
Introduction to Magnetic Resonance Imaging

درس مقدمه ای بر تصویرگری پزشکی

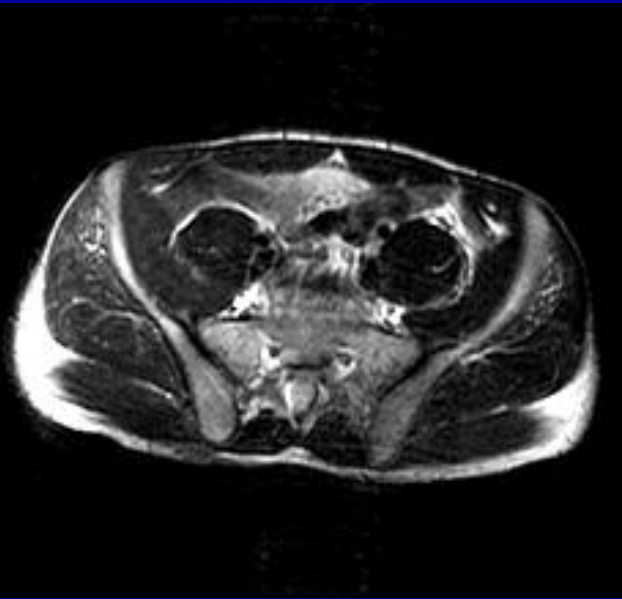
Sahand University of Technology
Faculty of Biomedical Engineering

M. Shamsi



Magnetic Resonance Imaging

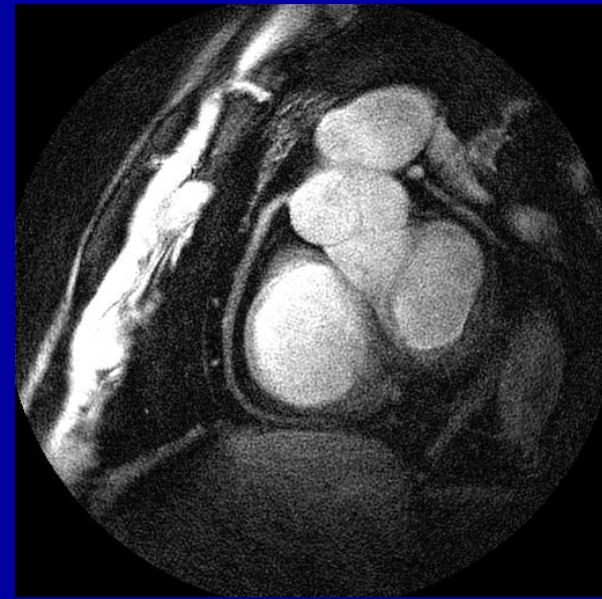
- Non-invasive medical imaging method, like ultrasound and X-ray.
- Clinically used in a wide variety of specialties.



Abdomen



Spine



Heart / Coronary

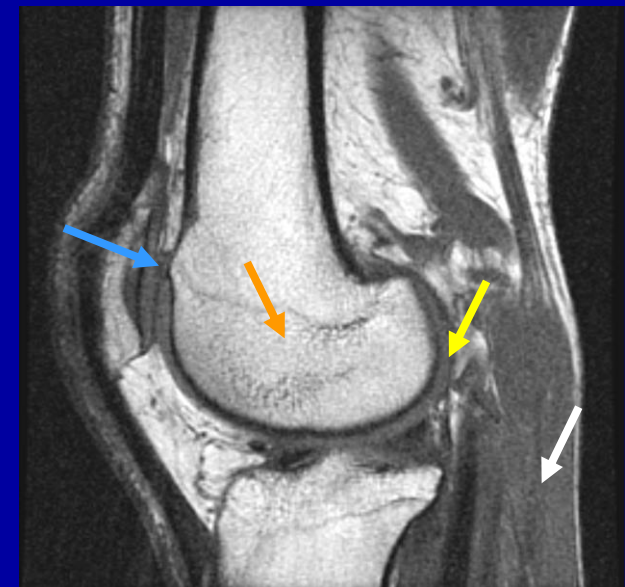
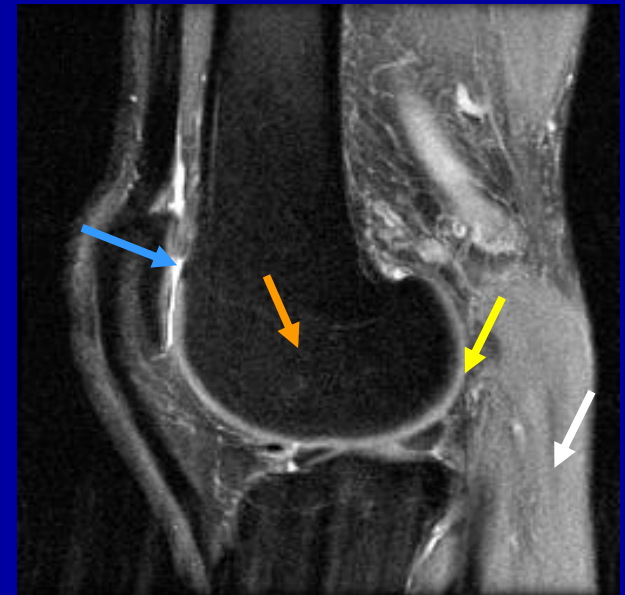
Magnetic Resonance Imaging

Advantages:

- Excellent / flexible contrast
- Non-invasive
- No ionizing radiation
- Arbitrary scan plane

Challenges:

- New contrast mechanisms
- Faster imaging



Topics

- MRI Physics
- Hardware
- MR Image Formation
- Contrast
- Applications of MRI

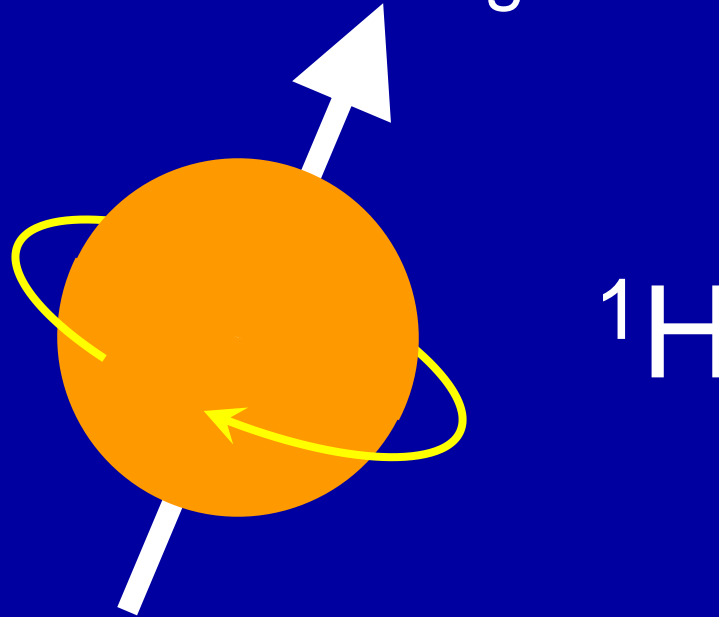
Topics

- MRI Physics
- Hardware
- MR Image Formation
- Contrast
- Applications of MRI

MRI Physics

Magnetic Resonance

- Certain atomic nuclei including ^1H exhibit nuclear magnetic resonance.
- Nuclear “spins” are like magnetic dipoles.

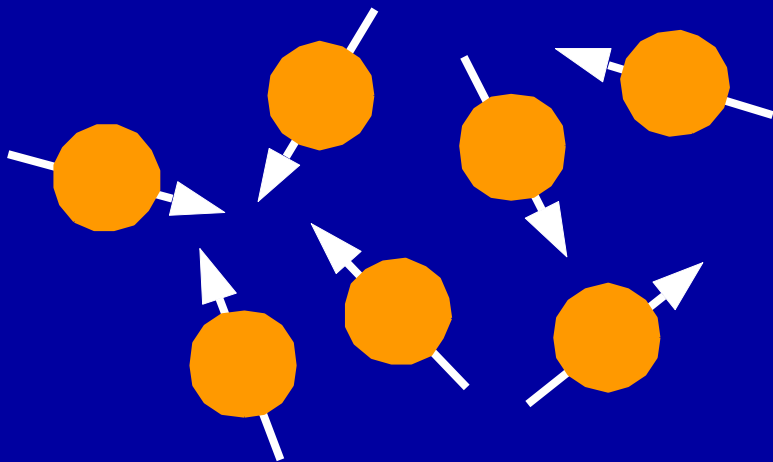


MRI Physics

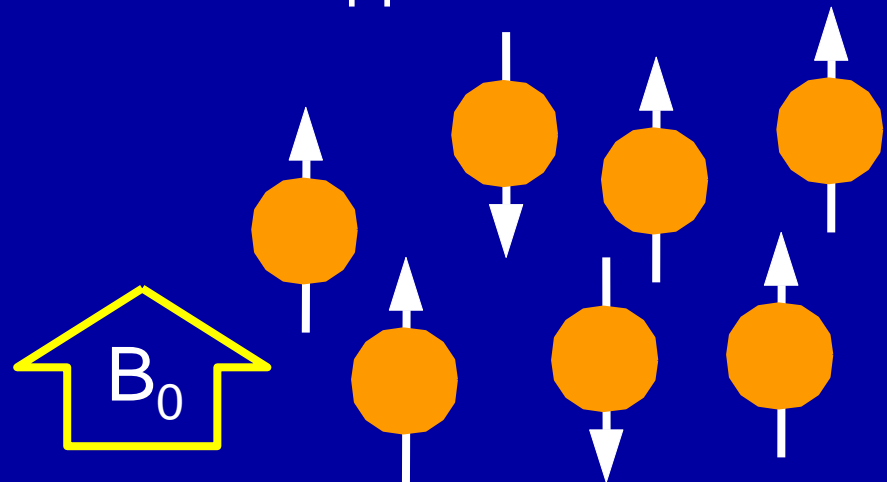
Polarization

- Spins are normally oriented randomly.
- In an applied magnetic field, the spins align with the applied field in their equilibrium state.
- Excess along B_0 results in net magnetization.

No Applied Field



Applied Field



MRI Physics

Possible nuclear spin states

- High Energy

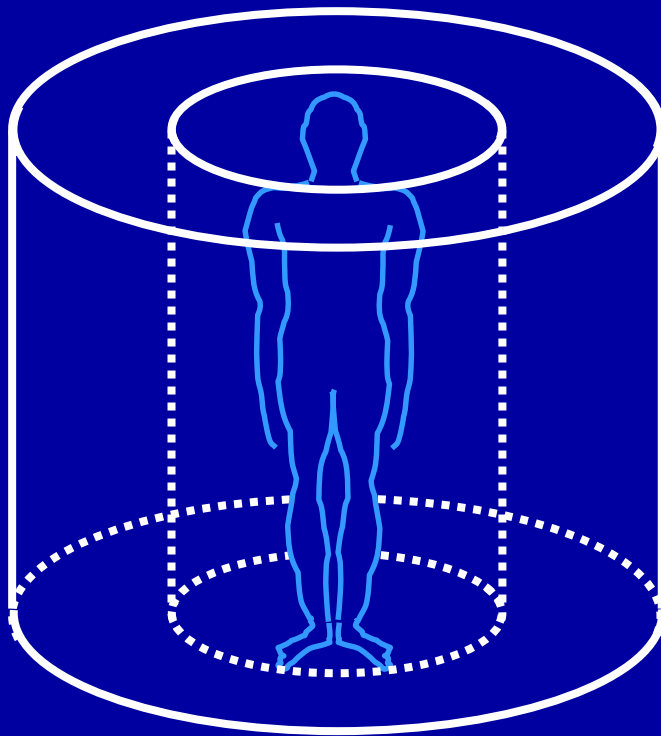


- Low Energy



MRI Physics

Static Magnetic Field



Longitudinal

z

x, y

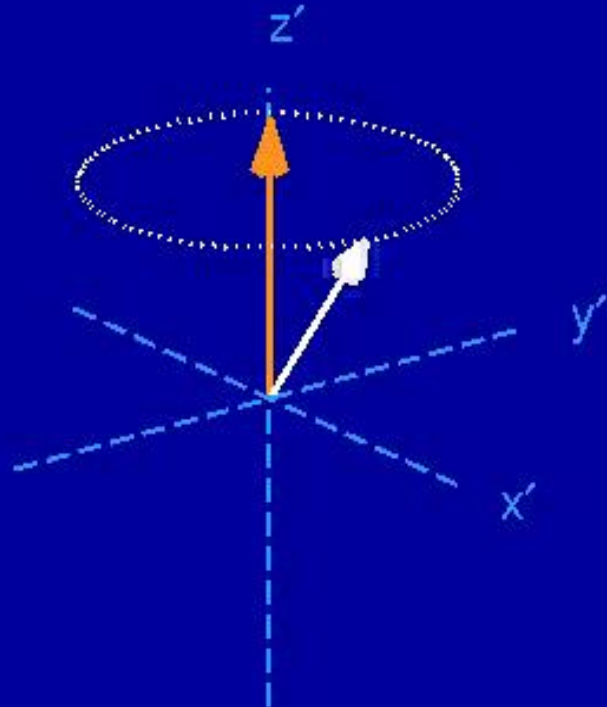
Transverse

MRI Physics

Precession

- Spins precess about applied magnetic field, B_0 , that is along z axis.
- The frequency of this precession is proportional to the applied field:

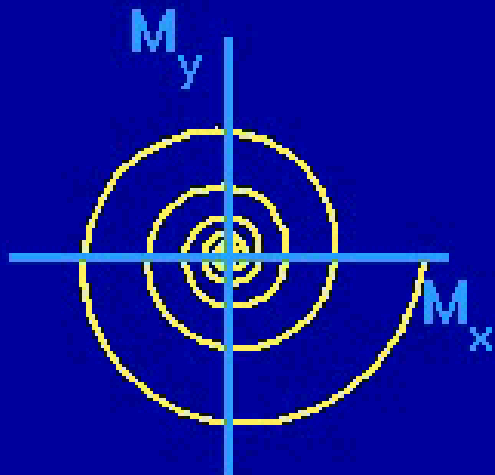
$$\omega = \gamma B$$



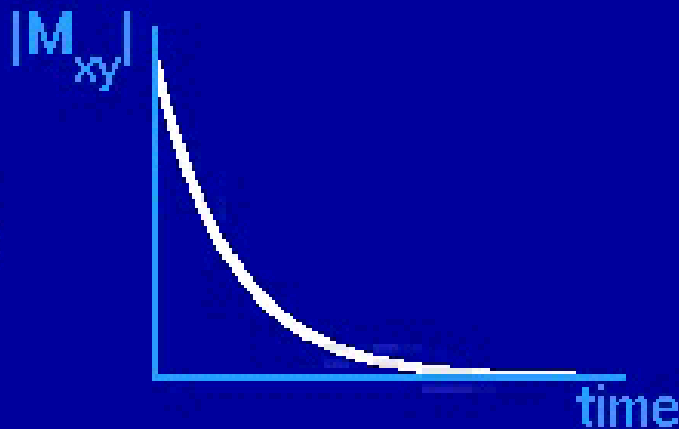
MRI Physics

Relaxation

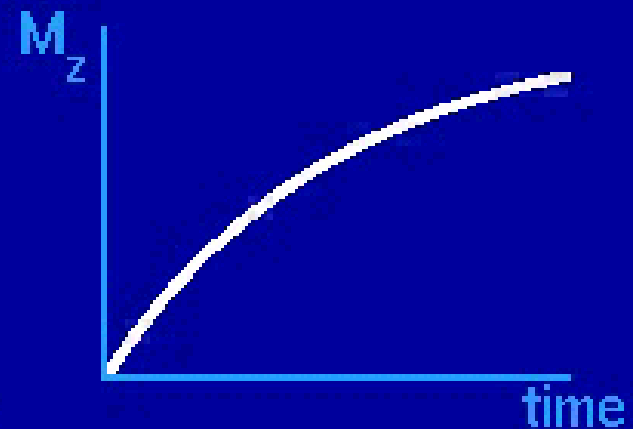
- Magnetization returns exponentially to equilibrium:
 - Longitudinal *recovery* time constant is T_1
 - Transverse *decay* time constant is T_2
- Relaxation and precession are independent.



