



MR HARDWARE & SAFETY

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CIBM MRI EPFL AIT

PHYS-473 MRI Practicals on CIBM preclinical imaging systems, 17 September 2024

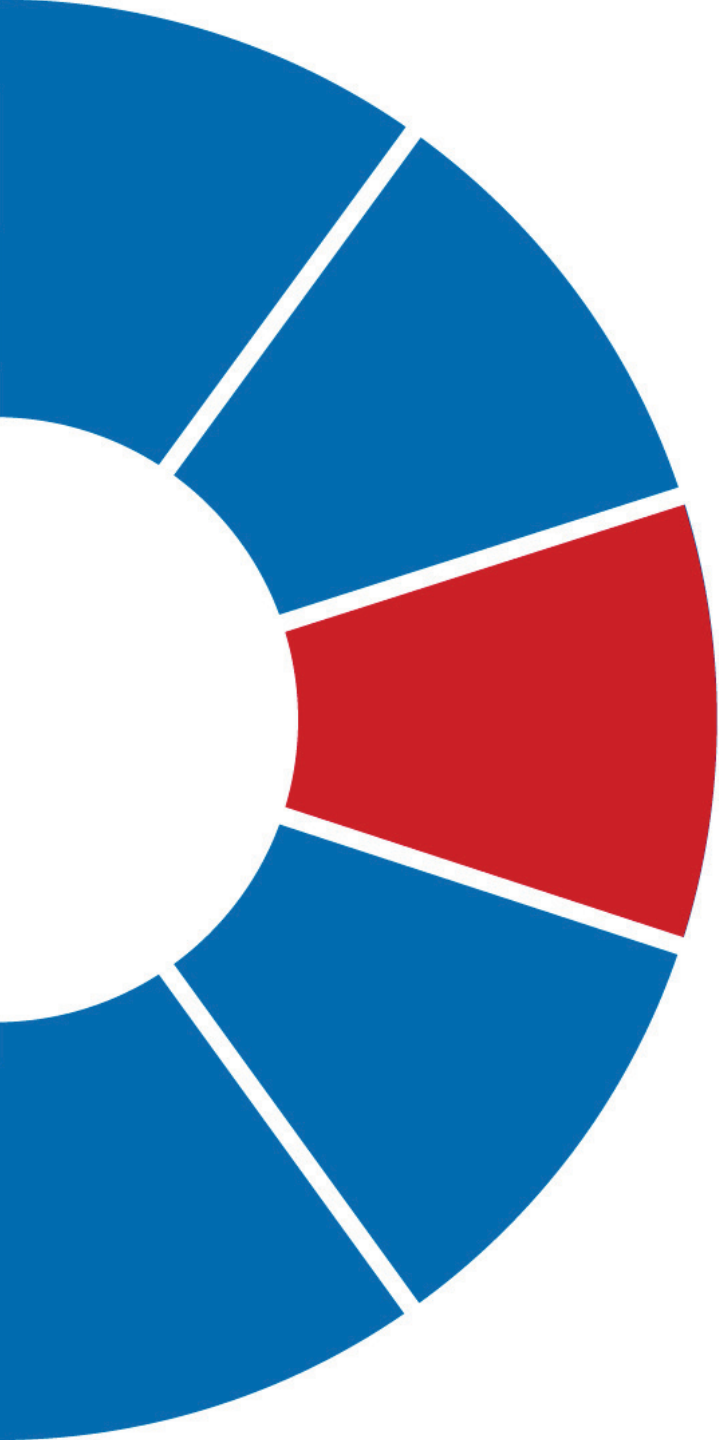


C I B M . C H

OUTLINE



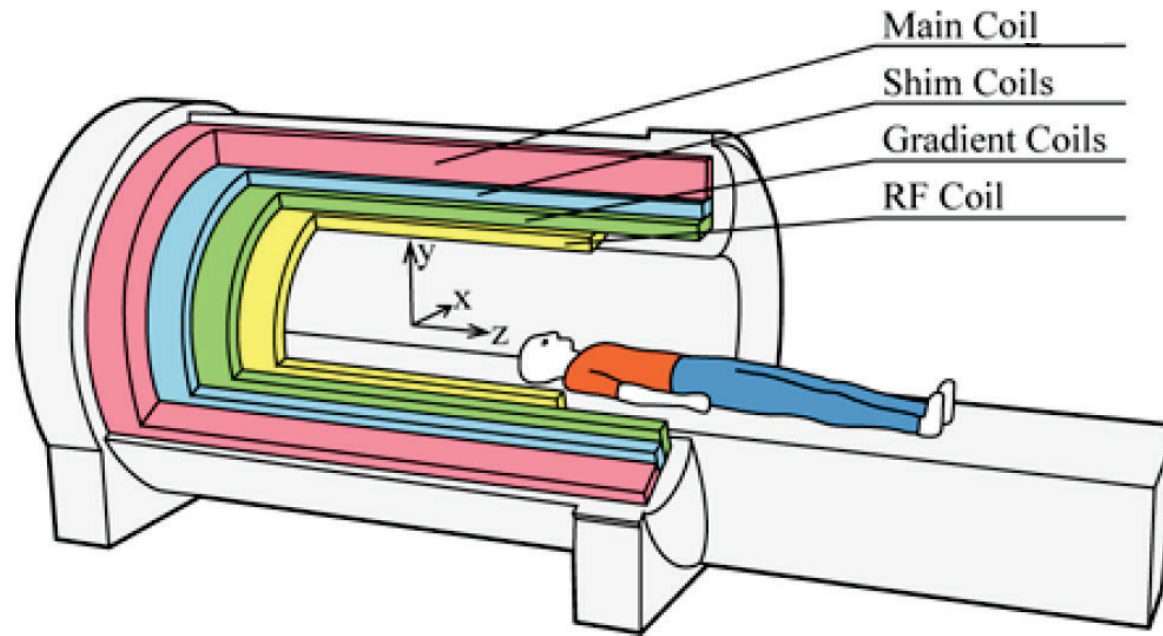
- Overview of the MR system
- MR Safety
- Visit and demo session



OVERVIEW MR SYSTEM

MRI SYSTEM OVERVIEW

- Coils are everywhere!



STATIC FIELD (B_0)

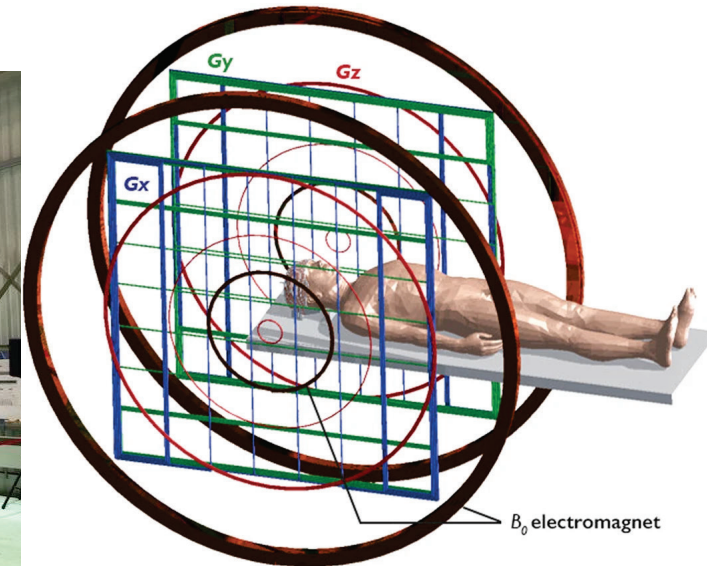
- Produces the static magnetic field B_0
 - Permanent magnet (<1 T)
 - Electromagnet (resistive, <1 T)
 - Superconducting magnet (from 0.5T up to 11.7T human, 21.1T preclinical)



