Medical Imaging
Magnetic Resonance Imaging, Instrumentation
(Outline of Lecture 3)

3. MRI Hardware

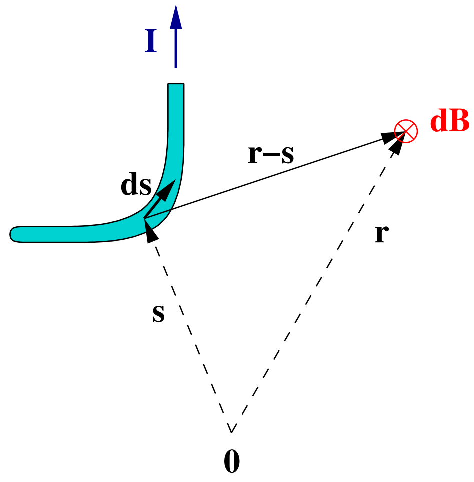
A. Main magnet

Requirements: strong magnetic field, homogeneous in a sufficiently large region

Electromagnet built up of solenoid coils

Relation electric current ⇒ magnetic field: "Thin wire" approximation of Biot–Savart law

$$\vec{B}(\vec{r}) = \frac{\mu_0 I}{4\pi} \int \frac{d\vec{s} \times (\vec{r} - \vec{s})}{\|\vec{r} - \vec{s}\|^3}$$



Simplest approximation: infinitely long solenoid with n_m – turns per meter.

$$\vec{B} = \mu_0 I n_m \vec{e}_z$$

3. MRI Hardware

Real magnets:

- inhomogeneity of the $\vec{B}$ field
- stray fields
- magnetic field $B > 1T$ requires high current $\Rightarrow$ high amount of power dissipated in form of heat.

Therefore *superconducting* magnets with shielding

- $T < 12K$, liquid helium
- restrictions on: current density, magnetic fields
- radiation shields, cryocooler
- additional, independent coils for fine tuning of the field

3. MRI Hardware

B. Gradient Chain

Gradient field $\vec{B}_g = (g_x x + g_y y + g_z z)\vec{e}_z$

Requirements: linearity over the imaging volume, fast switching time

z-Gradient:

Two coaxial coils with opposite currents

Field for a ring current at z axis, Biot–Savart $\Rightarrow$

$$\vec{B}(z) = \frac{\mu_0 I R^2}{2(z^2 + R^2)^{3/2}}\vec{e}_z$$

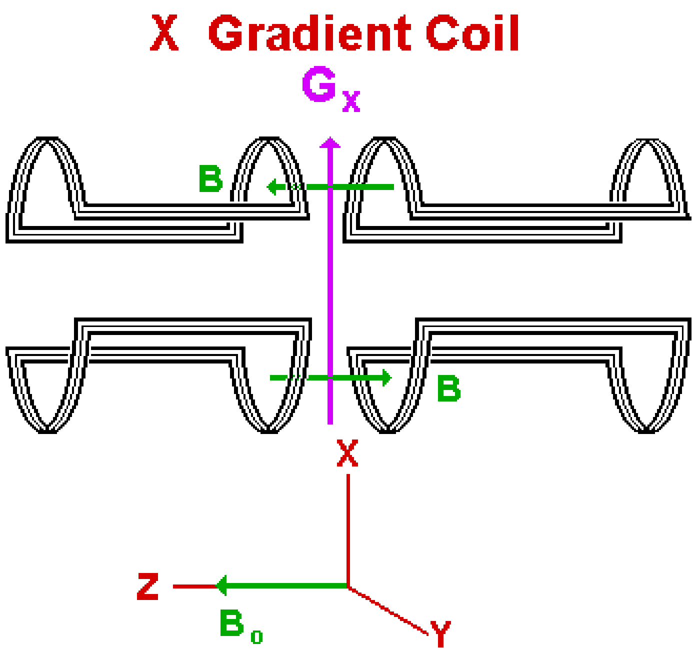
where R – radius of the ring

To increase linearity – use more than 2 rings with position dependent current.

Trade-off: linearity and small self inductance

3. MRI Hardware

x/y-Gradient



Fast on/of switching induces eddy currents ⇒ active shielding

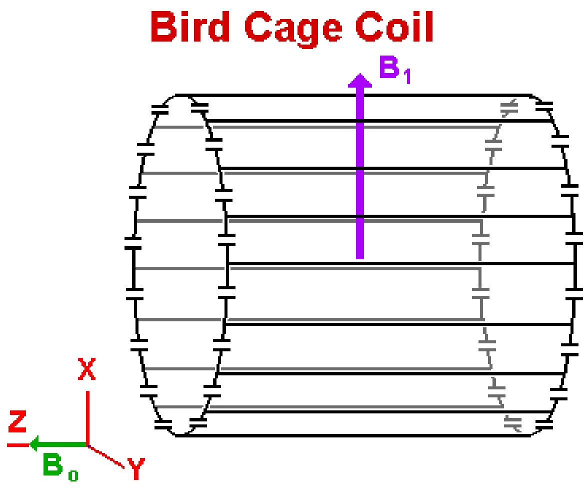
3. MRI Hardware

C. RF Coils A single circular coil is not optimal:

$$B(y) = \frac{\mu_0 I R^2}{2(y^2 + R^2)^{3/2}}$$

inhomogeneous field, fast decay with distance.

Better solution – birdcage coil



Consider a cylinder oriented along the z-axis with the current distribution $I_z = I_0 \cos\phi$ in its jacket. This gives a homogeneous transversal field.

Application of an alternating current gives a rotating transversal field.

Exercises

1. Consider a solenoid electromagnet with the following layout: radius $R = 0.5m$, length $l = 1m$, made of copper wire with cross section radius $r = 0.5cm$ and 20 turns per centimetre.

a) Calculate the current needed to have a magnetic field of 1 Tesla in the solenoid. Use the approximation of an infinitely long solenoid.

b) Copper has specific resistance $1.6 \times 10^{-8} Ohm \cdot m$. Calculate the voltage and power needed to operate such a magnet.

2.
a) Calculate the magnetic field of an infinitely long straight wire carrying the current I. Use Ampère's circuital law and utilize the symmetry of the problem.

b) Calculate the force exerted by a wire of length $l = 1m$ onto a parallel wire of the same length at distance $a = 2cm$ if both wires carry a current I as calculated in exercise 1. Use the approximation of an infinite wire for the magnetic field.

3. Calculate the magnetic field on the symmetry axis for a ring current. Use Biot–Savart's law.