Precession



Decay



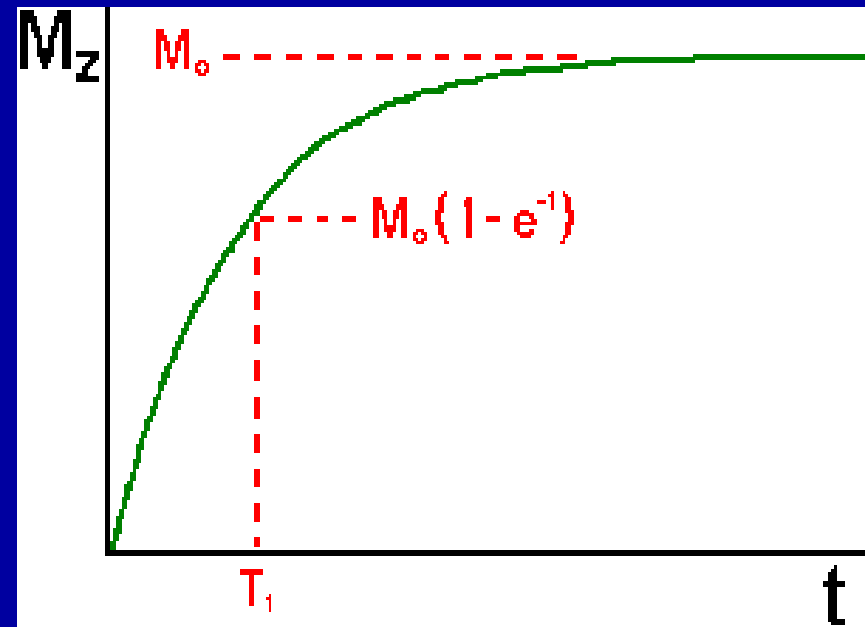
Recovery

MRI Physics

T_1 Relaxation Time

- After RF pulse
 - 1. Spins go back to the lowest energy state
 - 2. Spins get out of phase
- T_1 also called spin-lattice relaxation time
- Spins give energy to the surrounding lattice

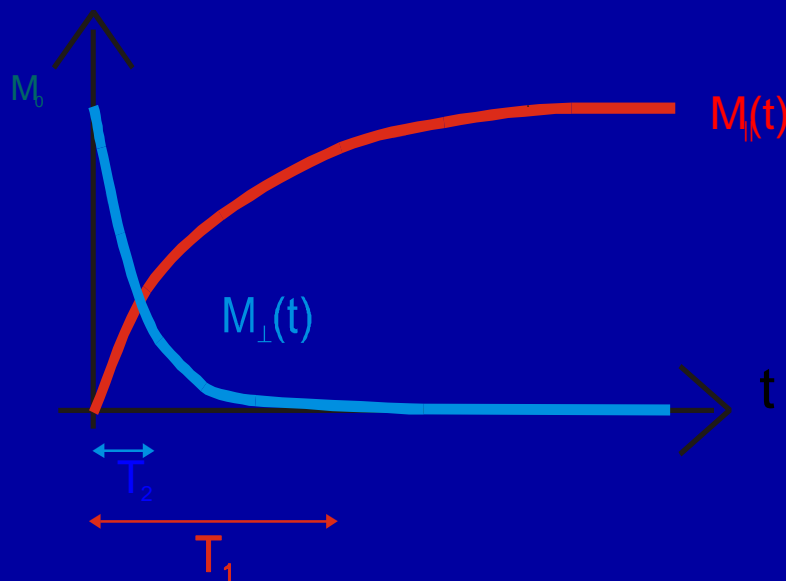
$$M_z(t) = M_0(1 - e^{-t/T_1})$$



MRI Physics

T_2^* Relaxation Time

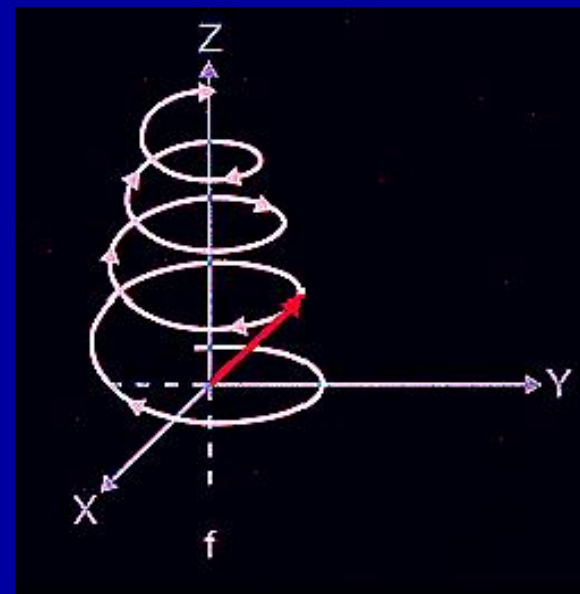
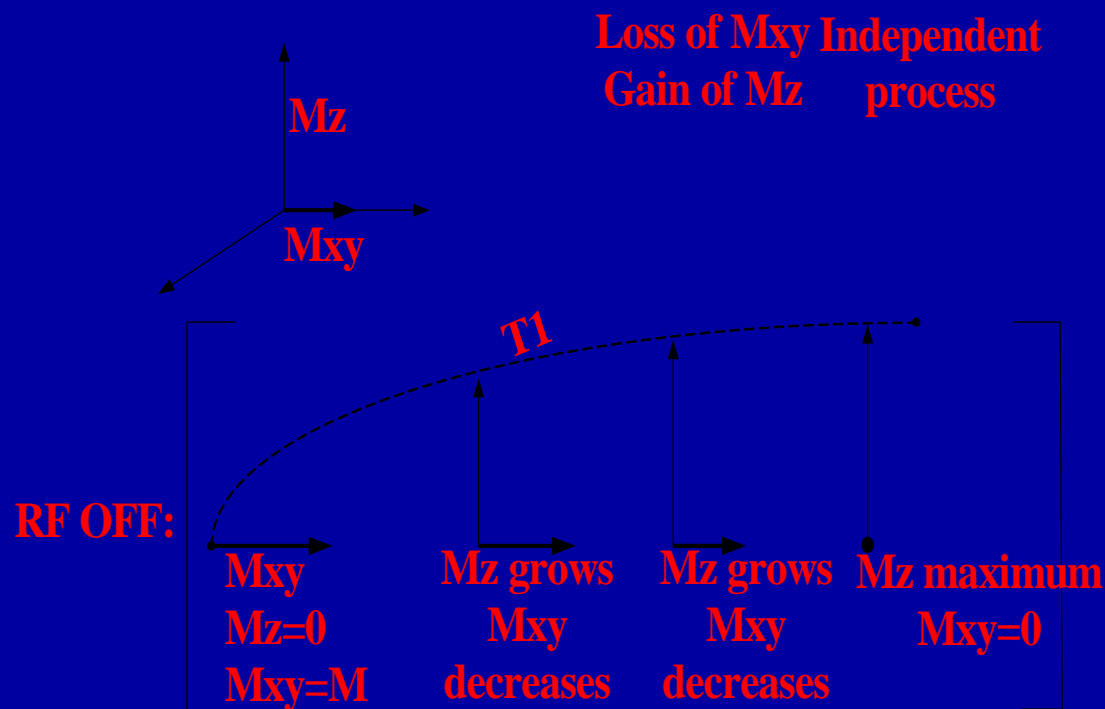
- Due to
 - Interactions among individual spins
 - External magnetic field inhomogeneity



MRI Physics

T_1 and T_2

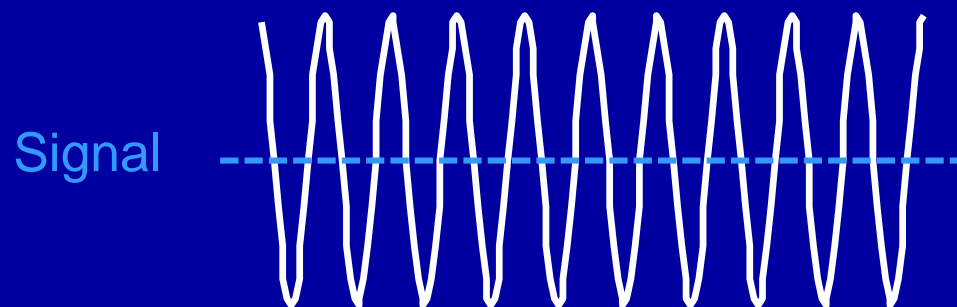
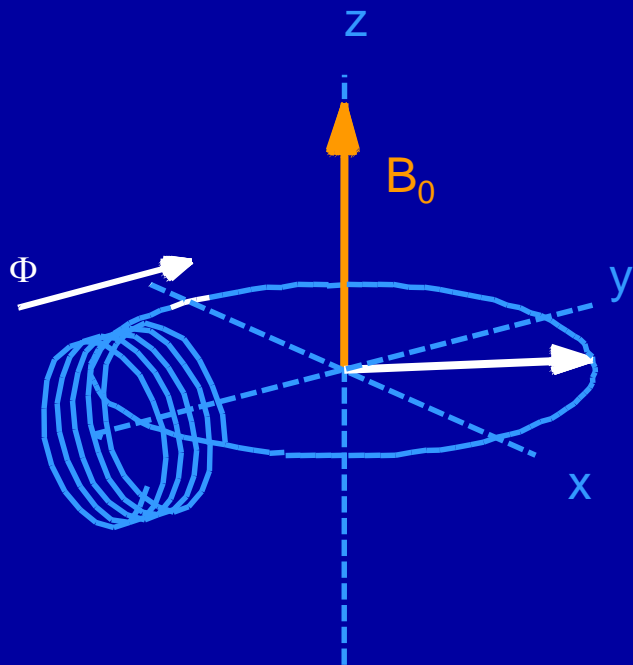
- T_2 usually much faster than T_1



MRI Physics

Signal Reception

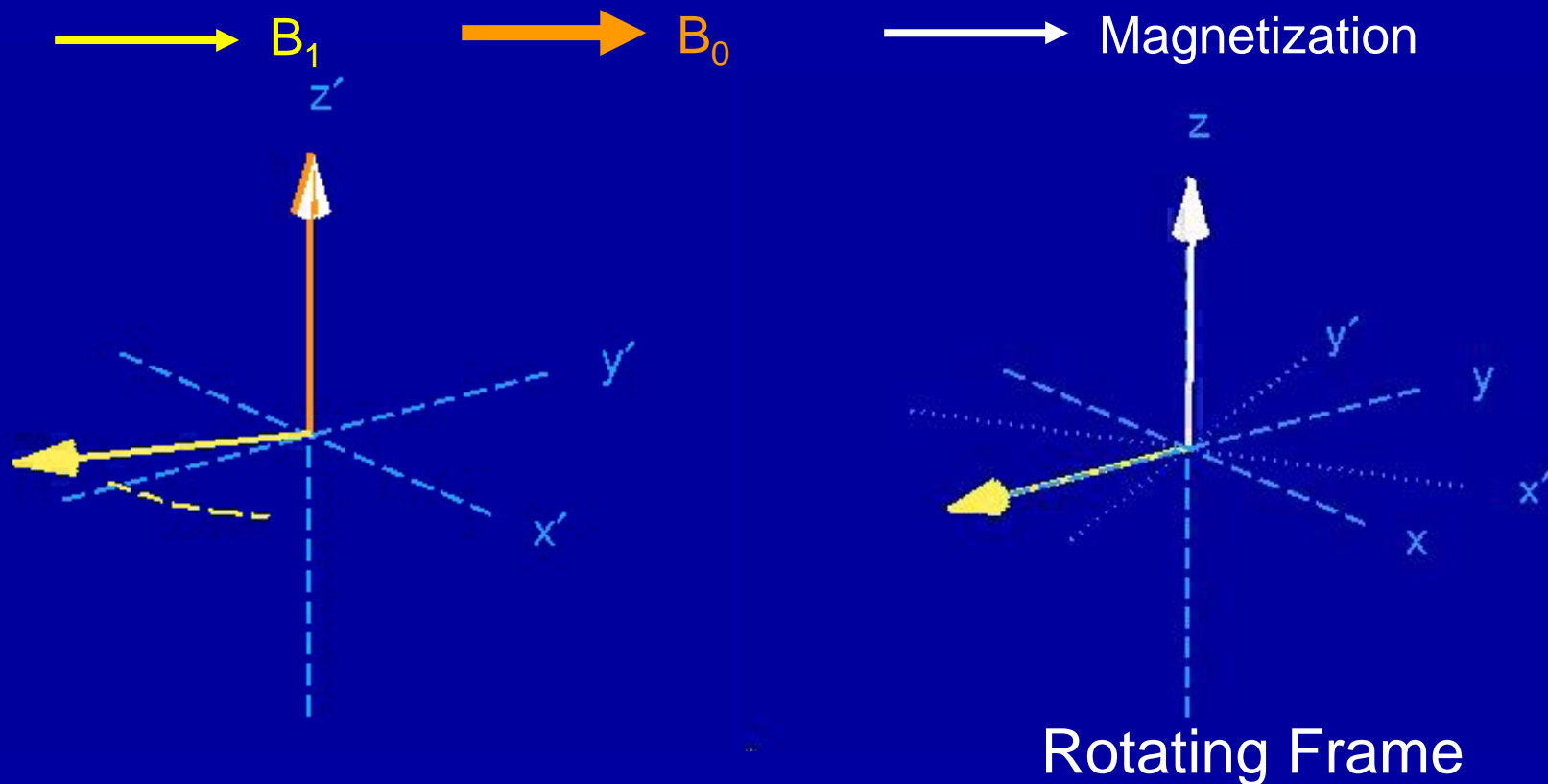
- Precessing spins cause a change in flux (Φ) in a transverse receive coil.
- Flux change induces a voltage across the coil.



MRI Physics

Excitation

- “Excite” spins out of their equilibrium state.
- Transverse RF field (B_1) rotates at γB_0 about z-axis.



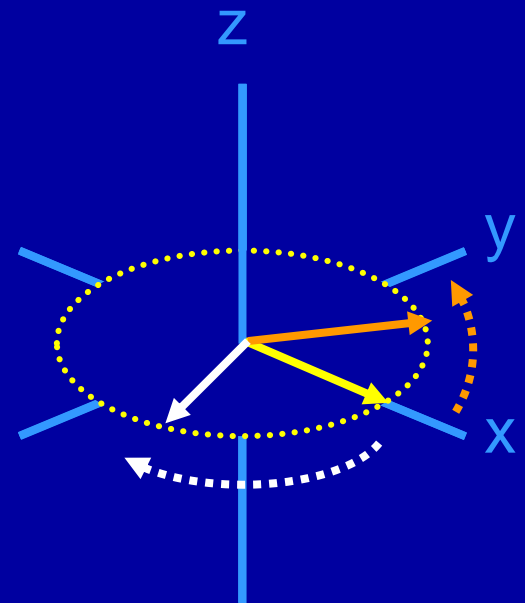
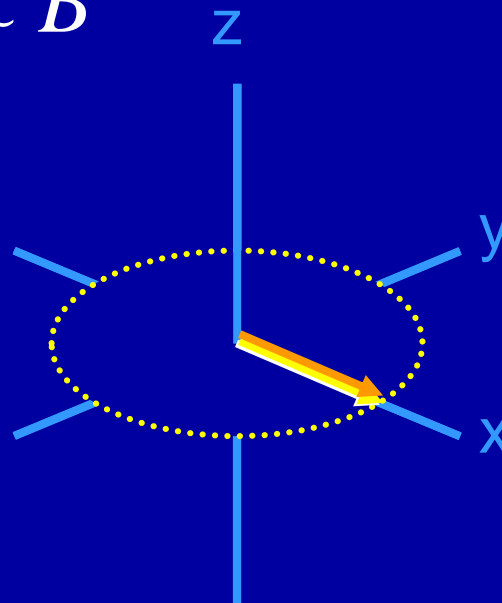
MRI Physics

Off-Resonance

- Practically, the magnetic field strength is not perfectly uniform.
- Resonant frequency is proportional to field strength: $\omega \propto B$

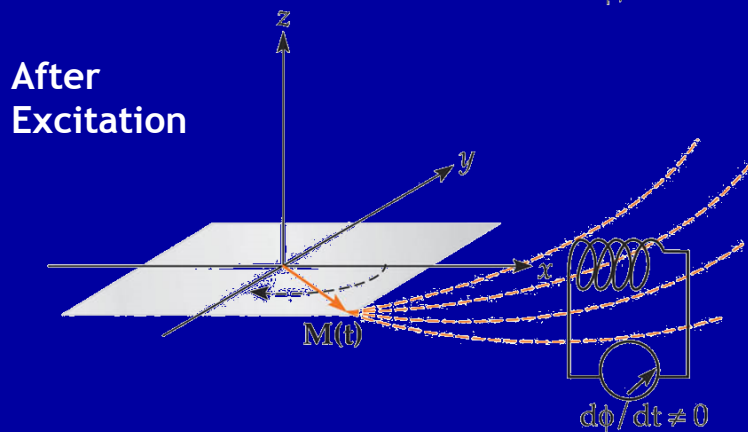
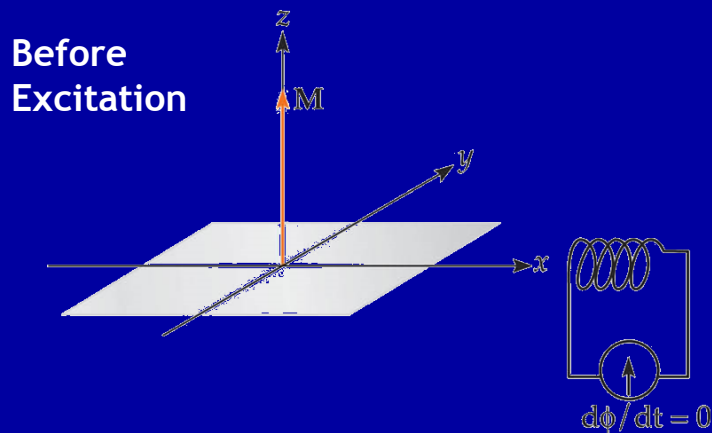
Off-resonance:

$$\Delta\omega = \omega - \omega_0$$

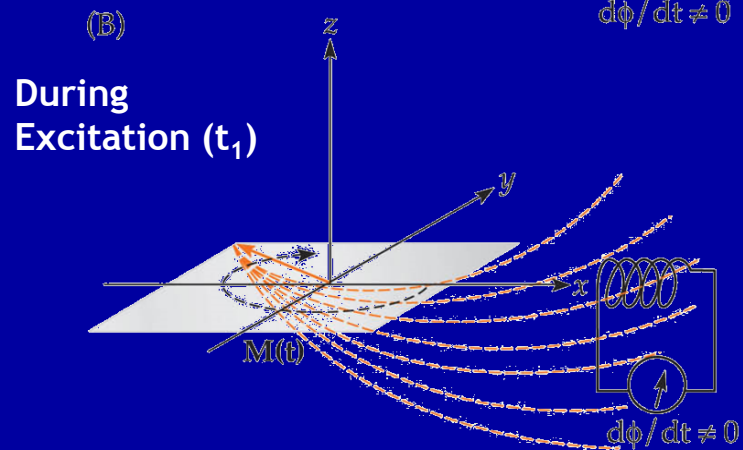
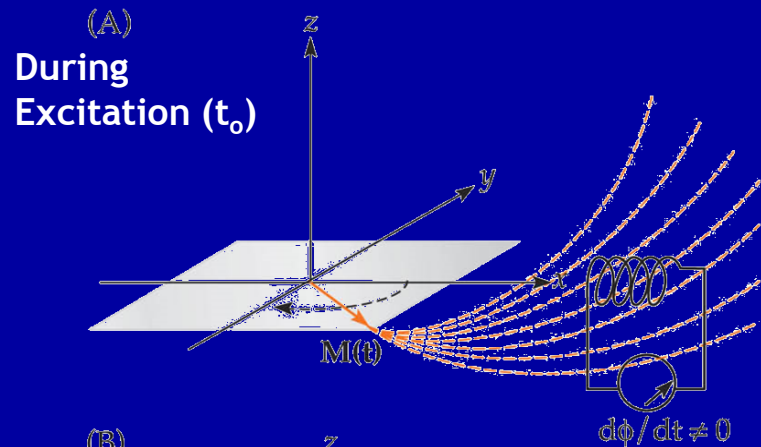


MRI Physics

Origin of the MR Signal



Excitation tips the net magnetization (M) down into the transverse plane, where it can generate current in detector coils.