Hyperfine Swoop, 64 mT, 630 kg



Iseult project, 11.7 T, ~150 tons

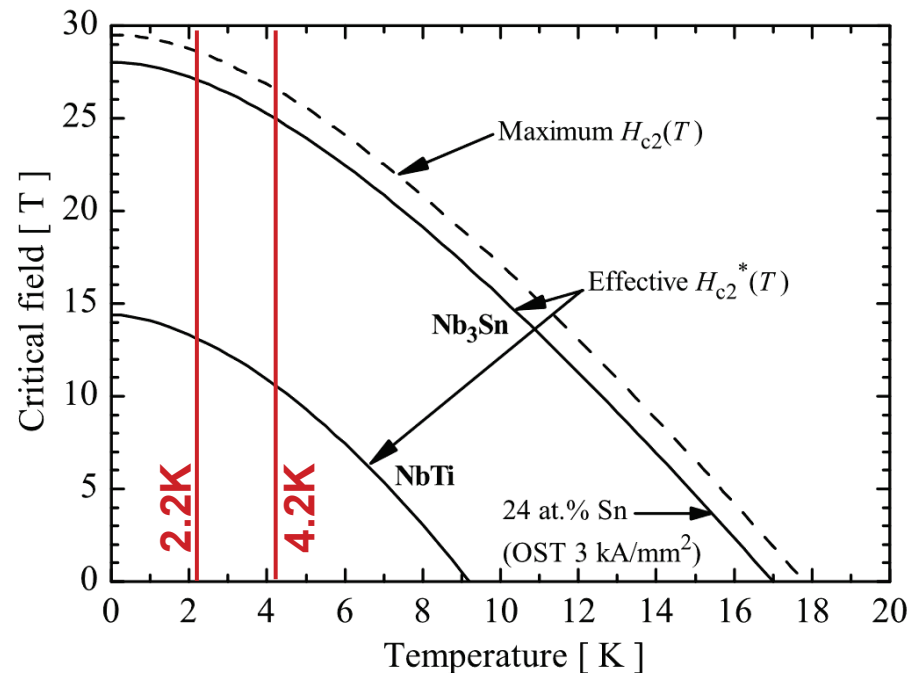


6.5 mT electromagnet, MGH
Bruker's strongest horizontal MRI, 21.0 T

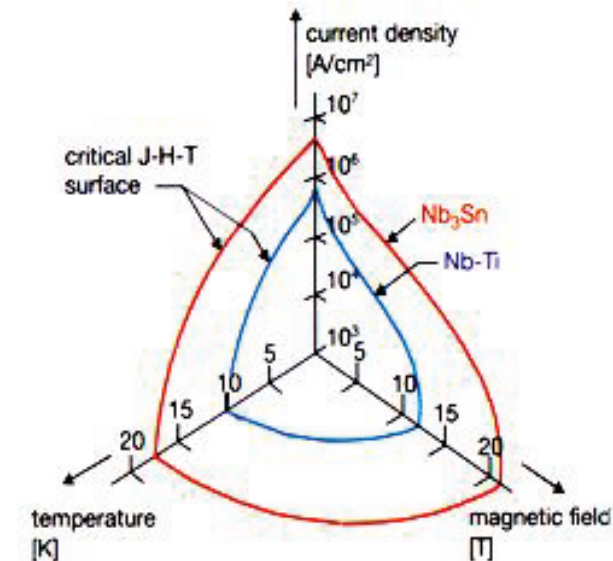


SUPERCONDUCTING B_0 COIL

- Superconductor: zero resistance below a critical temperature, field and current density
- MRI magnets mostly use NbTi and NbSn filaments



Cheng et al. IEEE Transactions On Applied Superconductivity. 2007



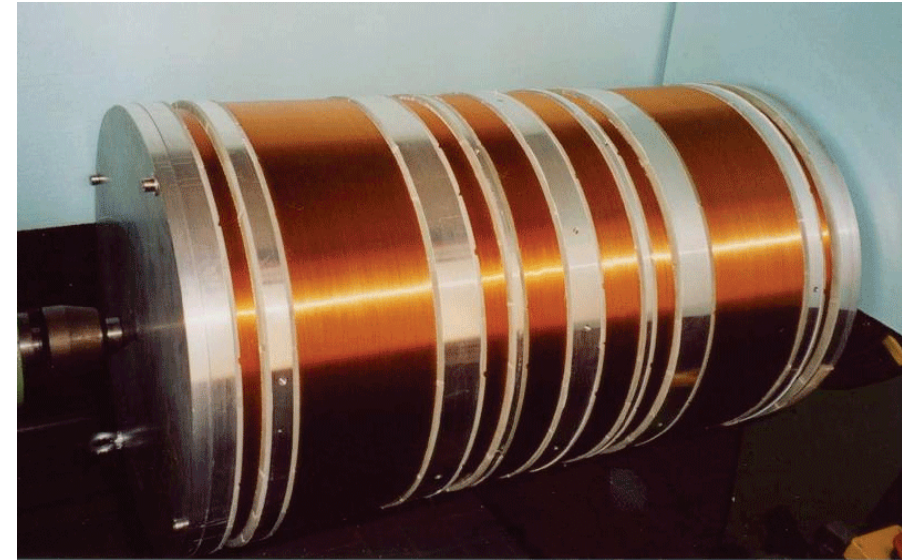
Lyndon Evans. The LHC. 2009

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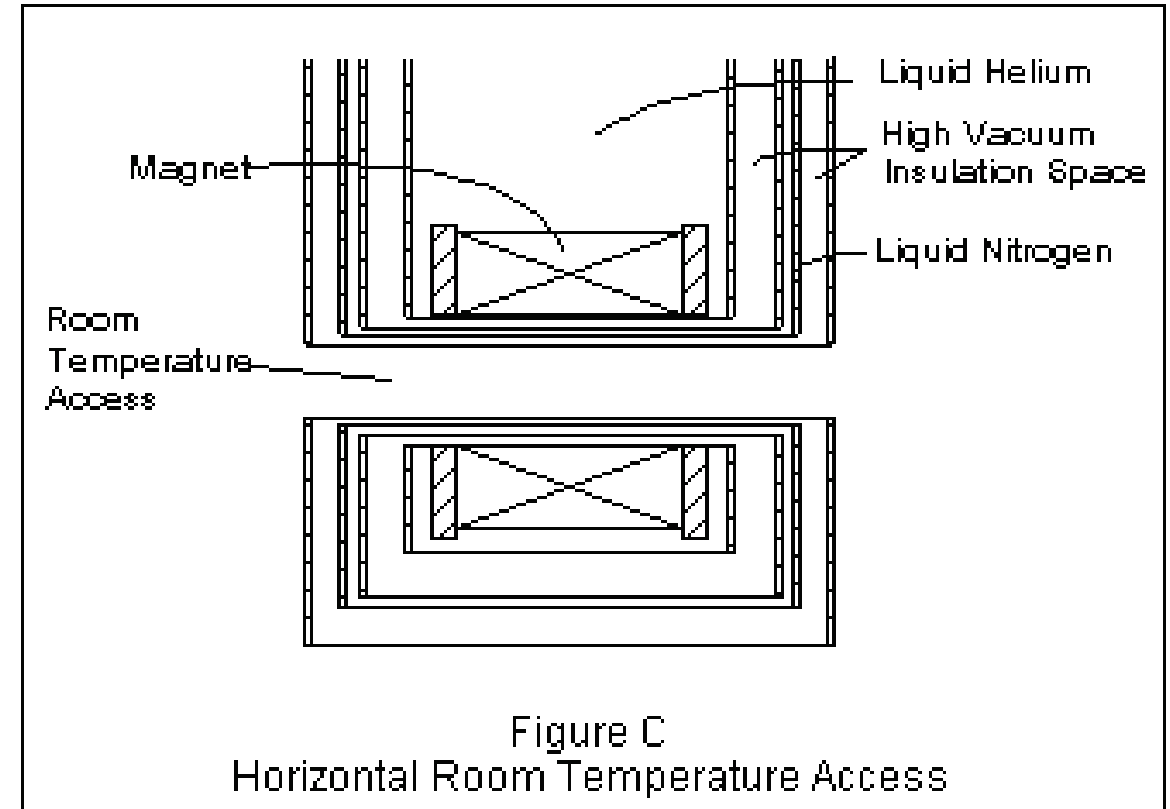
Bruker.com



