF-signal is created by a coil
- nuclei are excited
- Magnetization vector is tipped into the transversal plane

Receiving:
- induction in a coil in the reactive field (near field of the atom) during relaxation
- precession $\rightarrow$ change of magnetic flux $\rightarrow$ induced voltage
RF creation (Transmitting)

Figure: rf birdcage coil
## Travelling-wave excitation in MRI

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#### Motivation

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Travelling wave nmr

Working principle

Disadvantages

Advantages

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### Conclusion

### Wavelength

<table>
<thead>
<tr>
<th>Magnetic field</th>
<th>Larmor frequency</th>
<th>Signal wavelength (water $\epsilon_r = 81$)</th>
<th>Air</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5 T</td>
<td>64 MHz</td>
<td>70 cm</td>
<td>468 cm</td>
</tr>
<tr>
<td>3 T</td>
<td>128 MHz</td>
<td>35 cm</td>
<td>234 cm</td>
</tr>
<tr>
<td>7 T</td>
<td>300 MHz</td>
<td>12 cm</td>
<td>100 cm</td>
</tr>
<tr>
<td>9.4 T</td>
<td>400 MHz</td>
<td>10 cm</td>
<td>75 cm</td>
</tr>
</tbody>
</table>
Standing wave

stationary RF fields excite atoms

Figure: standing wave within the sample
Travelling wave

- electrodynamics requires field curvature
- standing wave: spatial variation in field amplitude
- travelling wave: phase variation
Travelling wave

Figure: travelling wave
Maxwell equation have to be fulfilled

Ansatz (TE): \( H_z = H_0 J_m(\beta c r) \cos(m\Psi) e^{i\beta z z} \)

boundary condition: \( \frac{\partial H_z}{\partial r} = 0 \)

solution: modes \( TE_{mn} \)

\[
f_{cutoff} = \frac{c \cdot p'_{mn}}{2\pi r}
\]

\( p'_{mn} \) mode dependent constant
\( p'_{11} = 1.84 \) cutoff frequency for \( TE_{11} = 303 \text{ MHz} \)

high magnetic fields necessary otherwise inefficient
Disadvantages

- only one receiving antenna possible → no parallel imaging
- bad signal to noise ratio (large distances to patient)
- hotspots may occur in upper body → deposition of RF energy leads to heating of tissue
- high magnetic fields necessary otherwise inefficient
Advantages

- large distance to patient $\rightarrow$ high voltages are kept away from patient
- more homogeneously excited nuclei
Spectroscopy

- first demonstrated by spectroscopy
- 10% ethanol in water
- excited with travelling wave and detected with the patch antenna
Spectroscopy

**Figure**: NMR spectrum
Figure: signal for varying distances
Impedance

- Impedance:
  \[ Z = \frac{E_0}{H_0} \]

- if the impedance is not matched
  ⇒ Reflection

- results in:
  superposition of standing wave and travelling wave
Impedance matching

Figure: impedance matching
Mri images

Figure: comparison between travelling wave (a) and traditional image (b)
Phase delay

![Figure: phase delay](image)
Conclusion / perspective

- excite nuclei without standing waves
- greater distance to patient
- high magnetic fields necessary otherwise inefficient
- in practice:
  - excite nuclei with travelling wave, receive signal with rf coils
- using more than one mode??
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**Figure**: brain image 9.4 Tesla
Thank you for your attention.
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