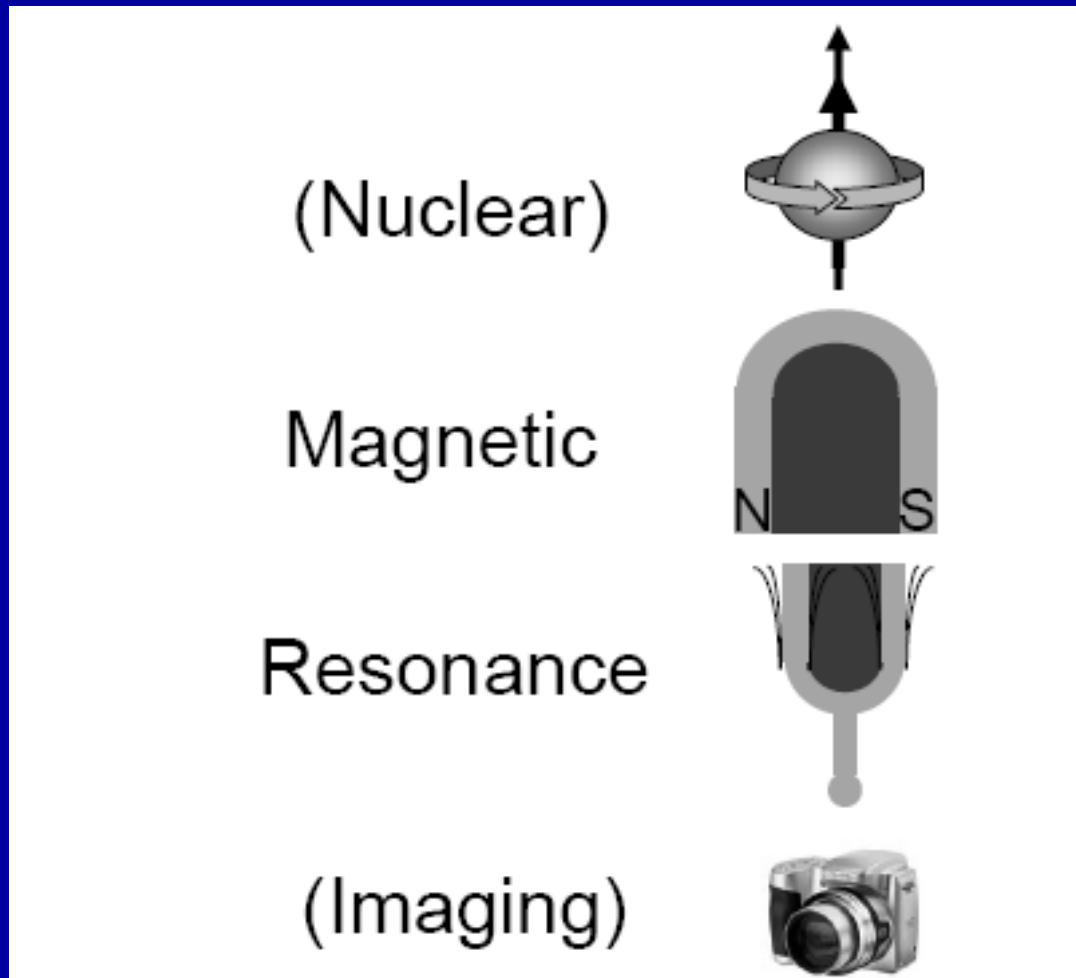


The amount of current oscillates at the (Larmor) frequency of the net magnetization.

Topics

- MRI Physics
- Hardware
- MR Image Formation
- Contrast
- Applications of MRI

MRI hardware



MRI hardware

The Big Magnet

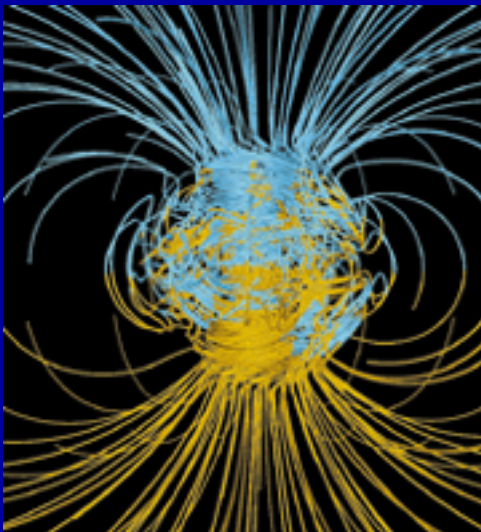
Main field = B_0

- Continuously on

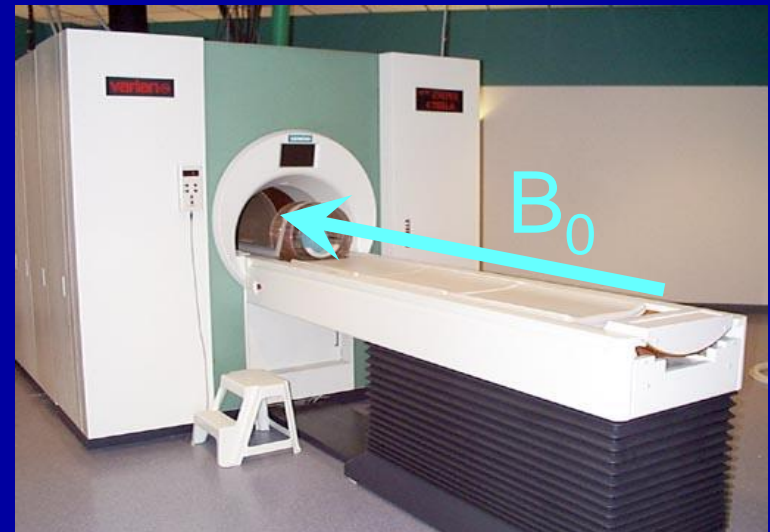
- Very strong :

Earth's magnetic field = 0.5 Gauss / 1 Tesla (T) = 10,000 Gauss

3 Tesla = $3 \times 10,000 \div 0.5 = 60,000 \times$ Earth's magnetic field

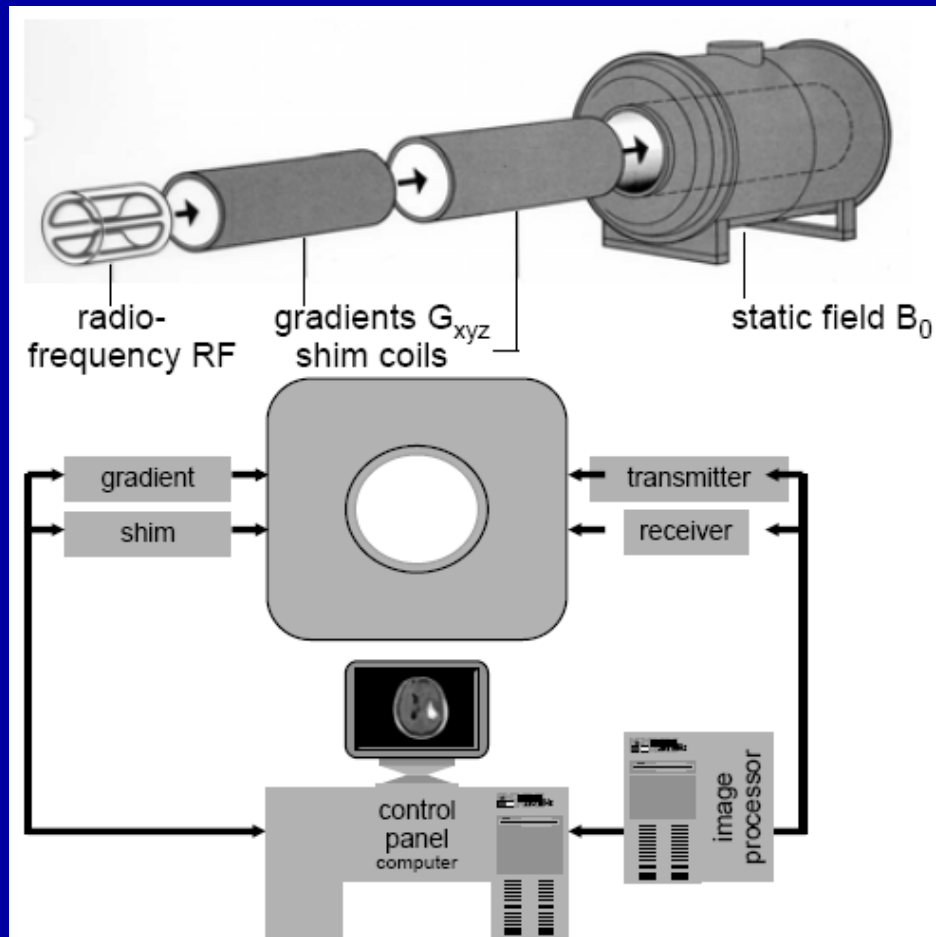


$\times 60,000 =$



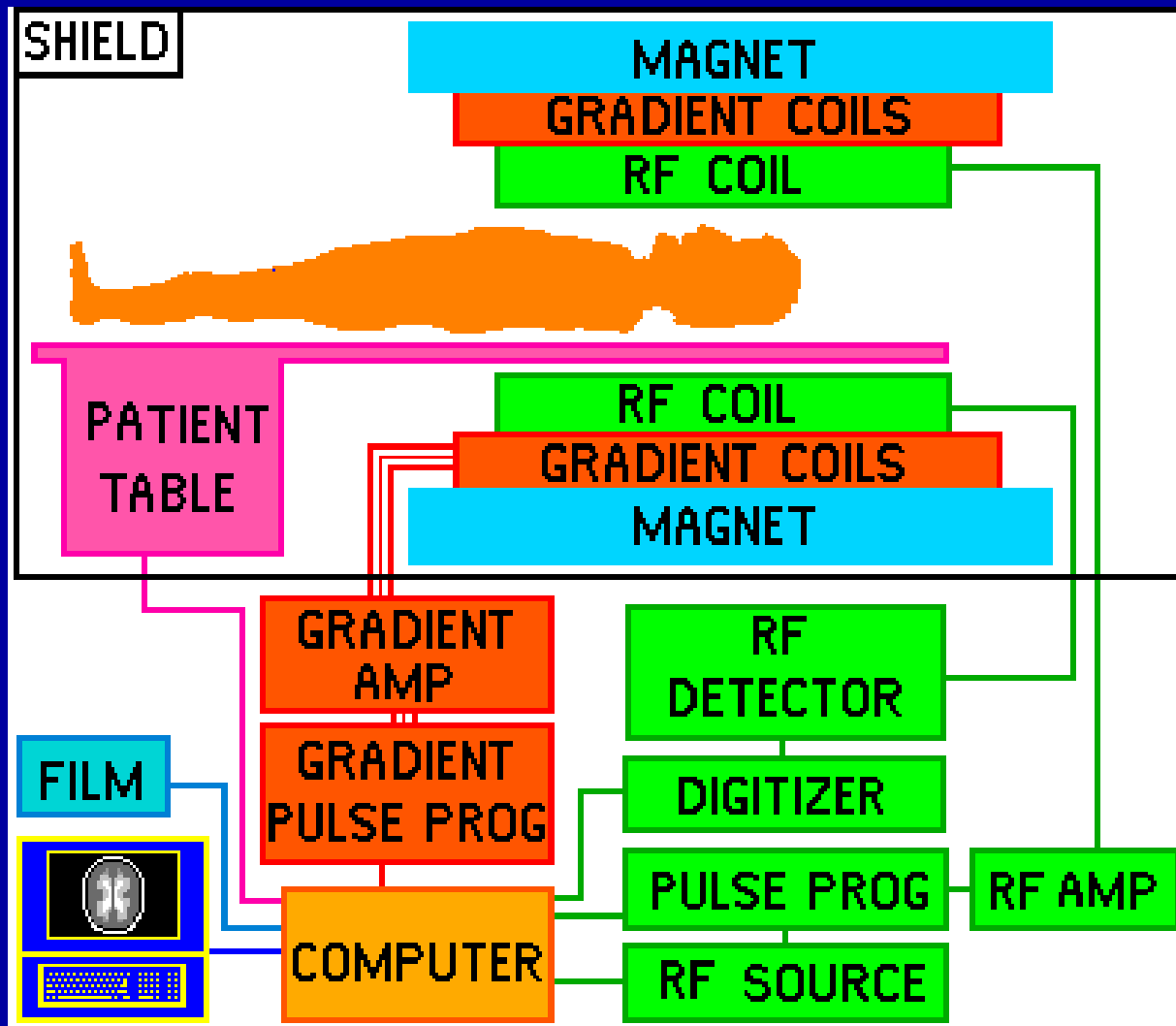
Robarts Research Institute 3T

MRI hardware

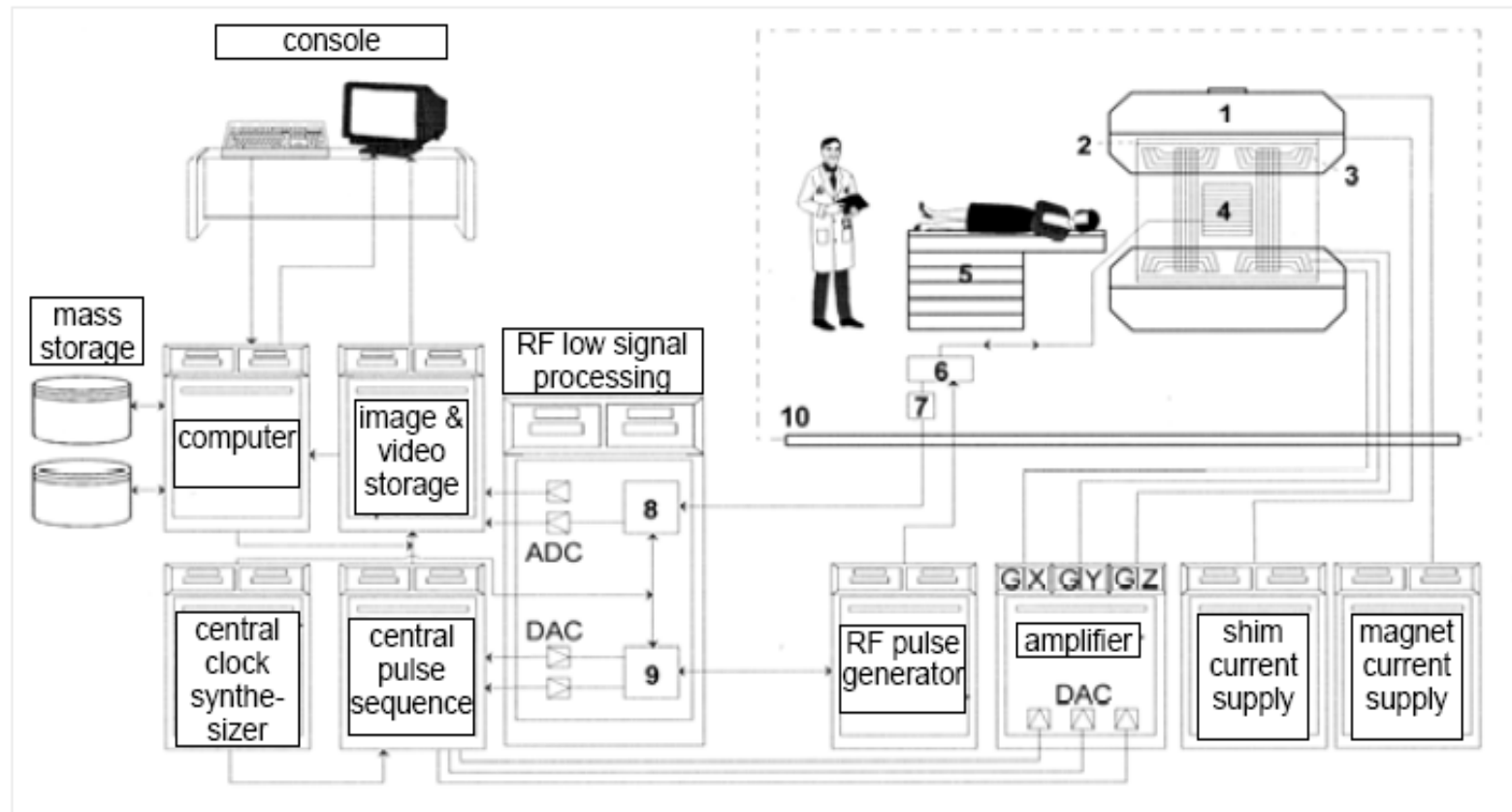


technical component	→	physical parameter
static field B_0	→	M_0
radiofreq. RF	→	signal
gradients G_{xyz}	→	image