mrquestions

SUPERCONDUCTING B_0 COIL

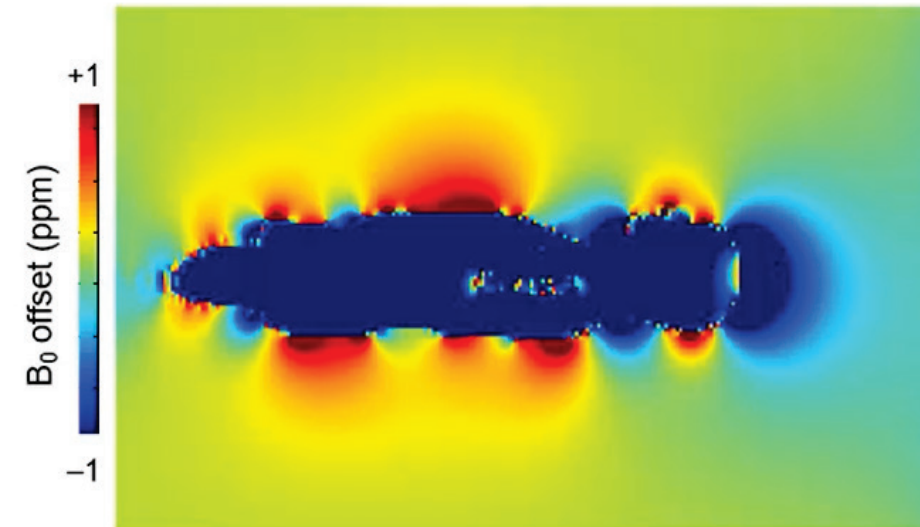
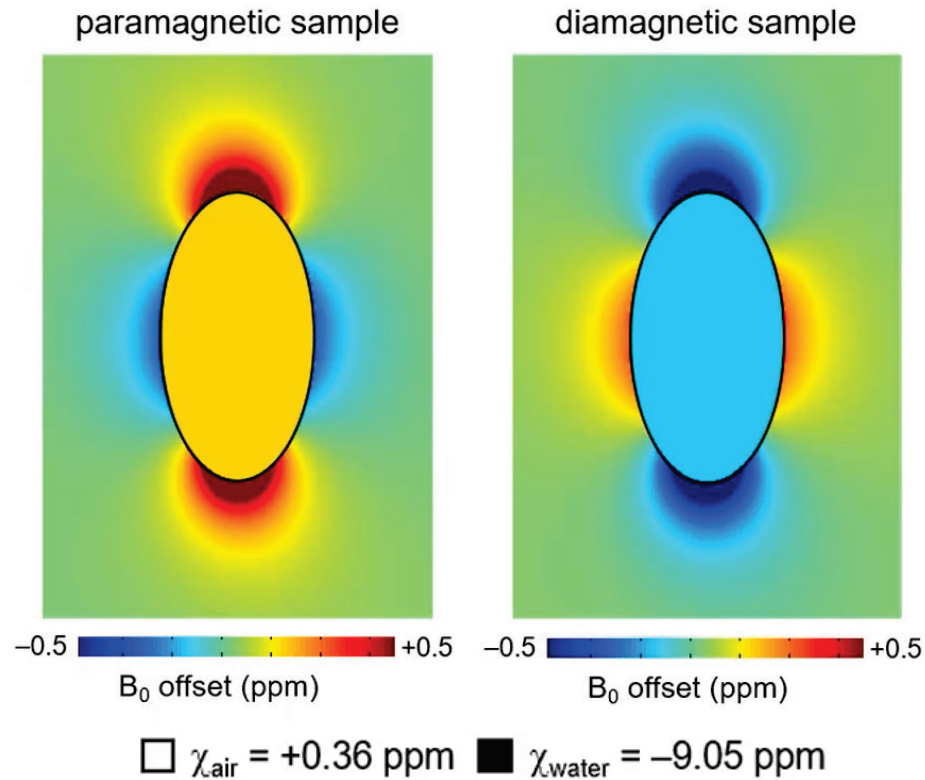
- Typically: cryogenic liquids required to maintain superconductivity.
 - Liquid nitrogen (77K)
 - Liquid helium (4.2K)
- Stefan–Boltzmann law:
Radiant emittance : $M = \epsilon\sigma T^4$
 - ϵ : Emissivity
 - σ : Stefan–Boltzmann constant
 - T : Temperature
- Insulation with vacuum, radiation shields, multilayer blankets.



American Magnetics

STATIC FIELD INHOMOGENEITY

- Induced by the scanner and local environment
- Induced by the imaging subject



Robin de Graaf, ISMRM 2019

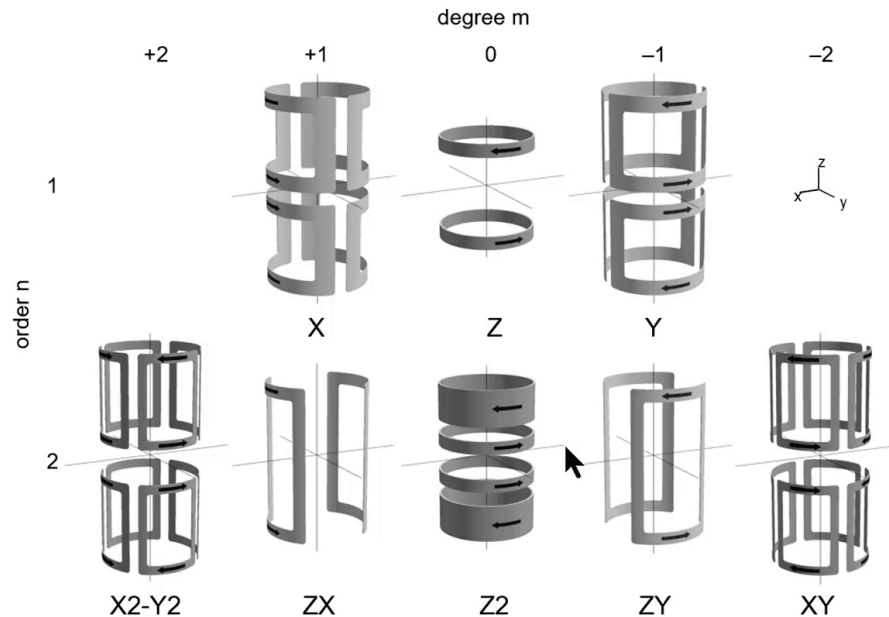
PASSIVE SHIMMING

- Pieces of iron or steel placed to compensate inhomogeneities of the main magnet.
- Usually installed once.