MRI hardware



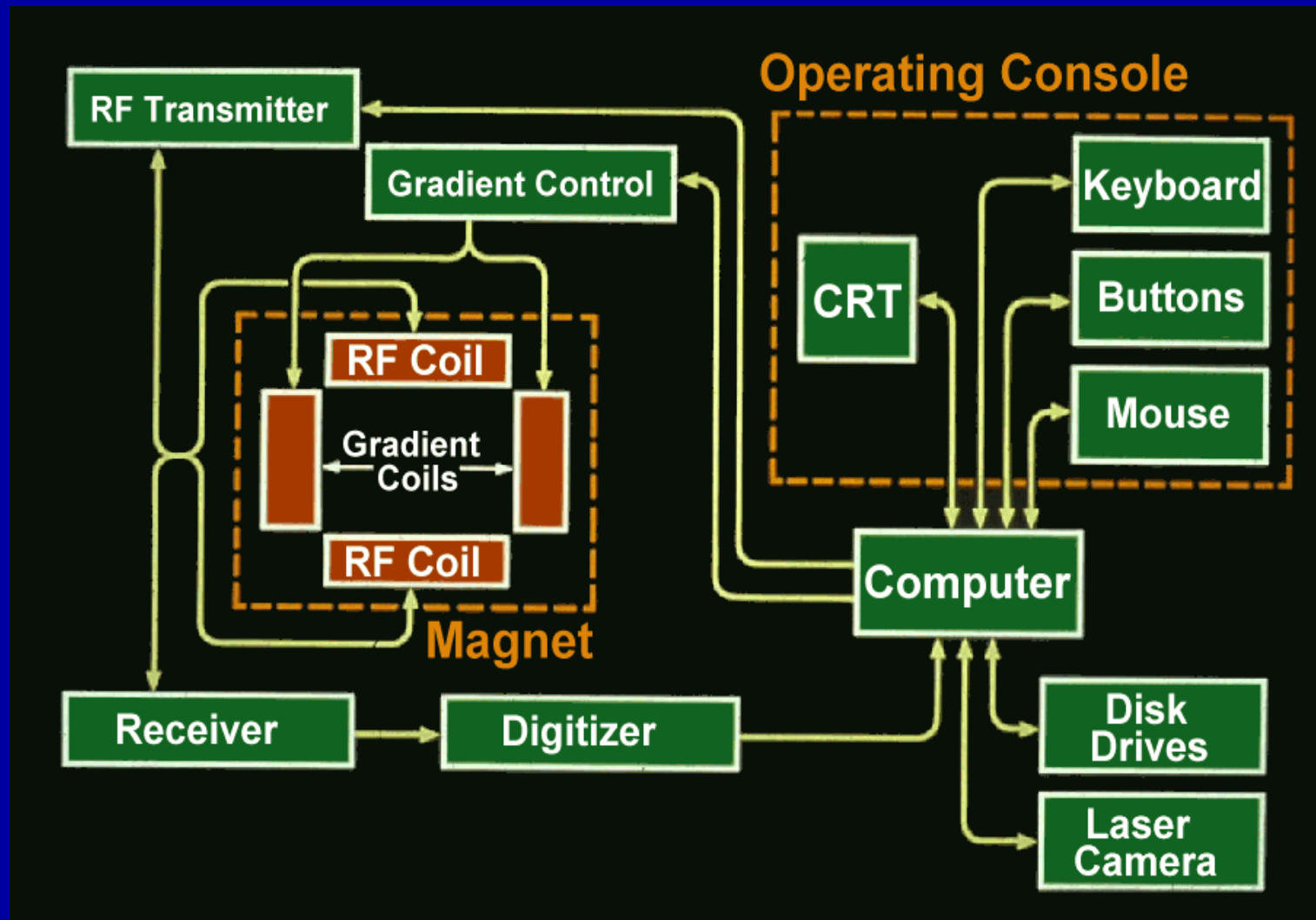
MRI hardware



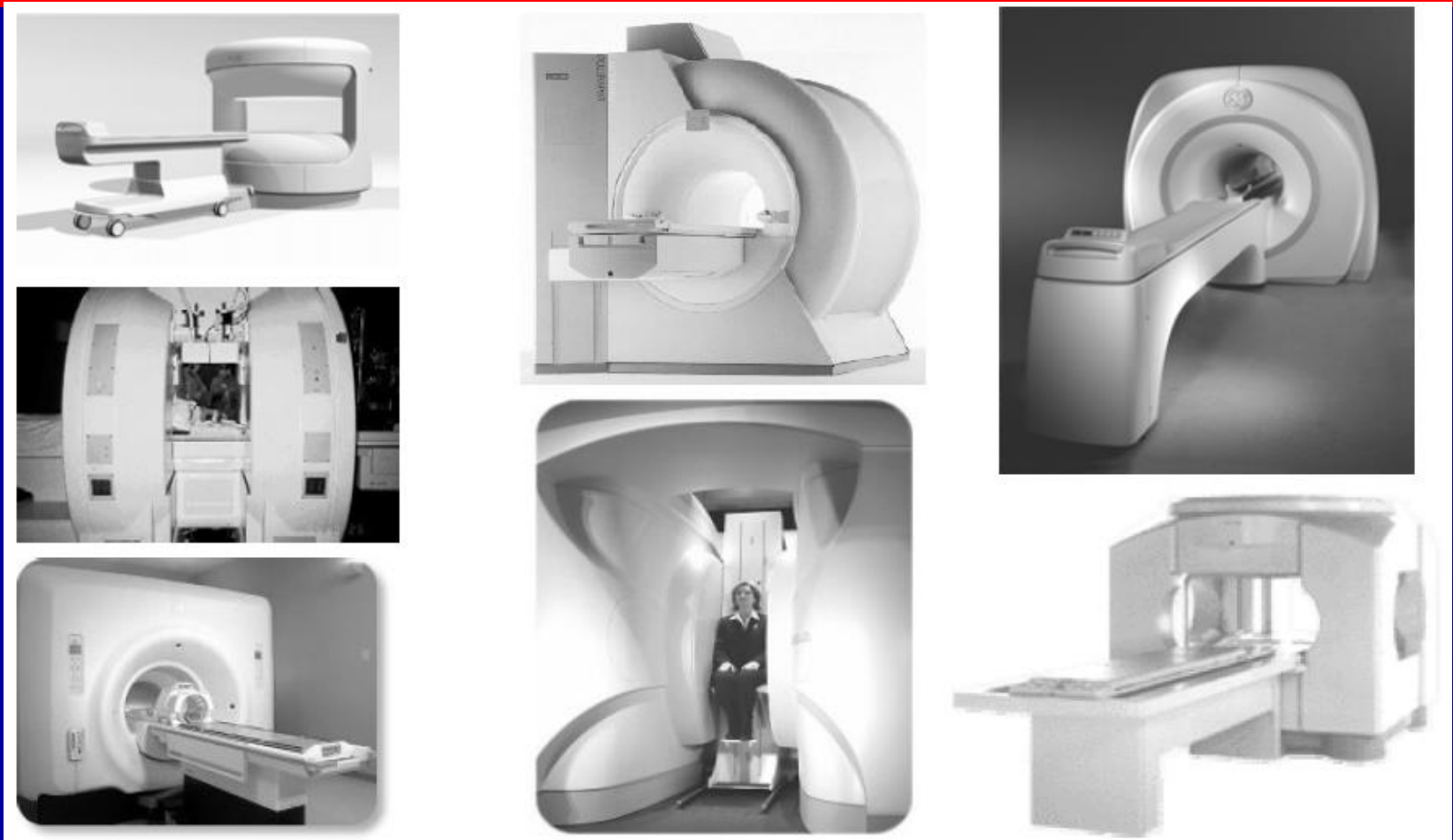
- 1 magnet with cryotank and cryoshield
- 2 shim coils
- 3 gradient coils
- 4 RF-resonator
- 5 patient couch

- 6 transmit/receive duplexer
- 7 preamplifier
- 8 low/high-pass filter
- 9 ESB-module
- 10 RF leak proof connections

MRI hardware



MRI hardware

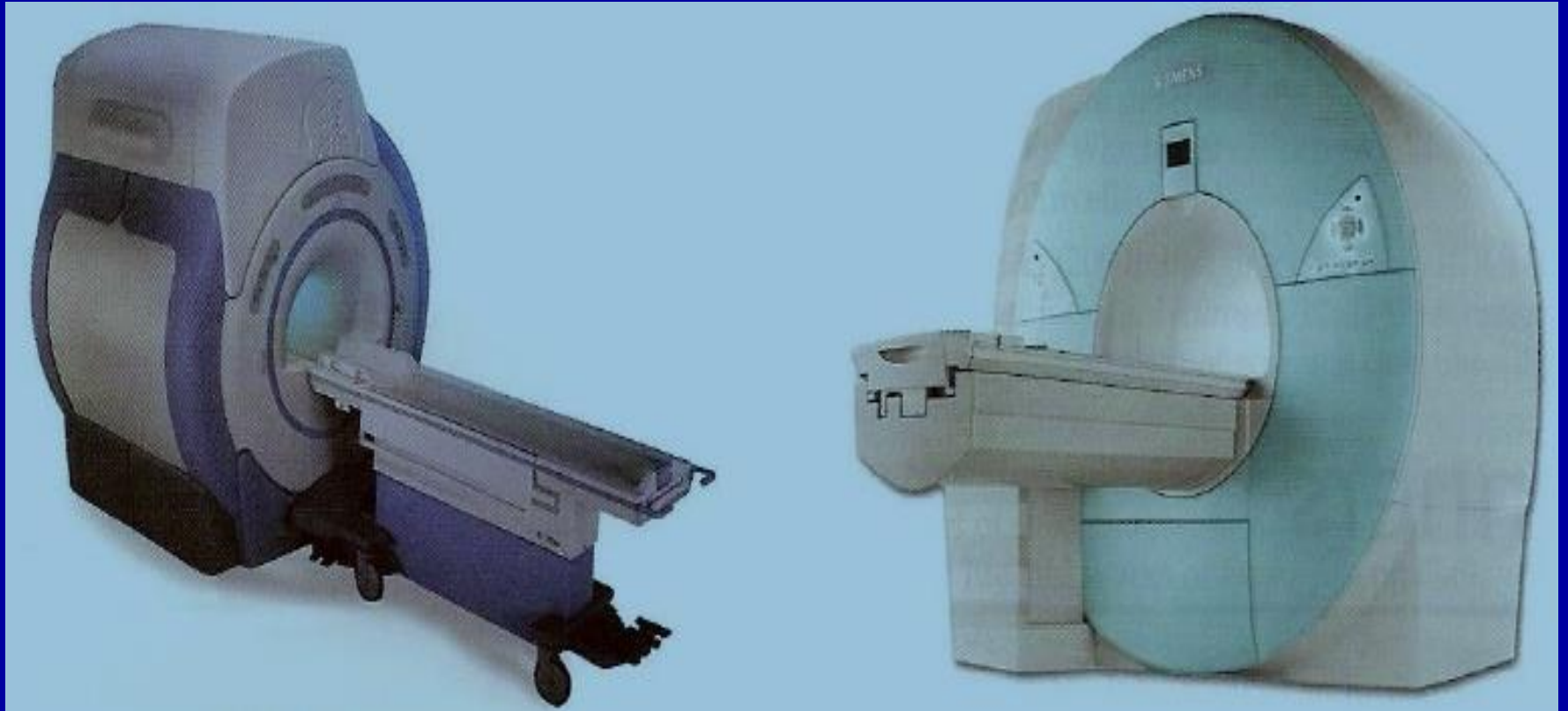


MRI hardware



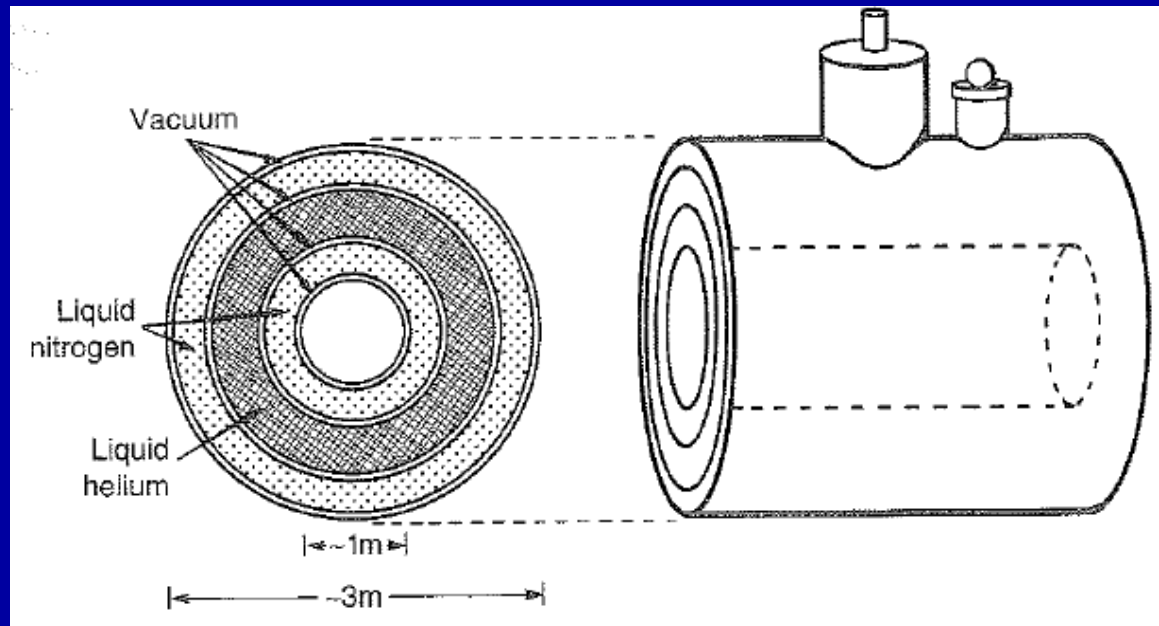
At \$2 million, the most expensive equipment in the hospital...

MRI hardware



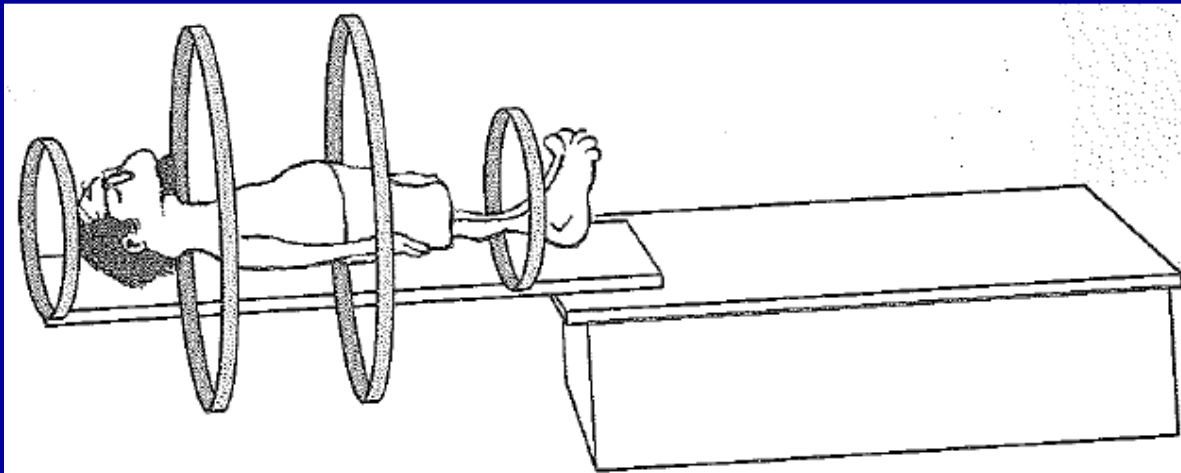
MRI hardware

Superconducting Magnet



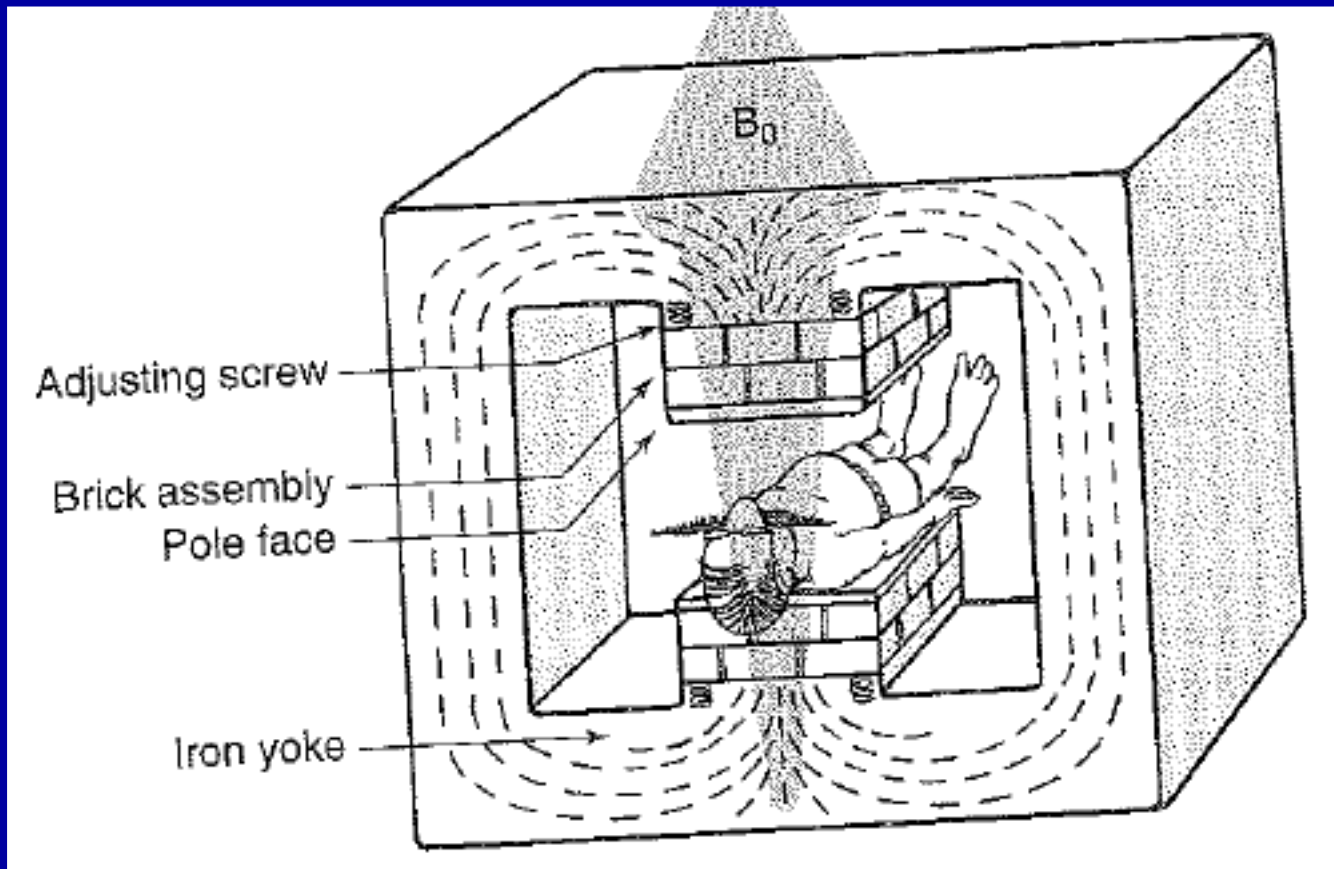
MRI hardware

Resistive Electromagnet

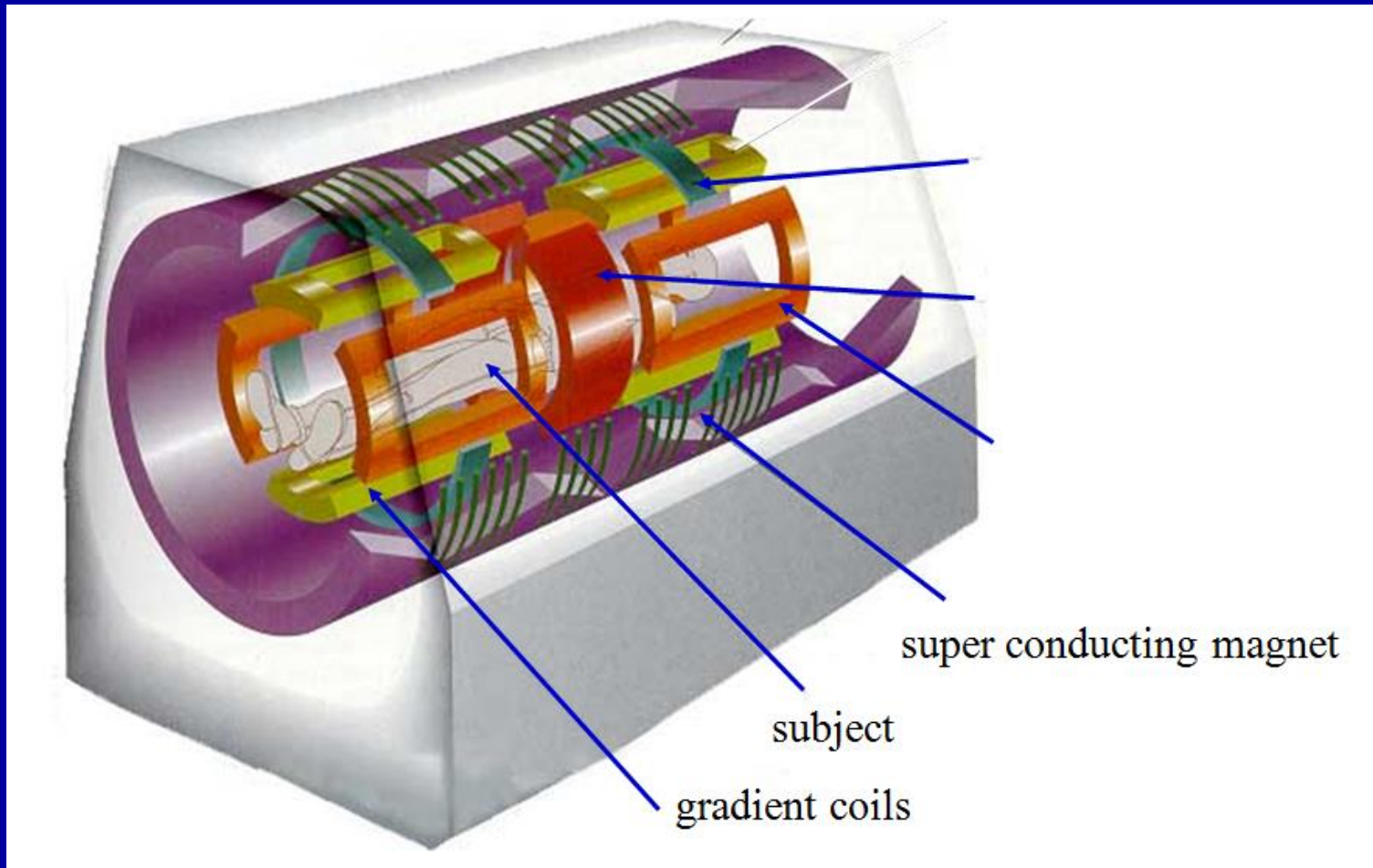


MRI hardware

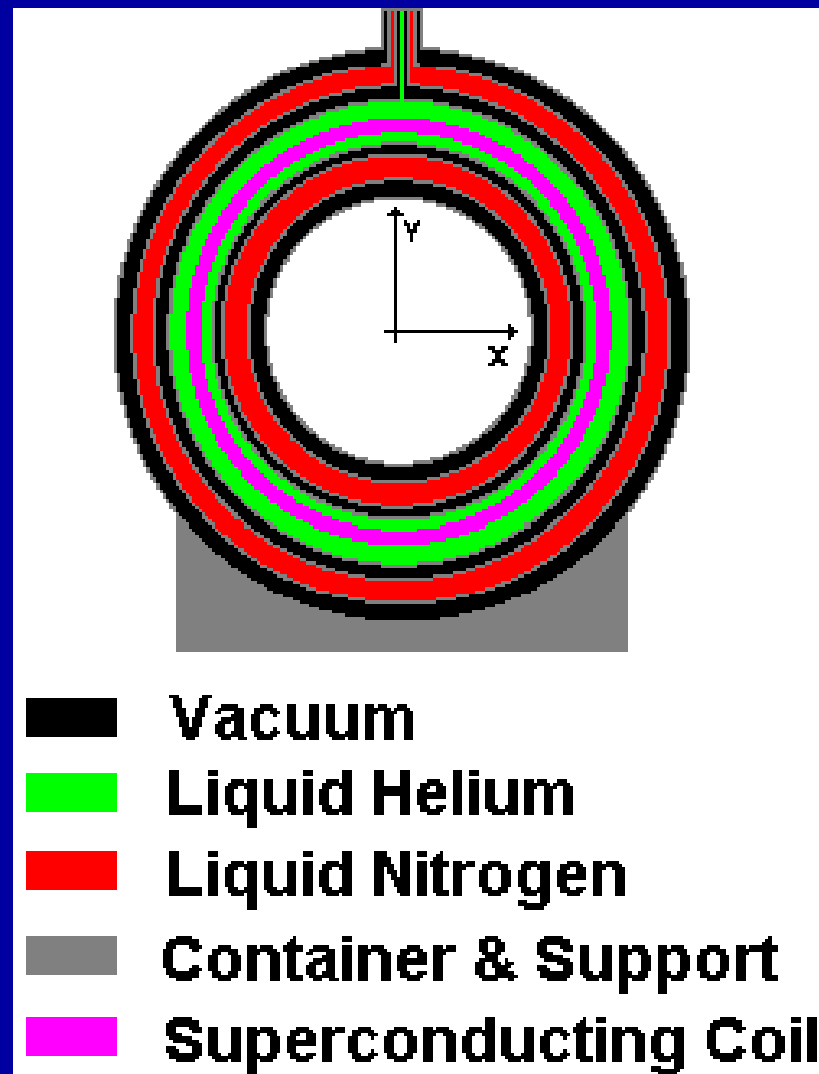
Permanent MRI System



MRI hardware

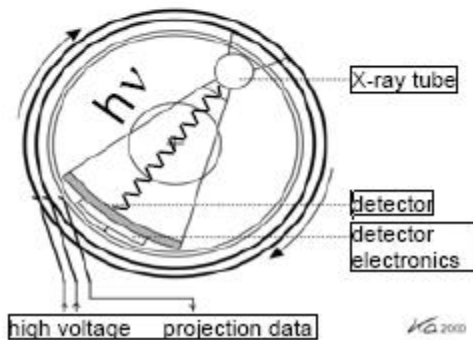


MRI hardware

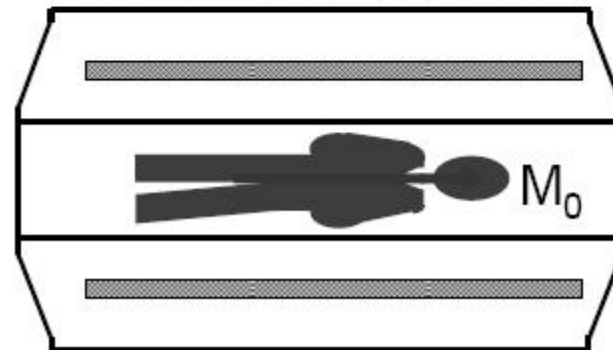
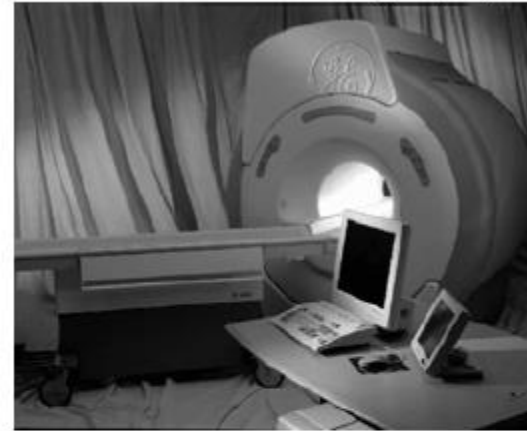


MRI hardware

CT = transmission tomography



MRI = "direct" tomography



MRI hardware

RF coils in use



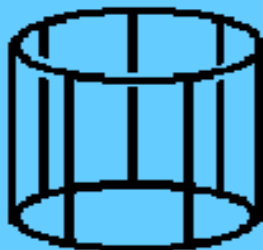
Surface Coils

Surface coils are commonly used for spines, shoulders, TMJ's, and other relatively small body parts.



Paired Saddle Coil

Paired saddle coils are commonly used for imaging of the knee. By running current in opposite directions in the two halves of the gradient coil, the magnetic field is made stronger near one and weaker near the other.



Bird Cage Coil

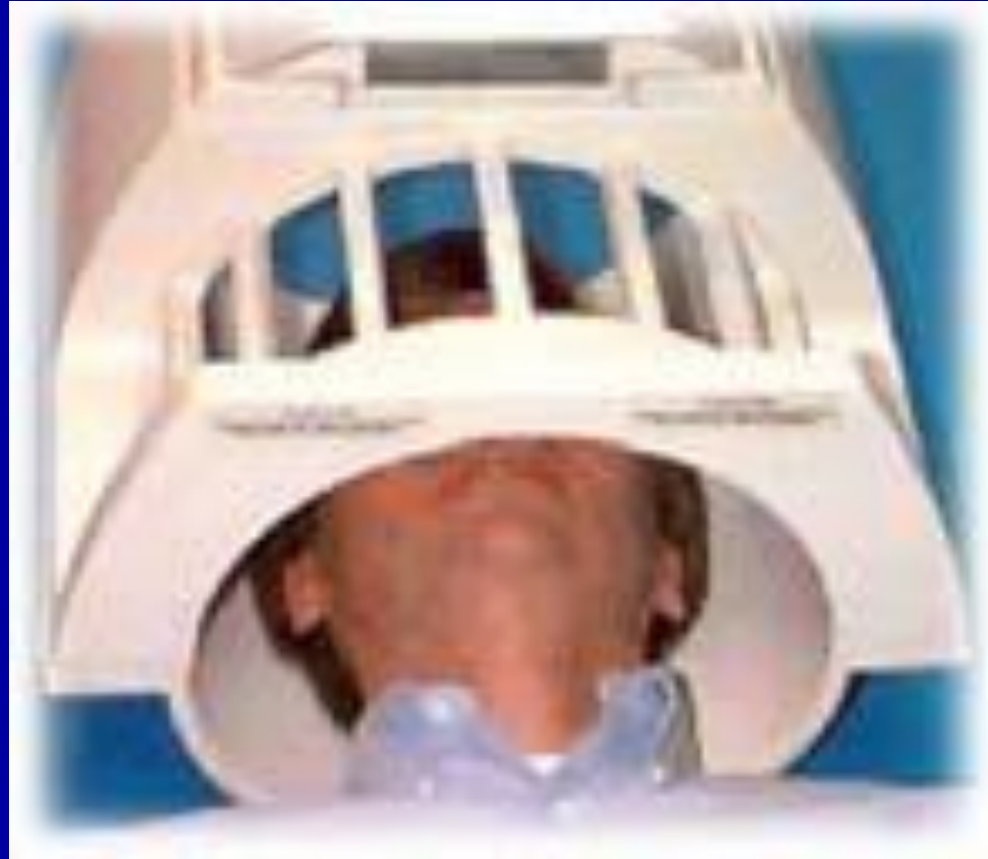
This coil is commonly used as a transceiver coil for imaging of the head.



Helmholtz Pair Coil

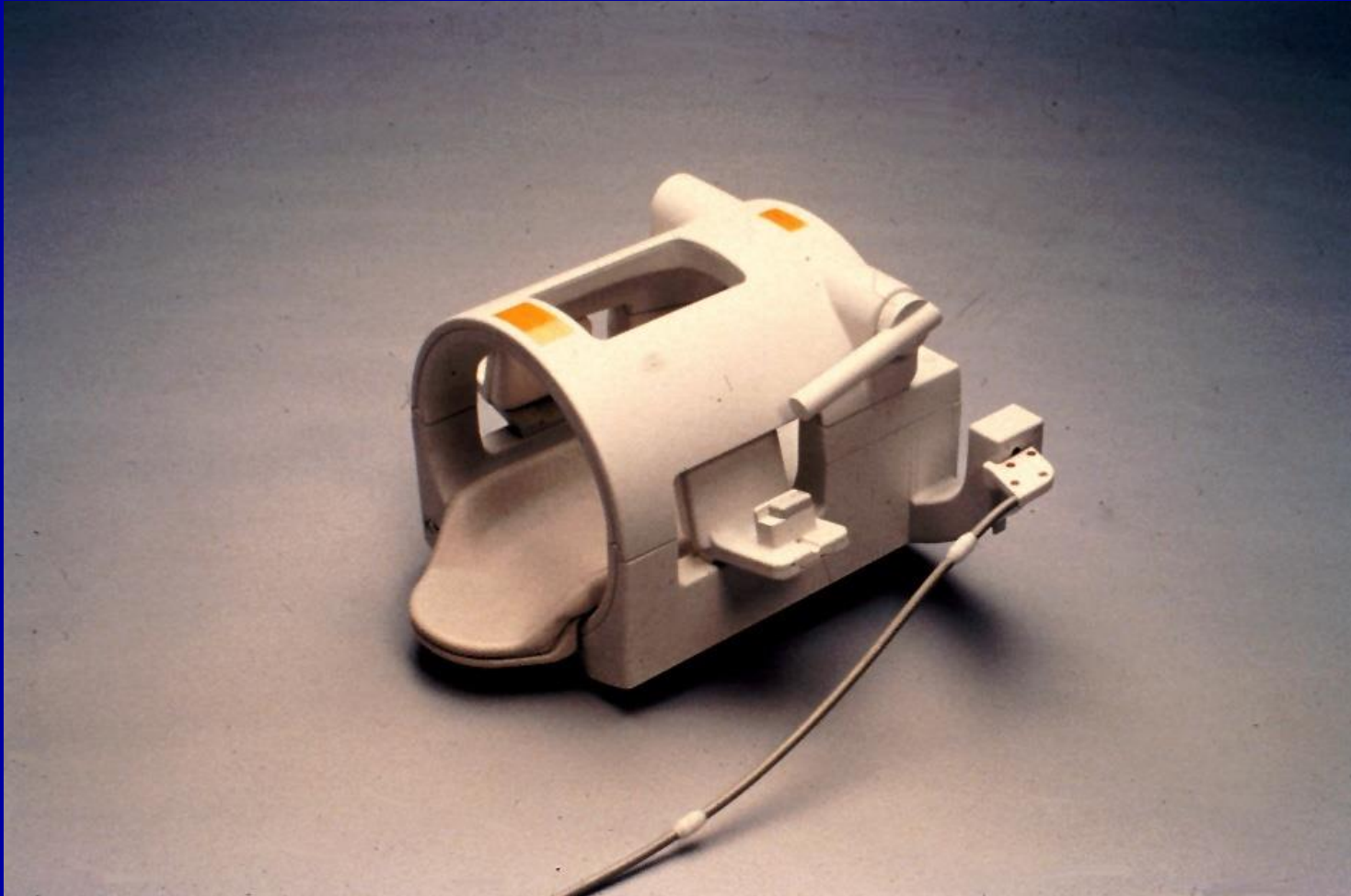
Z-gradient used occasionally as RF coils for pelvis imaging and cervical spine imaging.