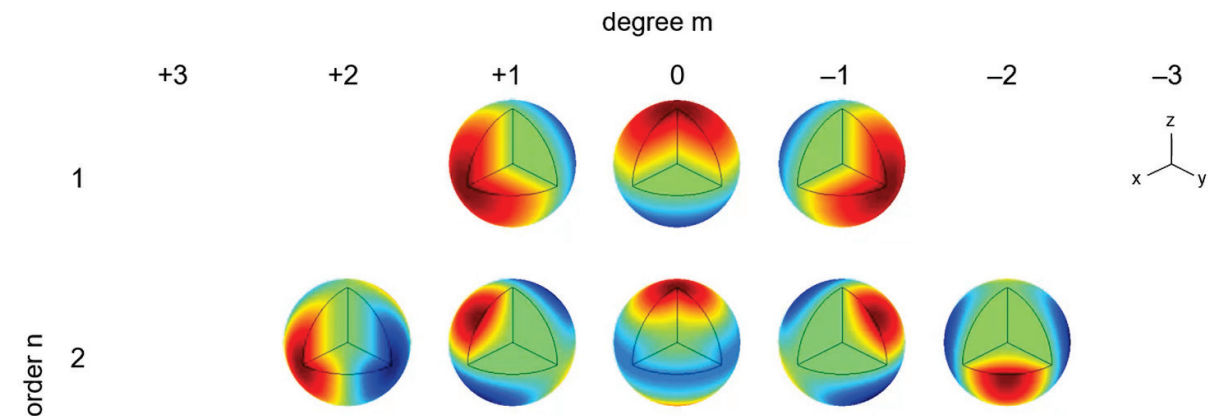


mriquestions.com

■ Superconducting or resistive shim coils



First and second order shim coils

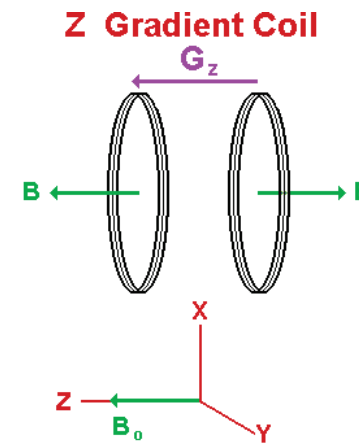
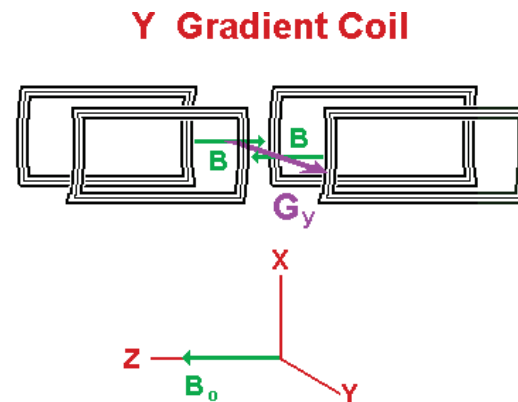
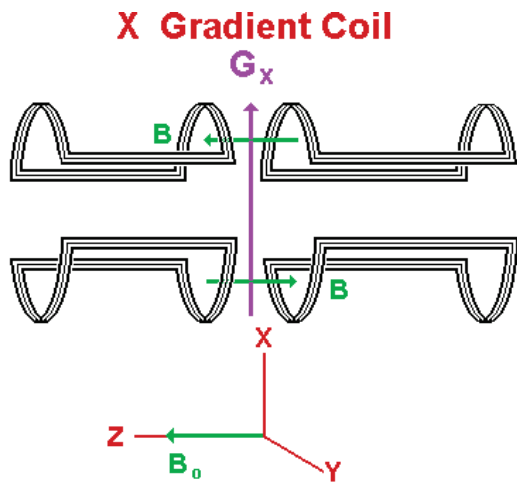


Spherical harmonic functions up to second order on the surface of the unit sphere.

Robin de Graaf, ISMRM 2019

GRADIENT COILS

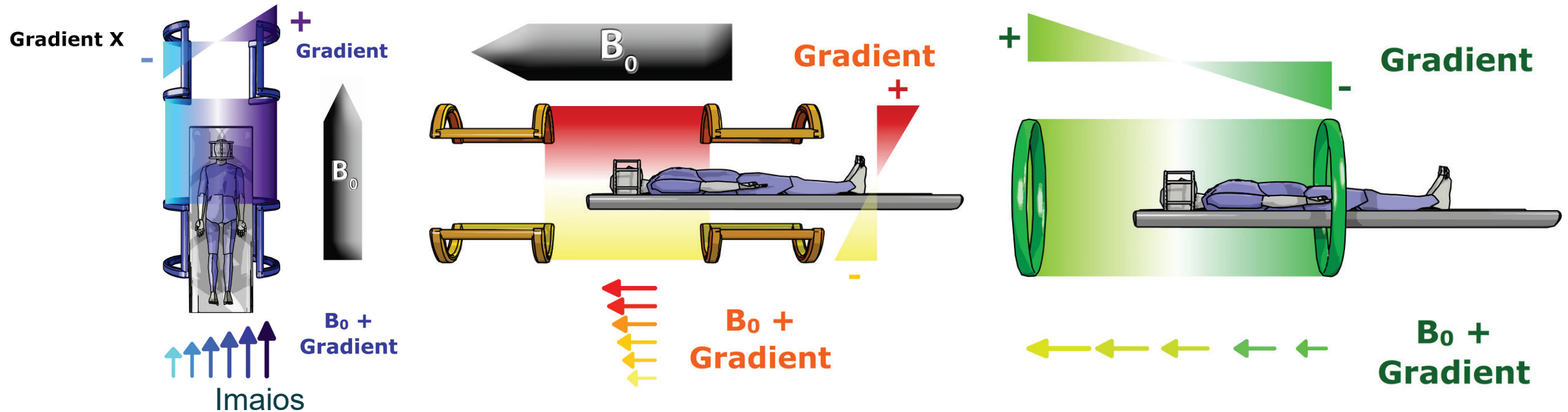
- Produce calibrated distortions of B_0 in the x-, y- or z- directions.
- Adds a magnetic field component parallel to B_0
- Typical strength: 40mT/m (human), 300mT/m (small)



mriquestions.com

GRADIENT COILS

- Linear variation in magnetic field intensity in a direction in space



RADIO-FREQUENCY COILS

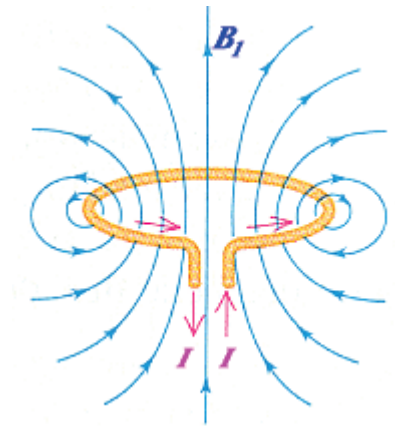
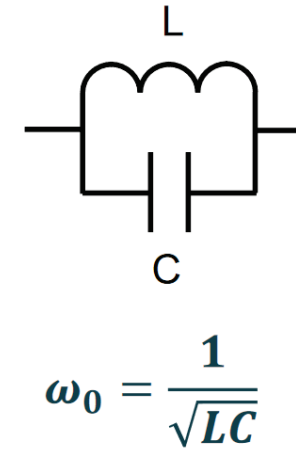
- Resonant circuit
- Generate/measure an oscillating field B_1 perpendicular to B_0
 - Tip the net magnetization (B_1^+ : transmit field)
 - Pick up the NMR signal (B_1^- : receive field)

SURFACE COIL

- + Easy to build!
- + High sensitivity and efficiency close to the coil
- Inhomogeneous B_1
- Limited field of view



Doty et al. NMR Biomed. 2007

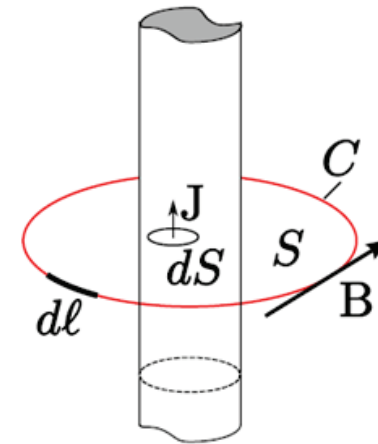


Ampère's law: current passing through a wire creates a magnetic field:

$$\frac{1}{\mu} \oint_C \mathbf{B} \cdot d\boldsymbol{\ell} = \int_S \mathbf{J} \cdot d\mathbf{S}$$

where:

- ▶ μ is permeability ($\mu_0 = 4\pi \times 10^{-7}$ H/m)
- ▶ $\mathbf{B}$ is magnetic field
- ▶ C is closed loop around current path
- ▶ $\mathbf{J}$ is current density
- ▶ S is surface enclosed by C



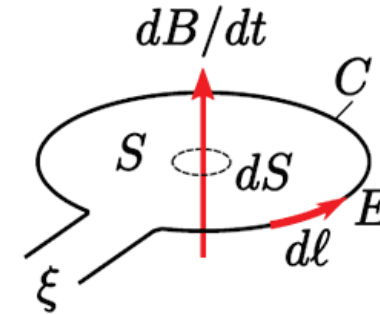
We design our probe to produce current distribution $\mathbf{J}$, to generate the desired magnetic field.