MRI hardware



Head Coil

MRI hardware



Head Coil

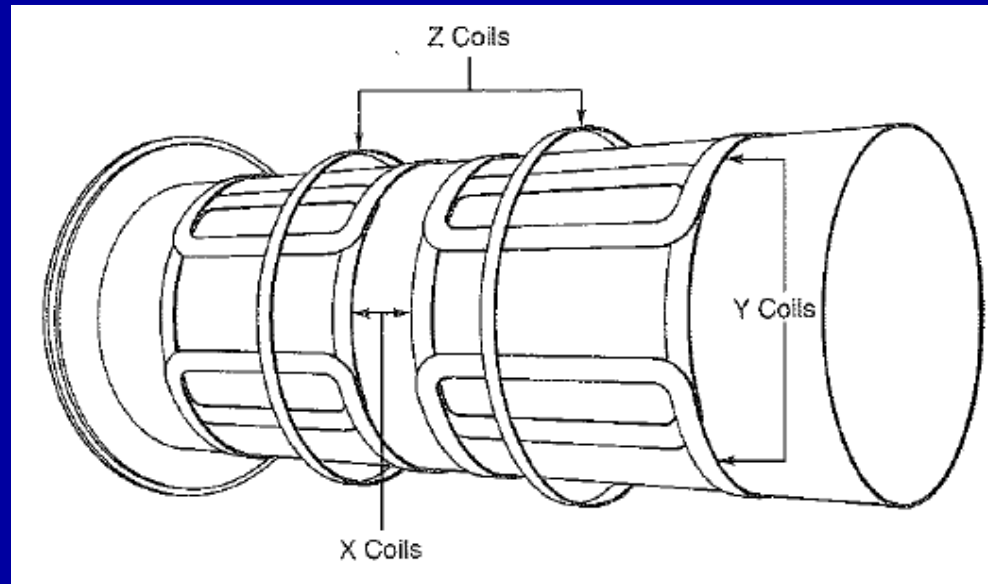
MRI hardware

RF Receiver Coils



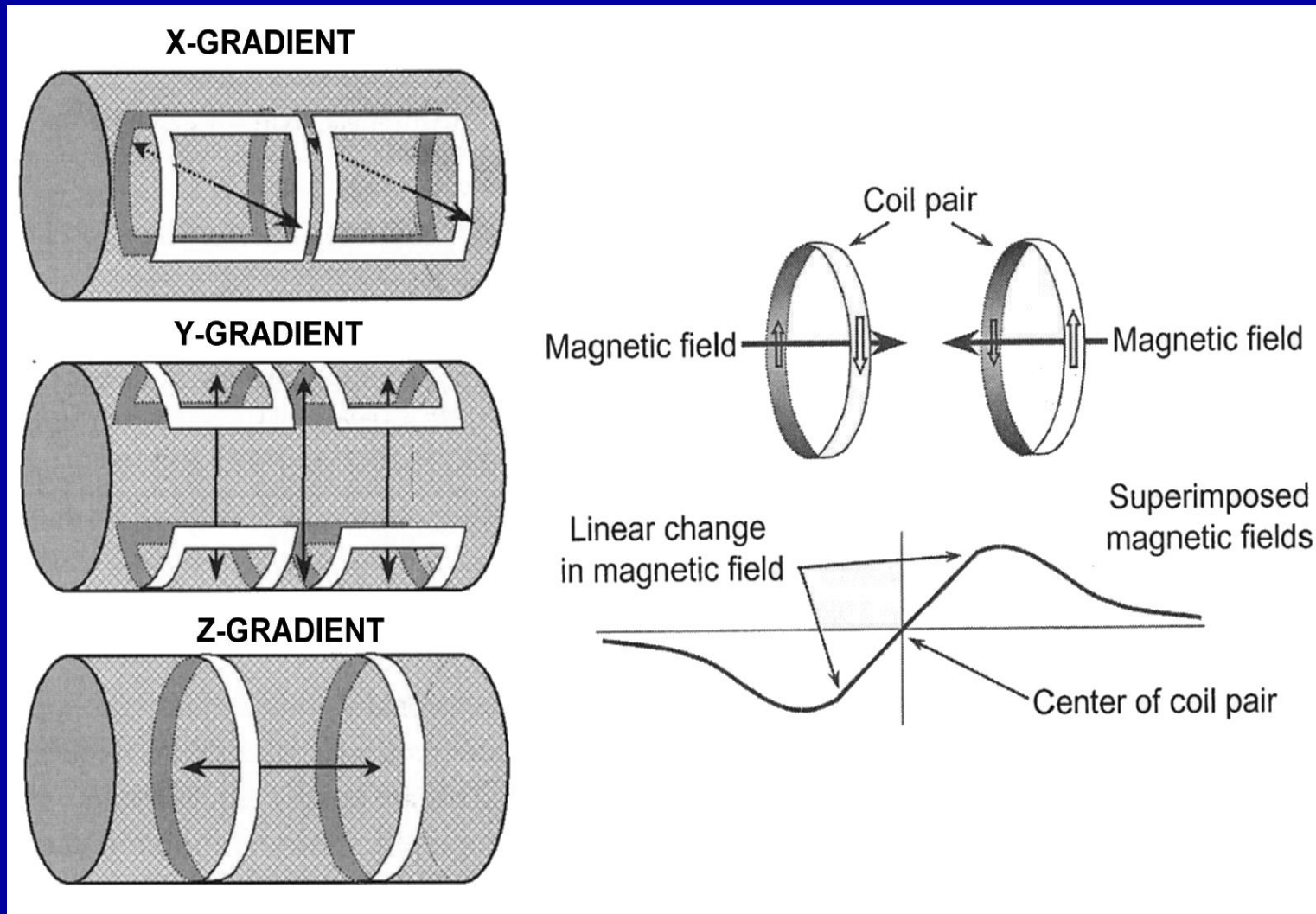
MRI hardware

Three Sets of Gradient Coils



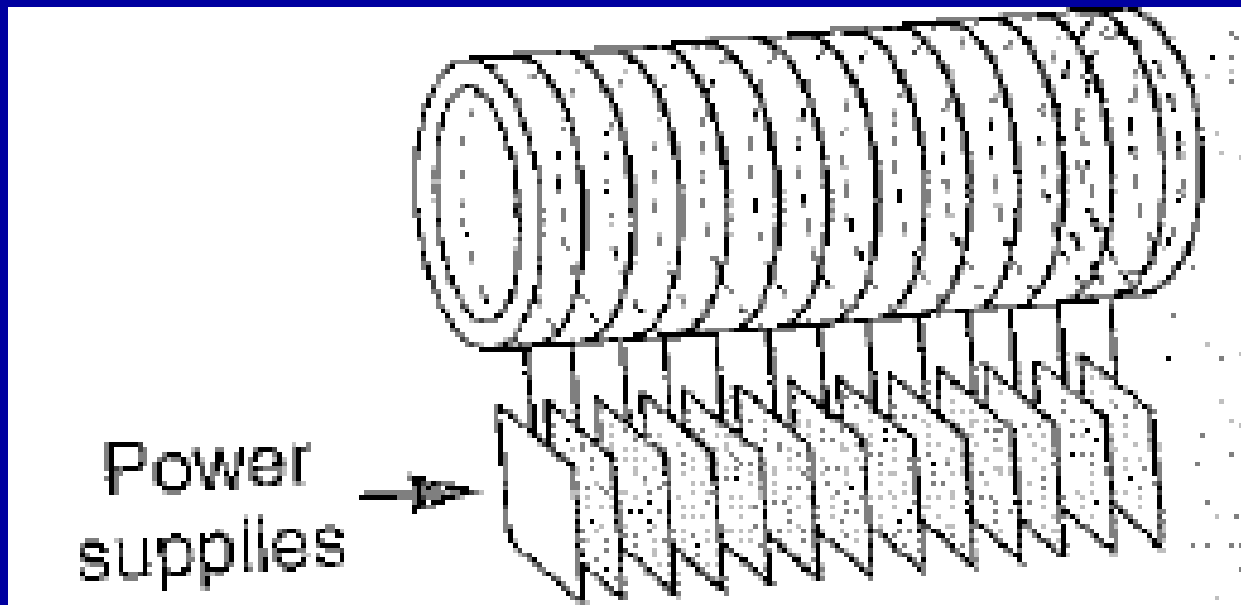
MRI hardware

GRADIENTS



MRI hardware

The Shim Coils

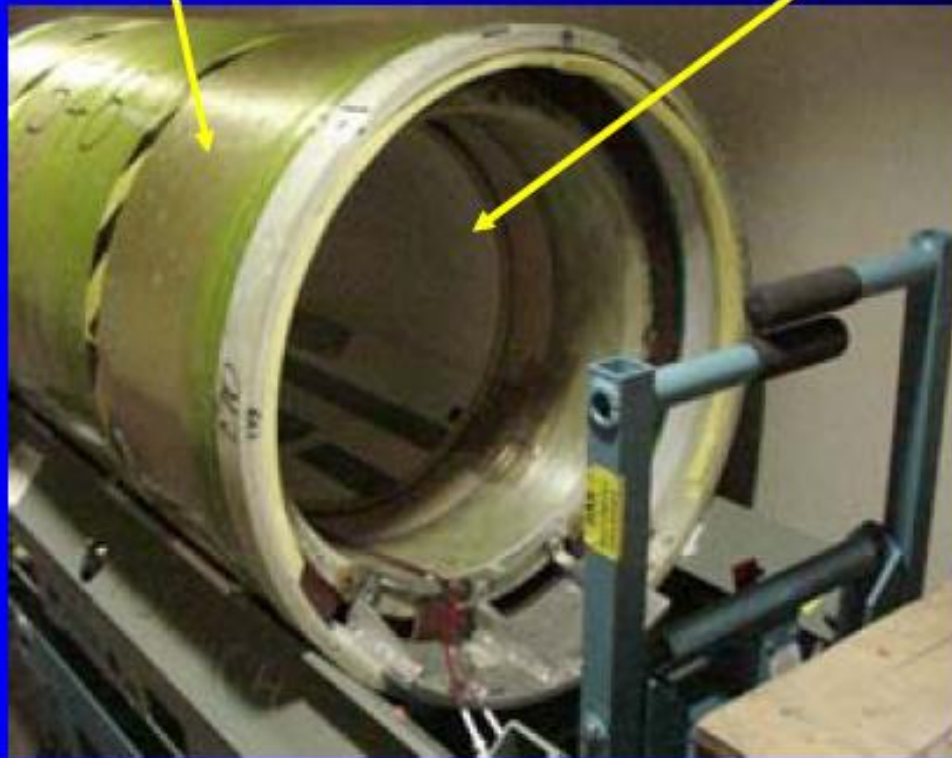


MRI hardware

Gradient Coil Example

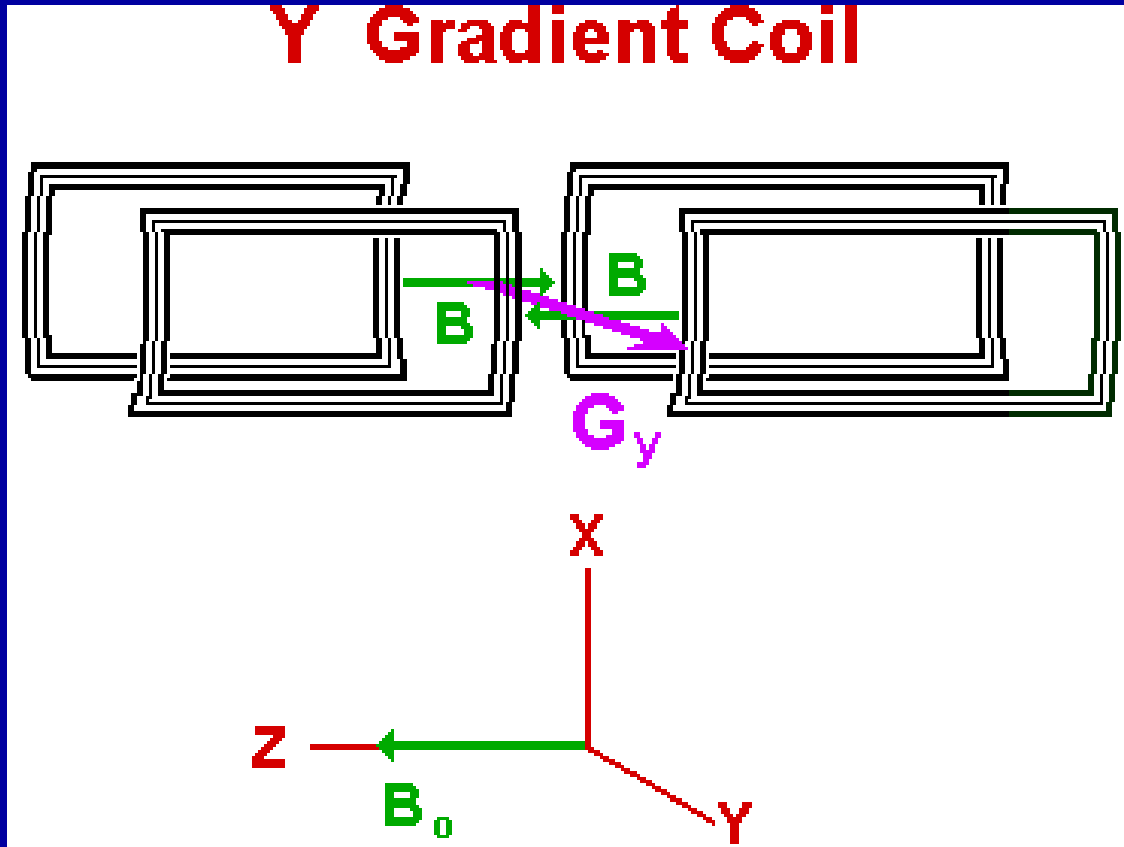
Whole Body Gradient Coils

Whole Body RF Coil

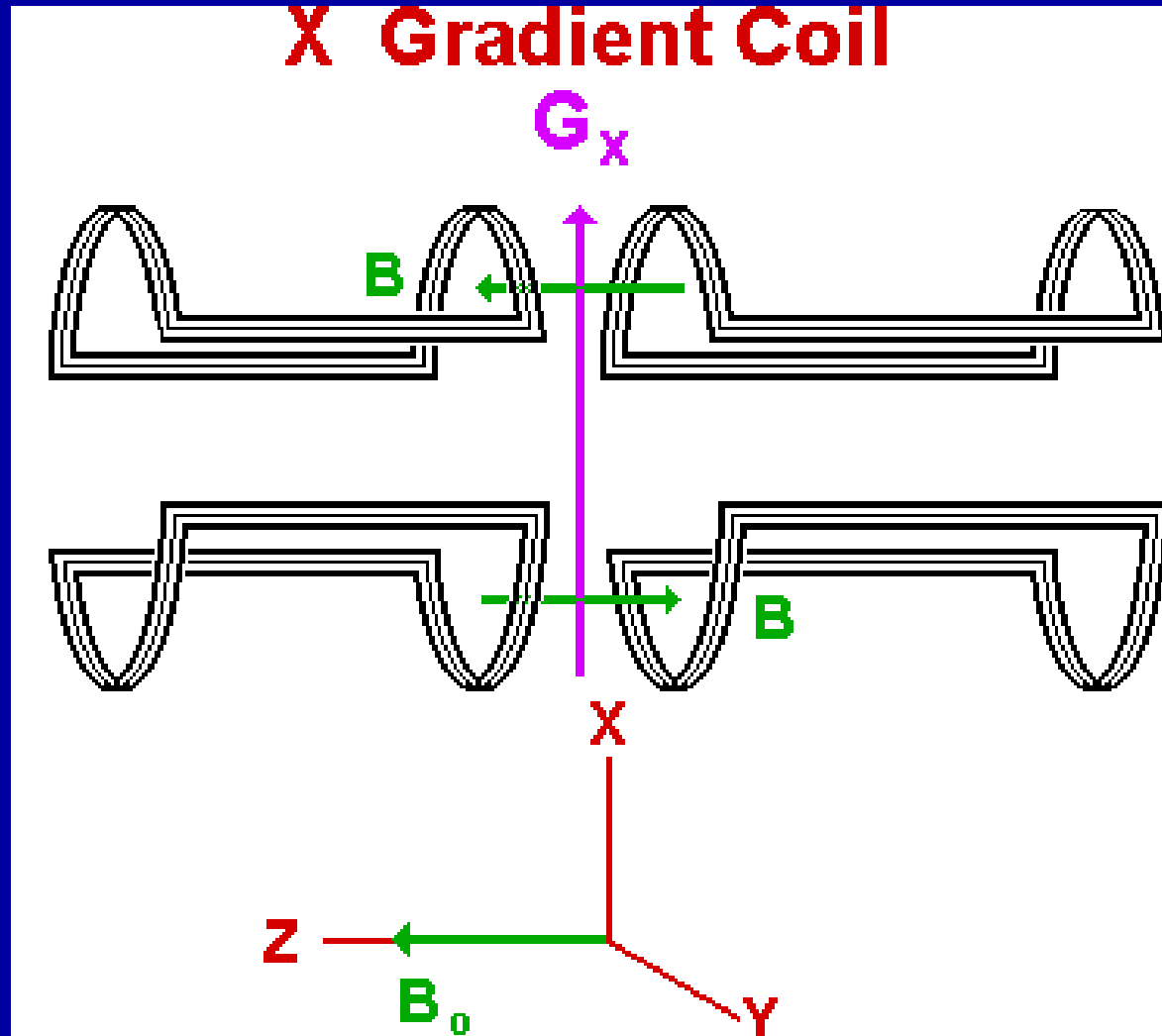


MRI hardware

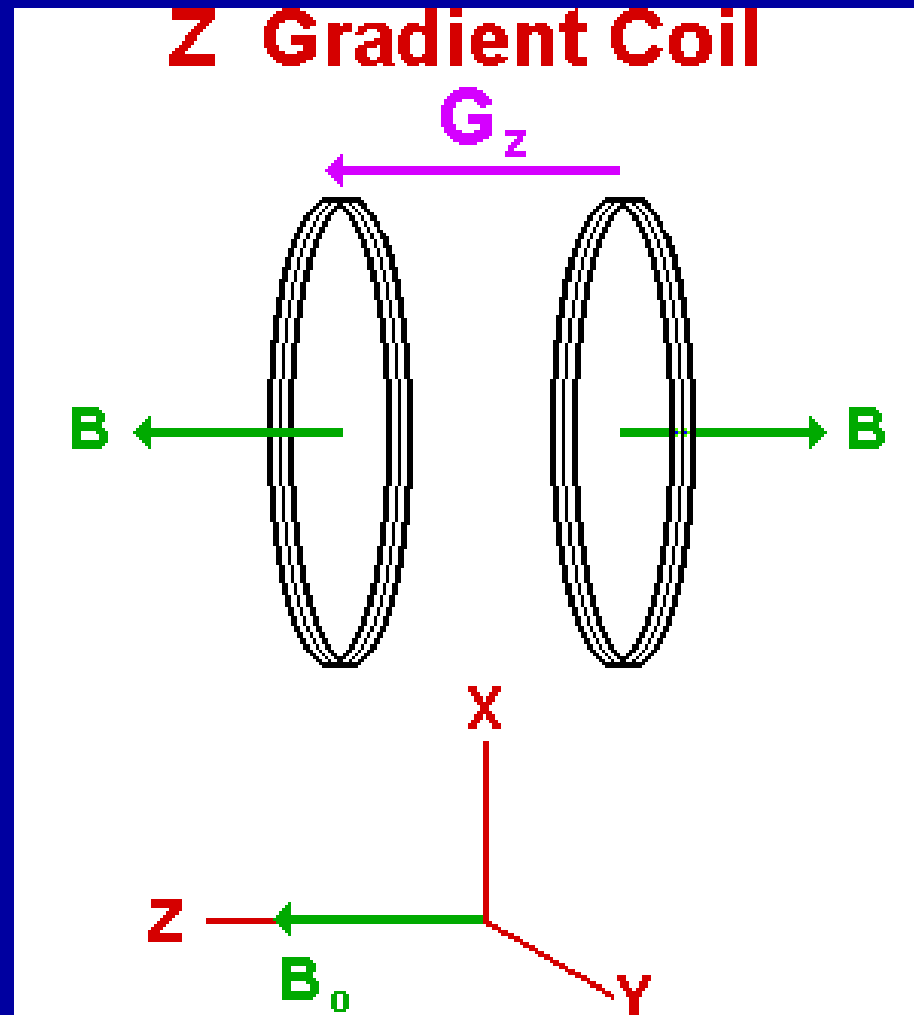
Y Gradient Coil



MRI hardware

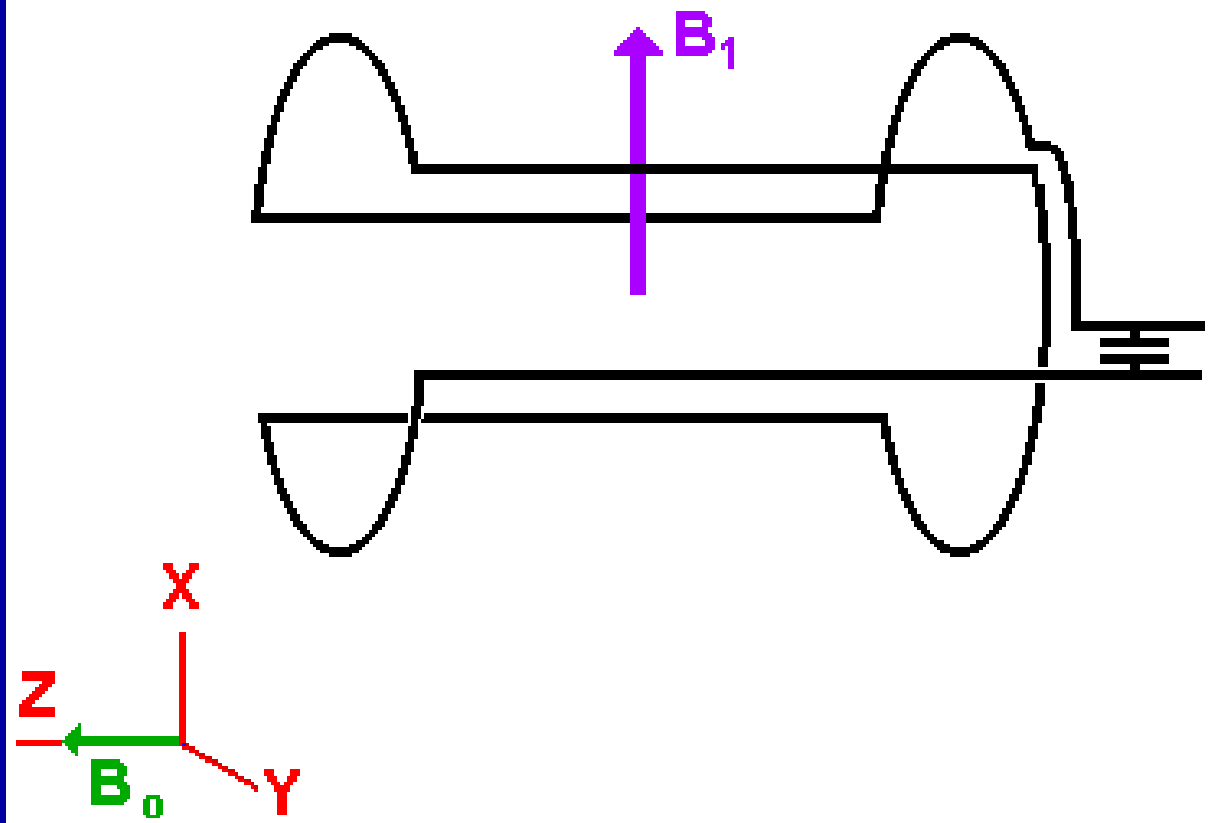


MRI hardware



MRI hardware

Saddle Coil

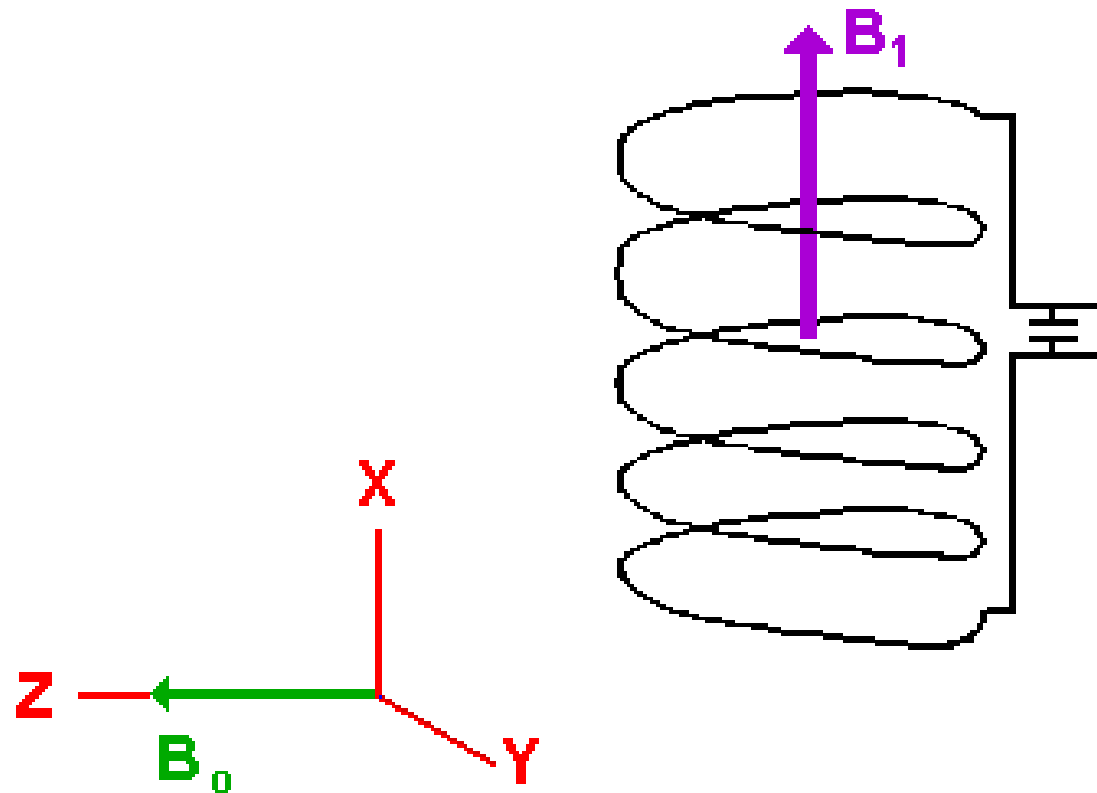


MRI hardware



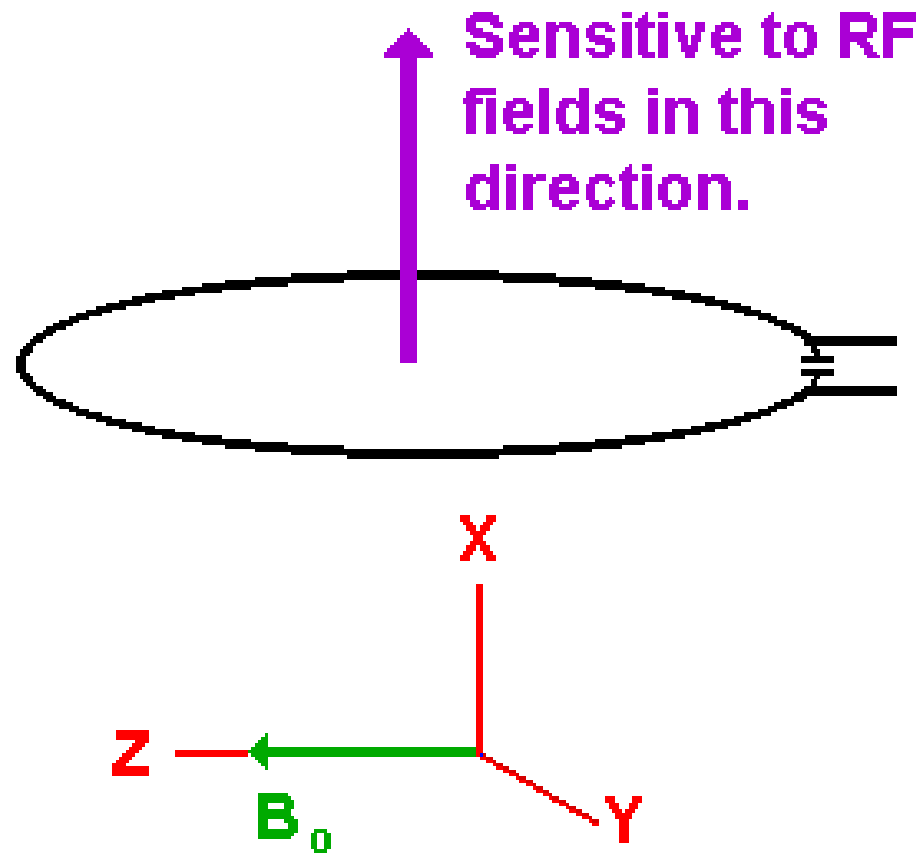
MRI hardware

Multi-Turn Solenoid

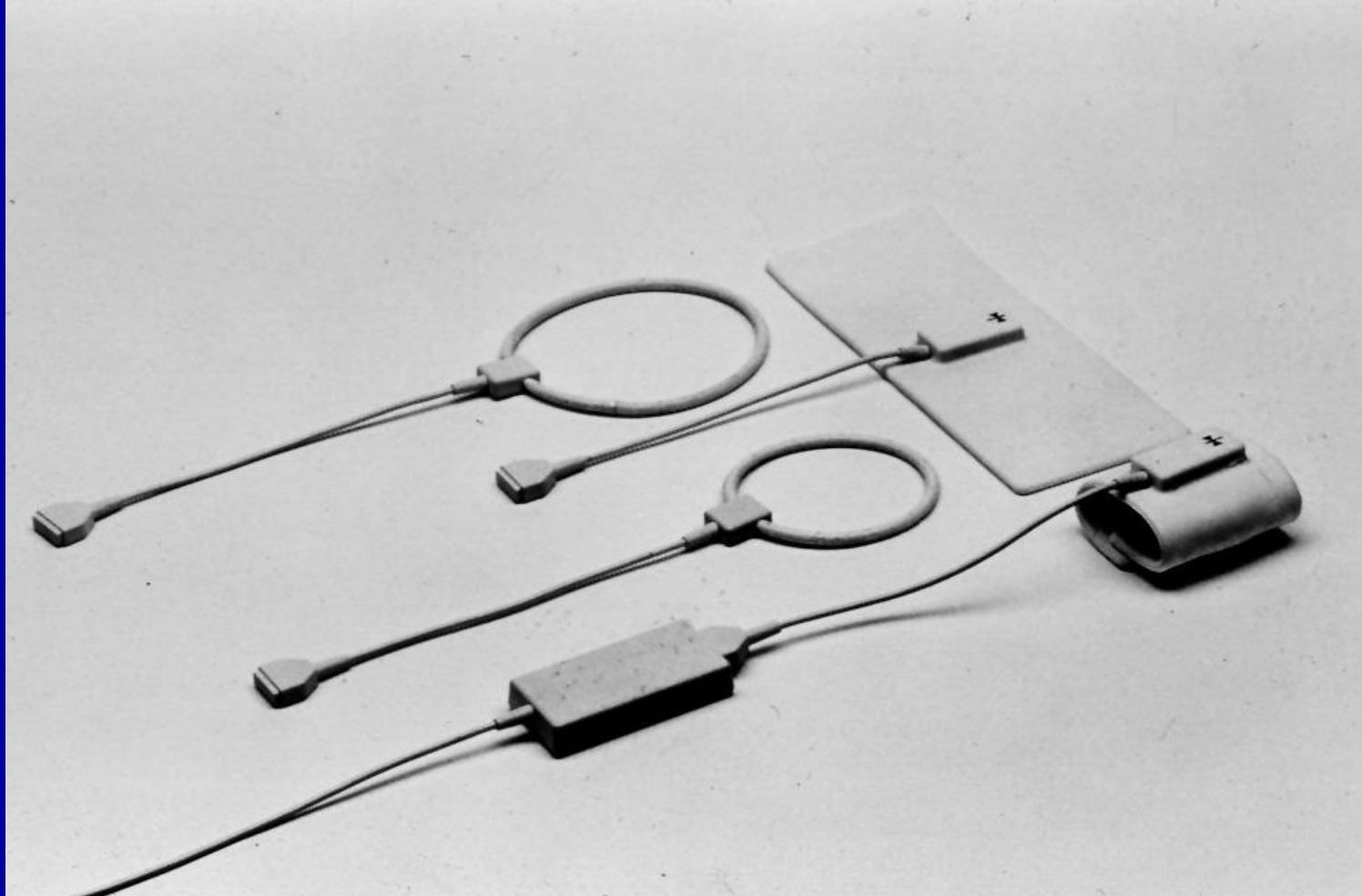


MRI hardware

Surface Coil



MRI hardware

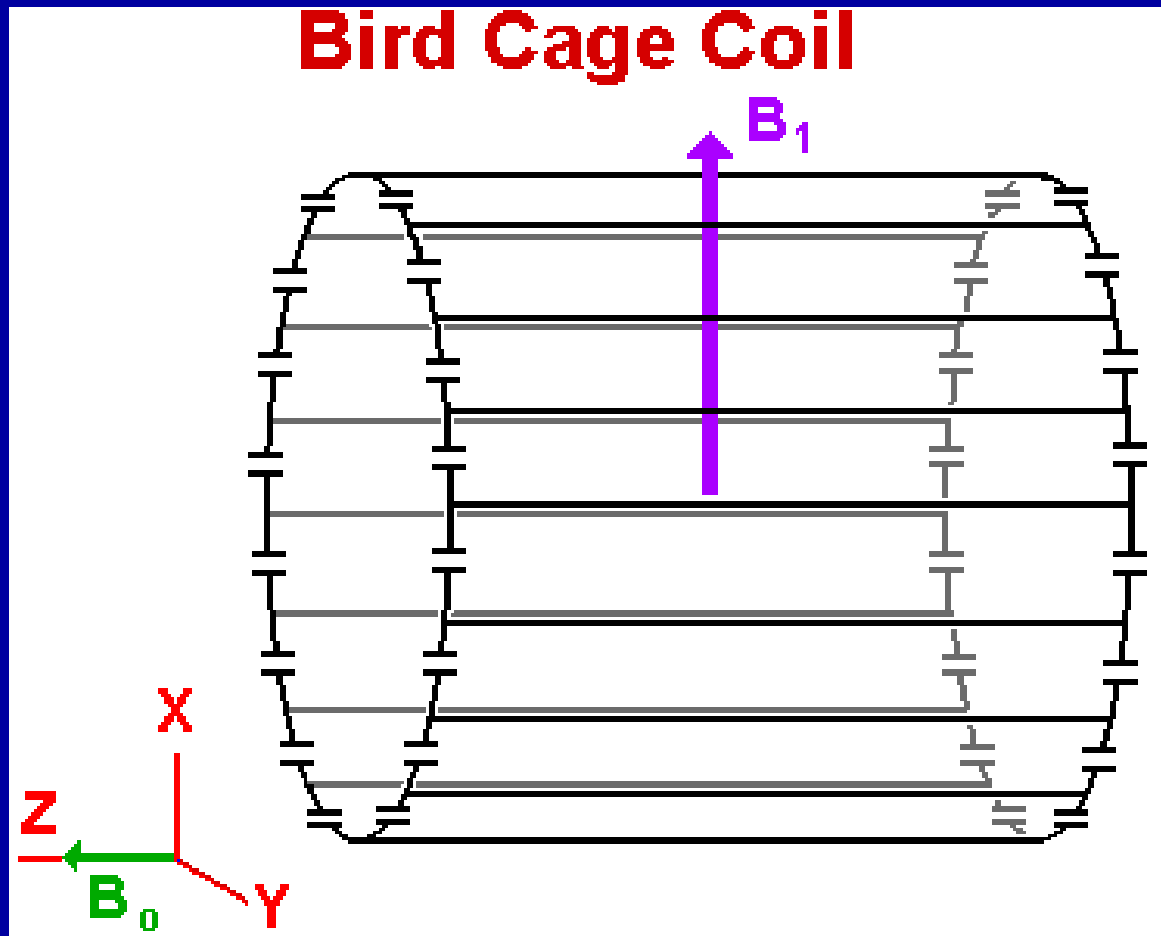


Surface Coils

MRI hardware



MRI hardware

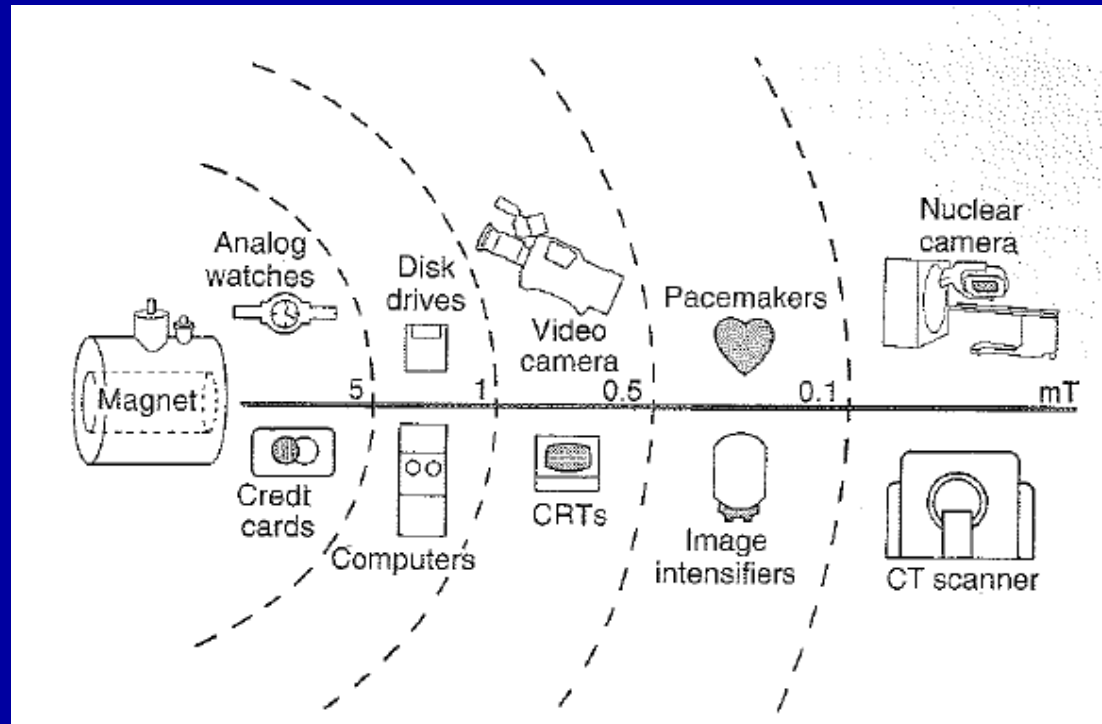


MRI hardware