Faradays law: time-varying magnetic field induces an EMF in a conductor:

$$\xi = \oint_C \mathbf{E} \cdot d\boldsymbol{\ell} = - \int_S \frac{d\mathbf{B}}{dt} \cdot d\mathbf{S}$$

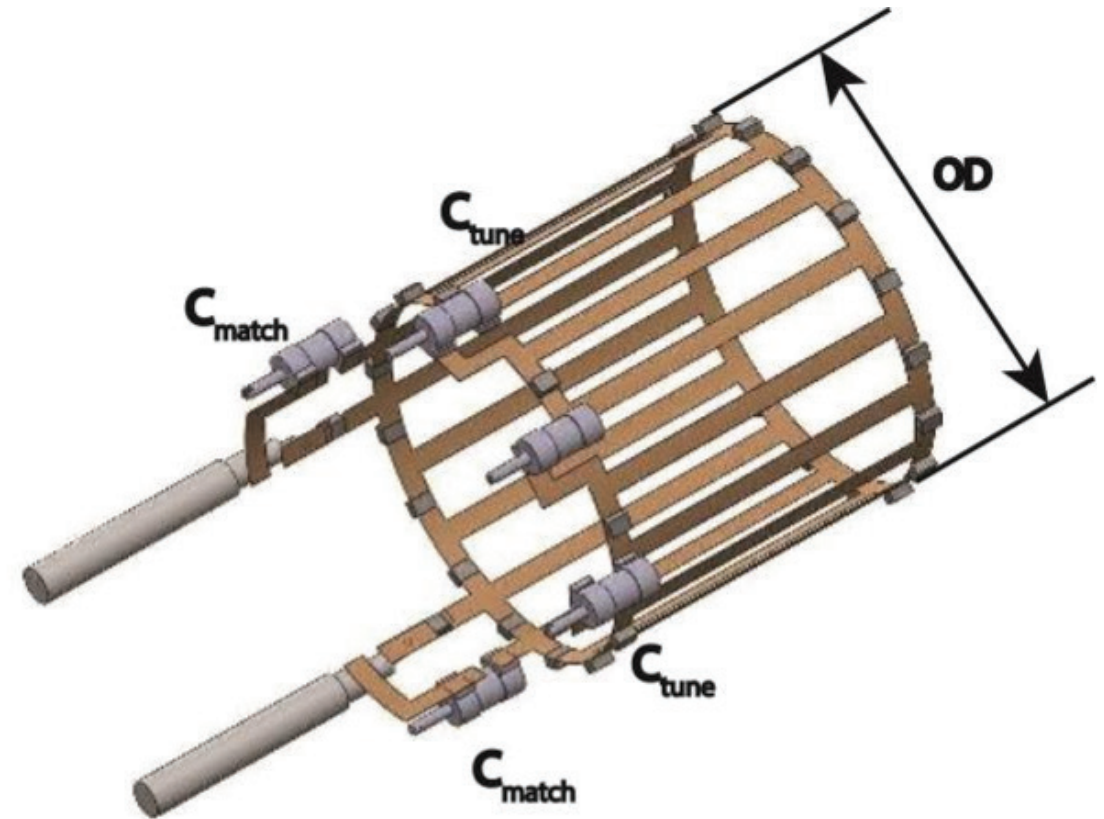
where:

- ▶ ξ is EMF induced across the loop
- ▶ $\mathbf{E}$ is electric field across loop section $d\boldsymbol{\ell}$
- ▶ line integral taken around loop C is
- ▶ $\mathbf{B}$ is the magnetic field
- ▶ surface integral taken over loop area S



VOLUME COIL

- + Homogenous B_1
- + Large field of view
- More complex
- Lower sensitivity

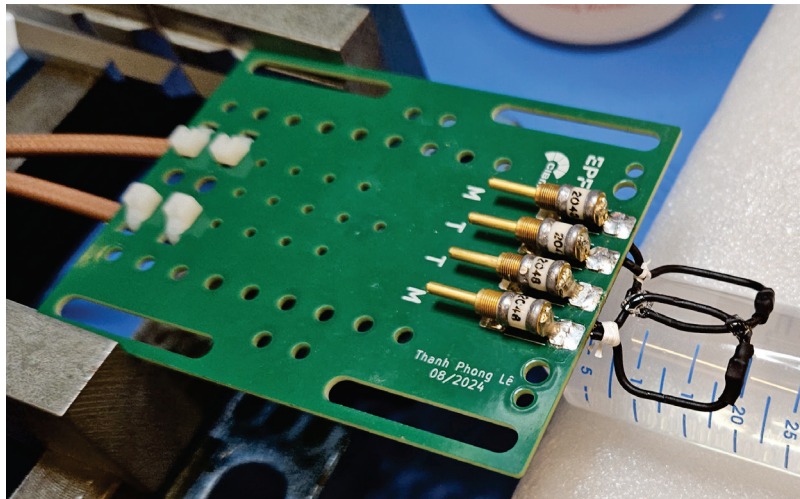


Cheng et al. IEEE. 2014

LINEAR VS QUADRATURE COIL

■ Quadrature coil

- Circularly-polarized B_1 field
- Doubles the power efficiency
- Increases SNR up to 1.4x

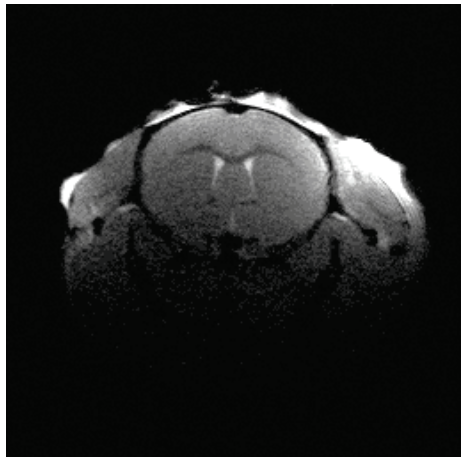


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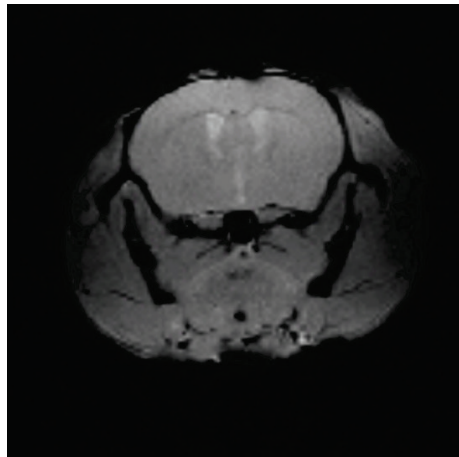
CIBM.CH

VOLUME COIL VS SURFACE COIL

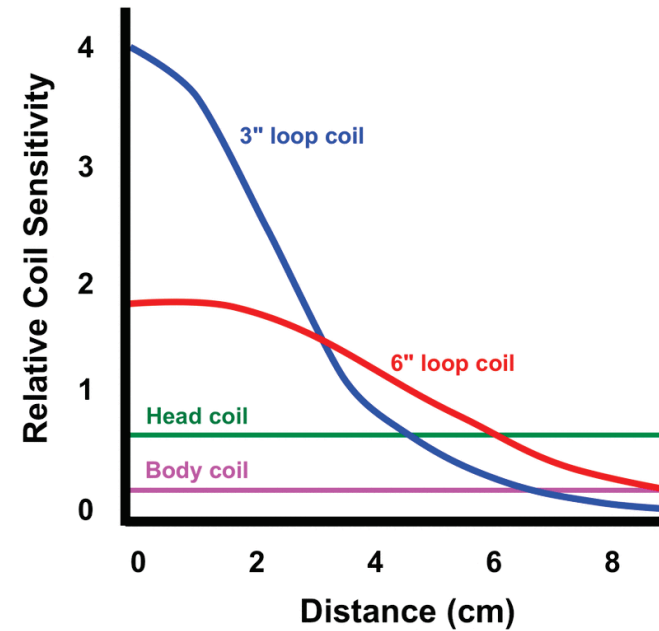
Mouse brain axial slice



Surface coil



Volume coil
(very long acquisition)



mriquestions.com

For humans

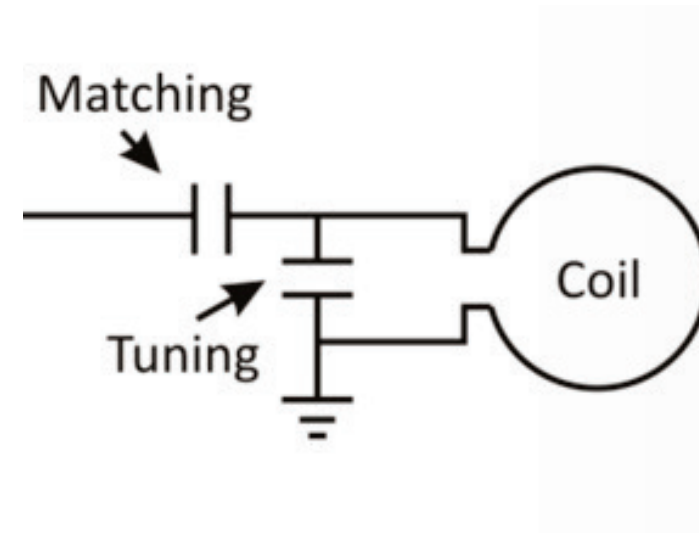


Nova 1ch Tx / 32 ch Rx (7T)
For human head

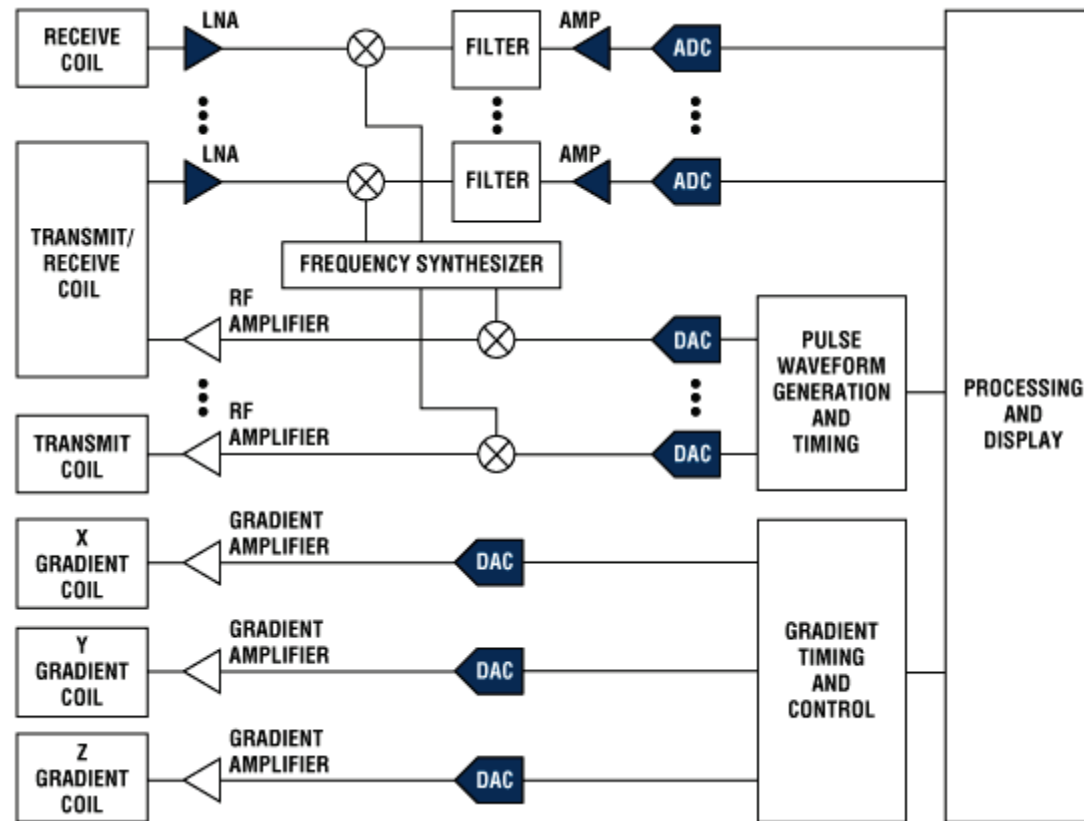
TUNING AND MATCHING

The coil's properties change as a function of the sample.

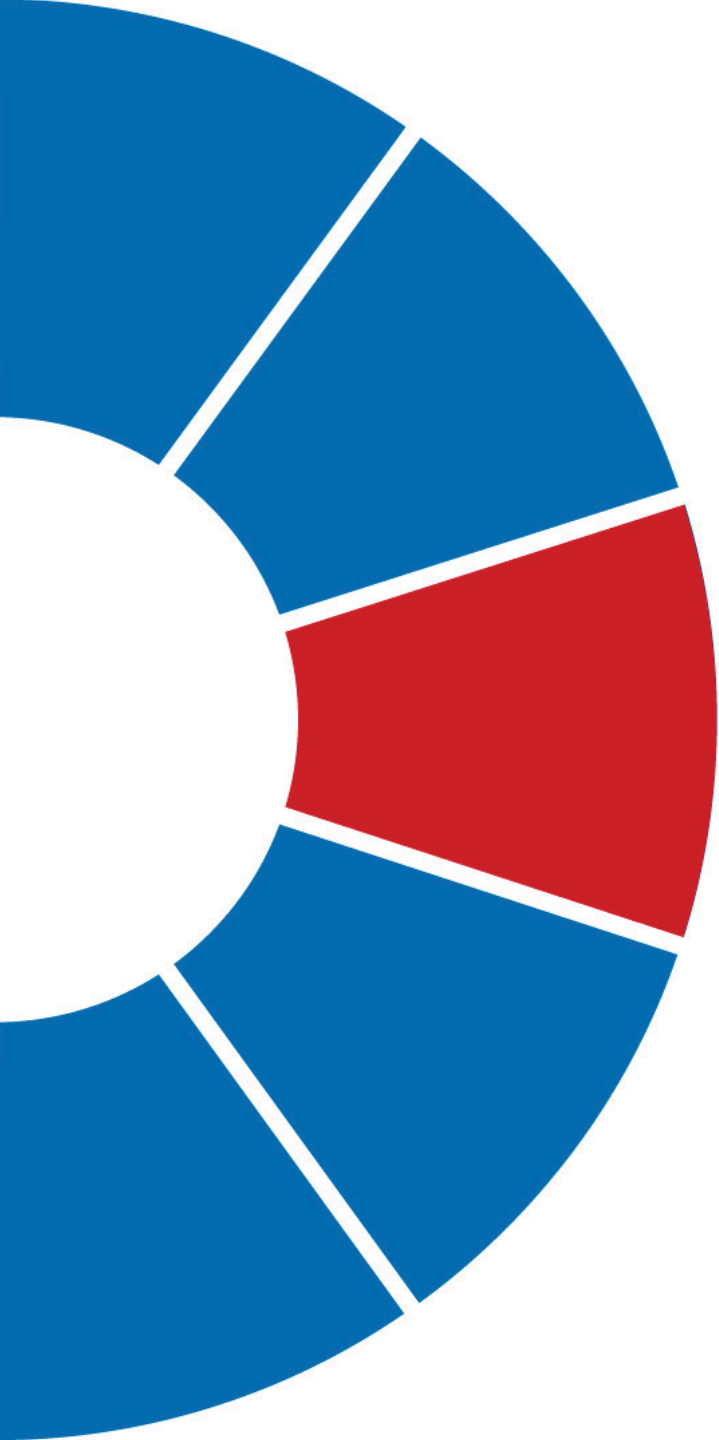
- Tune the resonance frequency of the coil to the Larmor frequency.
- Match the impedance between the transmission line and the coil for optimal power transmission.



BLOCK DIAGRAM MR SYSTEM



Analog Devices, 2010



SAFETY

DANGERS

- General aspects
- Magnetic field
- Cryogenes
- Radio-frequency waves
- Veterinary aspects

GENERAL ASPECTS

- No food, no water in the labs
- Store your belongings in the lockers close to the entrance.

MAGNETIC FIELD

- Magnet is always on!
- Anything ferromagnetic becomes a projectile!
- Do not stay close to the magnet if not necessary.
- Medical devices could stop working!

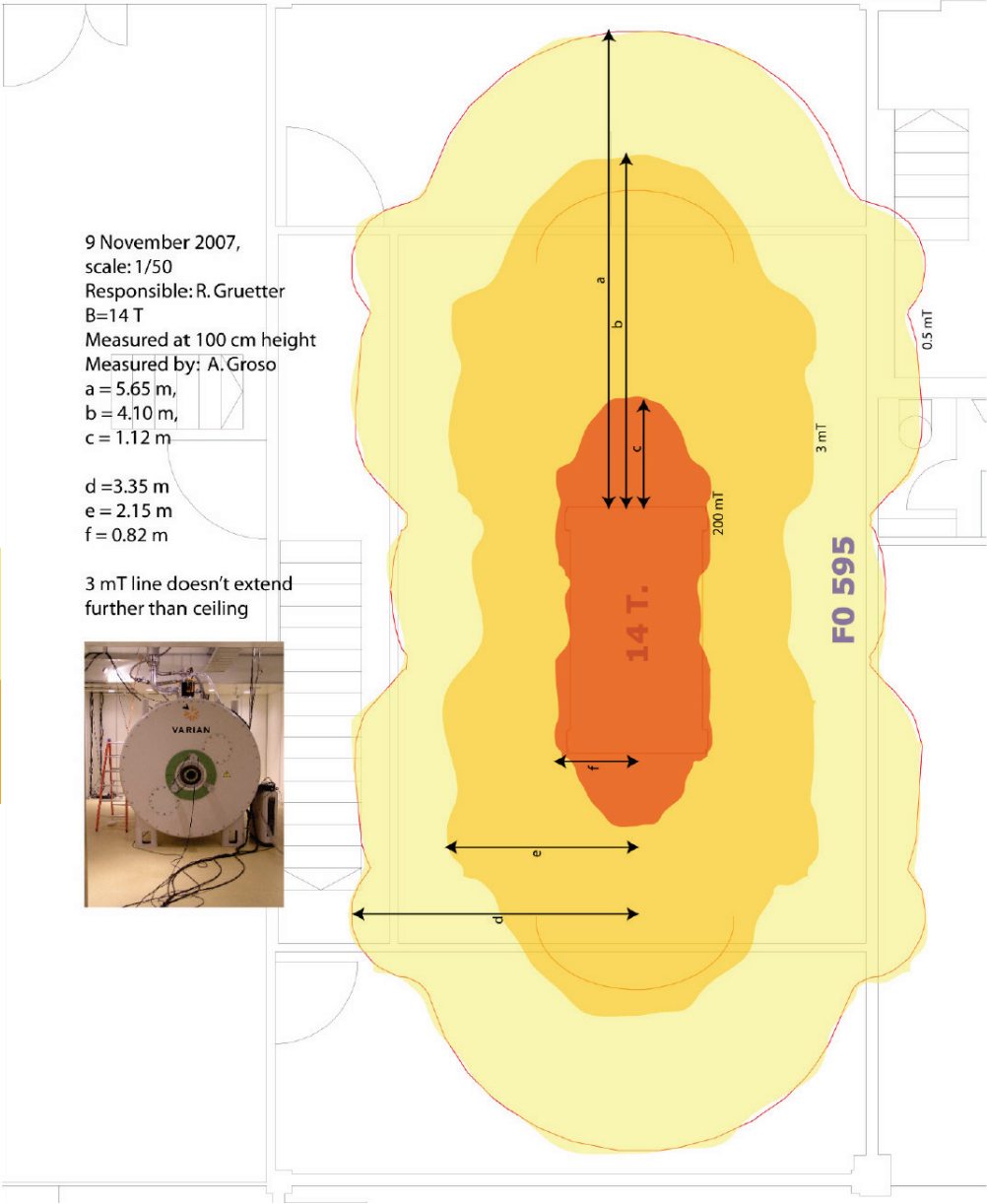


Imaging

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FIELD MAP

0.5 mT	Maximum value authorised for the holders of MD	No access to general public No access to holders of MD
3 mT	Possible attraction of ferromagnetic objects, they can become projectiles.	Any ferromagnetic object

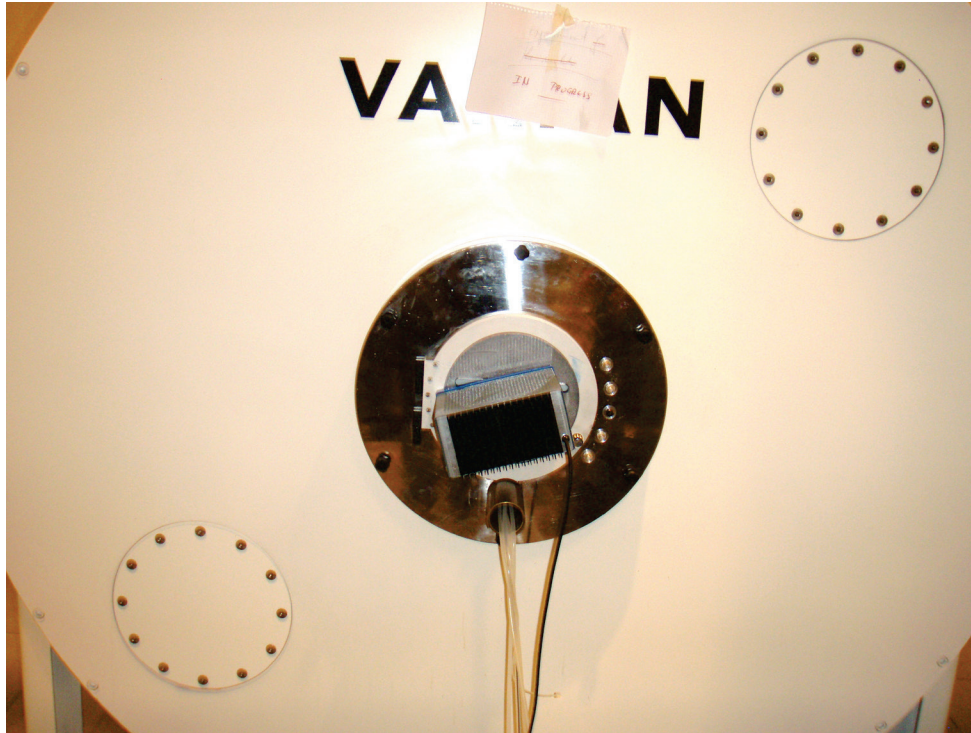


ging

BEFORE GOING TO THE MAGNET

- Remove all magnetic objects
 - Belt
 - Wallet, keys, phone
 - Watch
 - Pens
 - Shoes with steel
 - Hair pins
 - Jewelry, ear rings, bracelet, necklace, ...
 - Magnetic tools, devices, ...
- Some glasses/jewelry are magnetic. In doubt, remove them.

WHAT COULD HAPPEN ?



Laboratory power supply



Bracelet with
ferromagnetic materials

EMERGENCY DISCHARGE

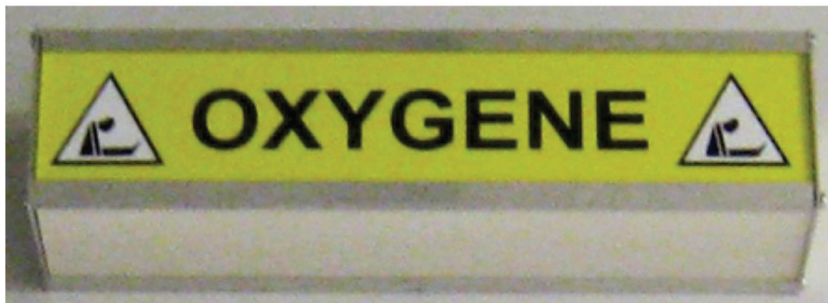
- To discharge the magnet as last resort to save someone's life.
- Cost: at least 500'000 CHF (if the magnet survives)

DO NOT TOUCH THE
EMERGENCY DISCHARGE
BUTTON!



CRYOGENS

- Nitrogen and helium are inert gases.
- Major risks:
 - Hypoxia and asphyxia.
 - Very cold
- Gas/liquid ratio: 700:1
- If you see/hear the alarm, evacuate and leave all doors open.



QUENCH

- Sudden loss of superconductivity.
 - Either initiated by the emergency discharge unit
 - Temperature too high
 - Magnet failure
 - Vacuum loss
- All the helium will boil off

RADIO-FREQUENCY WAVES

- Perturbations of telecommunications
- High voltage (300 V)
- RF heating
 - The subject absorbs RF power
 - Implants, conductive wires could exacerbate heating.

Table RIRs DOCs v.3989/1.1.26

Presets: – choose pre Lower freq: 590 MHz Upper freq: 605 MHz

Text: Search string Services Vectors *

☒ Table ☐ Allocations ☐ Applications

Swiss Allocations 590 - 605 MHz, Version of 1.1.2024					
Ba	National Allocation	Main Use	€	Notes	Strategy
590 - 605 MHz	for 470 - 608 MHz: BROADCASTING Land mobile 5.296 5.291A	for 470 - 608 MHz: Broadcasting primary. Land mobile secondary.	for 470 - 608 MHz: Broadcasting (terrestrial): Band IV, channel 21 - 34: 470-582 MHz: Annex 2, 8 M Hz: 582-608 MHz: Annex 2, CIV	for 470 - 608 MHz: Broadcasting (terrestrial): Band IV, channel 21 - 34: 470-582 MHz: Annex 2, 8 M Hz: 582-608 MHz: Annex 2, CIV DVB-T: RIR0201-71 DVB-T Retransmitter: RIR0201-72 470-518 MHz: Land mobile applications, inside shielded rooms only: RIR0507-08 Radio microphones and in-ear monitor systems: 470-694 MHz (max. 50 mW): RIR1009-10, ERC/REC 70-03, 477-694 MHz (max. 250 mW): RIR1009-11 Wireless audio applications: 477-694 MHz: RIR1013-20 UWB Applications, Annex 1	for 470 - 608 MHz: Terrestrial digital television broadcasting (DVB-T) or mobile multimedia services (as DVB-H) according to Regional Agreement GE06. 470-494 MHz: Wind profilers: Geographical sharing with wind profiler radars (RR 5.291A).

National Frequency Allocation Plan, OFCOM

MR SCREENING FORM

- To check whether you have anything that prevents you from going close to the magnet.





Magnetic resonance (MR) environment screening form for individuals

The MR system has a very strong magnetic field that may be hazardous to individuals entering the MR environment or MR system room if they have certain metallic, electronic, magnetic, or mechanical implants, devices, or objects. Therefore, all individuals are required to fill out this form BEFORE entering the MR environment or MR system room. Be advised, the MR system magnet is ALWAYS on. Please fill out this security questionnaire before entering the MRI room. An investigator is here at your disposal to help you fill out the form.

Code/Surname: _____ First name: _____

Age: _____

	Yes	No
1. Have you had prior surgery or an operation (e.g., arthroscopy, endoscopy, etc.) of any kind? If yes, please indicate type of surgery and date: Type of intervention: _____ Date: _____	☐	☐
2. Have you had an injury to the eye involving a metallic object (e.g., metallic slivers, foreign body)? If yes, please describe: _____	☐	☐
3. Have you ever been injured by a metallic object or foreign body (e.g., BB, bullet, shrapnel, etc.)? If yes, please describe: _____	☐	☐
4. Are you pregnant or suspect that you are pregnant?	☐	☐
Please indicate if you have any of the following:		
Aneurysm clip(s)	☐	☐
Cardiac pacemaker	☐	☐
Implanted cardioverter defibrillator (ICD) Electronic implant or device	☐	☐
Magnetically-activated implant or device	☐	☐
Neurostimulation system	☐	☐
Spinal cord stimulator	☐	☐
Cochlear implant or implanted hearing aid	☐	☐
Insulin or infusion pump	☐	☐
Implanted drug infusion device	☐	☐
Any type of prosthesis or implant	☐	☐
Artificial or prosthetic limb	☐	☐
Any metallic fragment or foreign body	☐	☐
Hearing aid (Remove before entering the MR system room)	☐	☐
Other implant _____	☐	☐



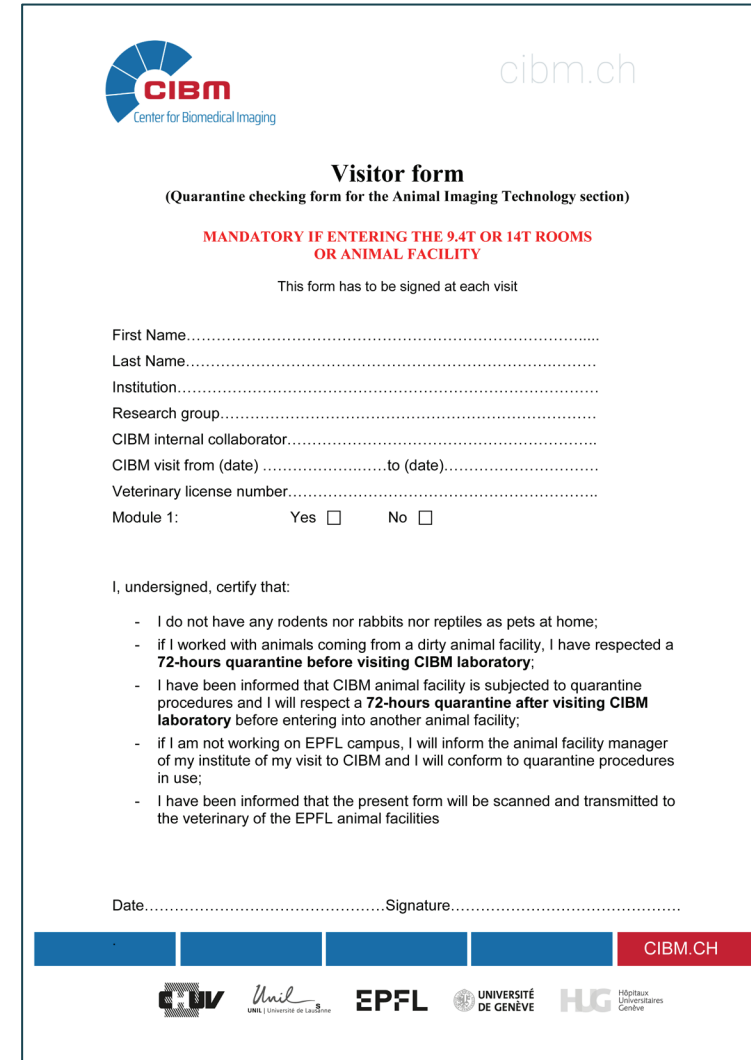
Remove **all** metallic objects before entering the MR environment or MR system room including hearing aids, beeper, cell phone, keys, eyeglasses, hair pins, barrettes, jewelry (including body piercing jewelry), watch, safety pins, paperclips, money clip, credit cards, bank cards, magnetic strip cards, coins, pens, pocket knife, nail clipper, steel-toed boots/shoes, and tools.

I attest that the above information is correct to the best of my knowledge. I have read and understand the entire contents of this form and have had the opportunity to ask questions regarding the information on this form.

Signature and date: _____

QUARANTINE CHECKING FORM

- Prevent any contamination from external sources.
- Form to be filled every time to confirm that the rules are respected before entering experimentation area.



The form is titled "Visitor form" and is for the "Quarantine checking form for the Animal Imaging Technology section". It includes the CIBM logo and website (cibm.ch). The form is mandatory for entering the 9.4T or 14T rooms or animal facility. It contains fields for personal and institutional information, a section for certifying rules, and a signature line. At the bottom, there are logos for CIBM, UNIL, EPFL, and HUG.

 cibm.ch

Visitor form
(Quarantine checking form for the Animal Imaging Technology section)

**MANDATORY IF ENTERING THE 9.4T OR 14T ROOMS
OR ANIMAL FACILITY**

This form has to be signed at each visit

First Name.....
Last Name.....
Institution.....
Research group.....
CIBM internal collaborator.....
CIBM visit from (date)to (date).....
Veterinary license number.....

Module 1: Yes ☐ No ☐

I, undersigned, certify that:

- I do not have any rodents nor rabbits nor reptiles as pets at home;
- if I worked with animals coming from a dirty animal facility, I have respected a **72-hours quarantine before visiting CIBM laboratory**;
- I have been informed that CIBM animal facility is subjected to quarantine procedures and I will respect a **72-hours quarantine after visiting CIBM laboratory** before entering into another animal facility;
- if I am not working on EPFL campus, I will inform the animal facility manager of my institute of my visit to CIBM and I will conform to quarantine procedures in use;
- I have been informed that the present form will be scanned and transmitted to the veterinary of the EPFL animal facilities

Date.....Signature.....

     CIBM.CH



THANK YOU FOR YOUR ATTENTION



C I B M . C H