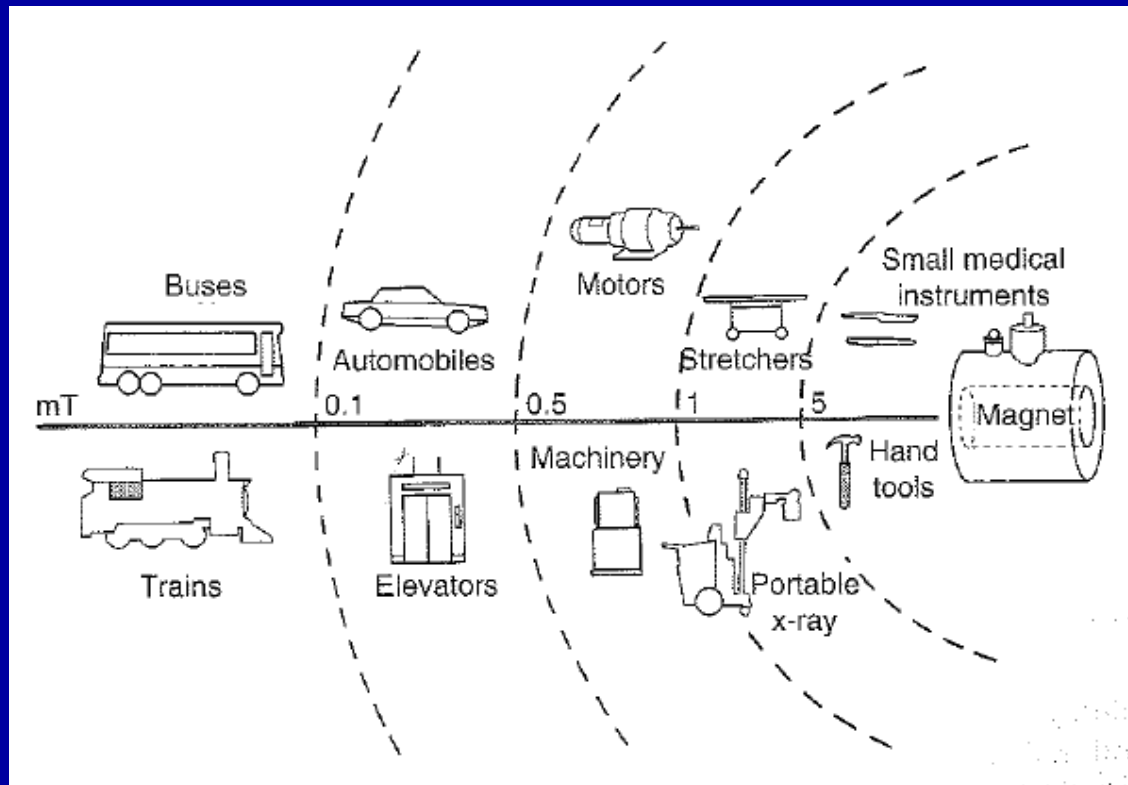
MRI hardware

Exclusion of Various Objects



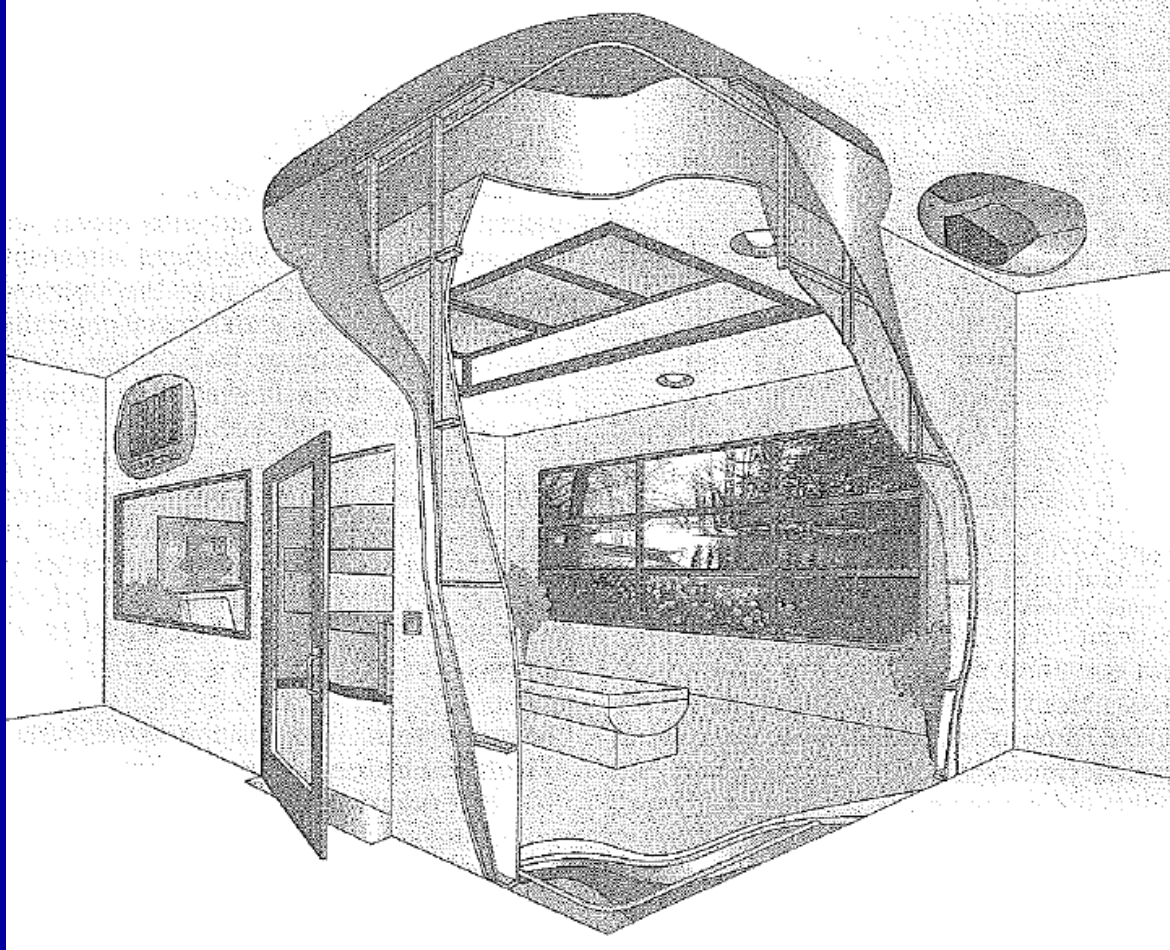
MRI hardware

Exclusion of Ferromagnetic Objects

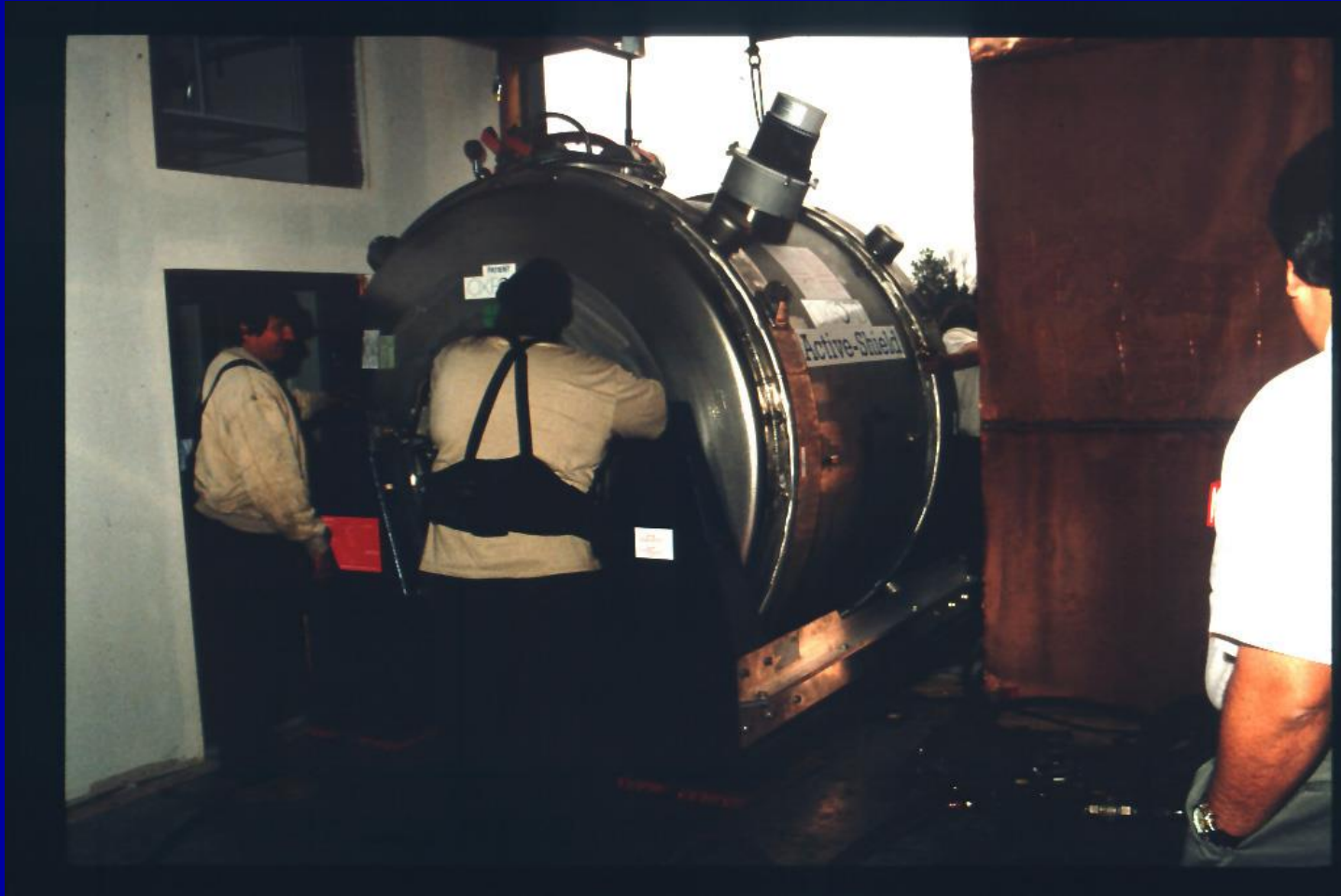


MRI hardware

Shielding of MRI Room

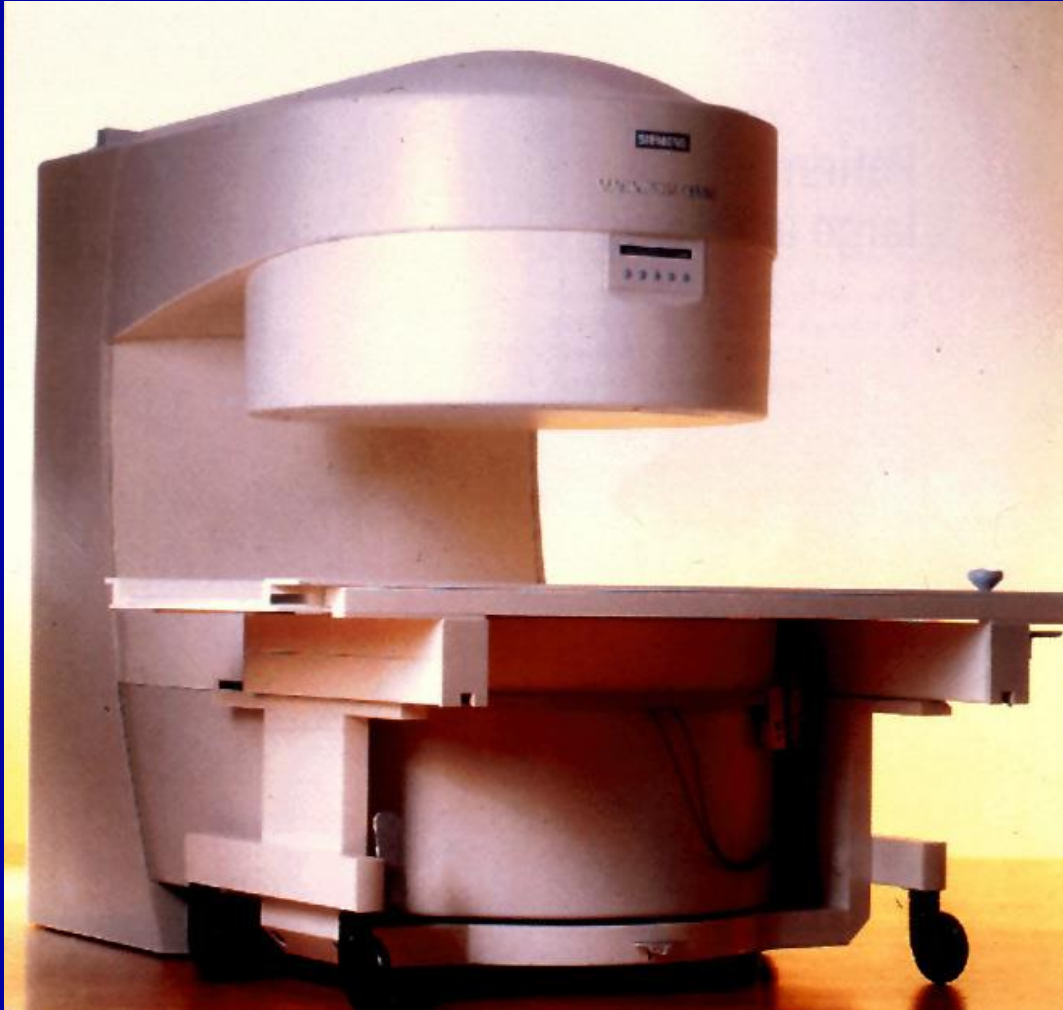


MRI hardware



- Delivery of 1.5T Superconducting Magnet

MRI hardware



- 0.2 T Open MRI with permanent magnet (11 tons)

MRI hardware



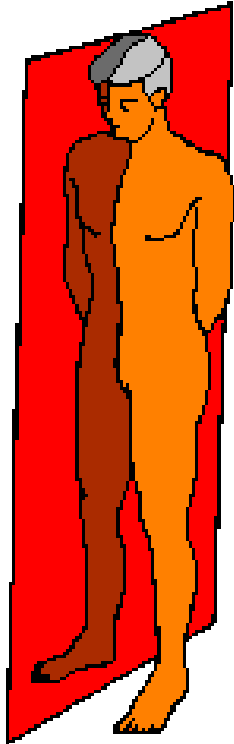
- 0.7 T Open MRI with superconducting magnet

MRI hardware

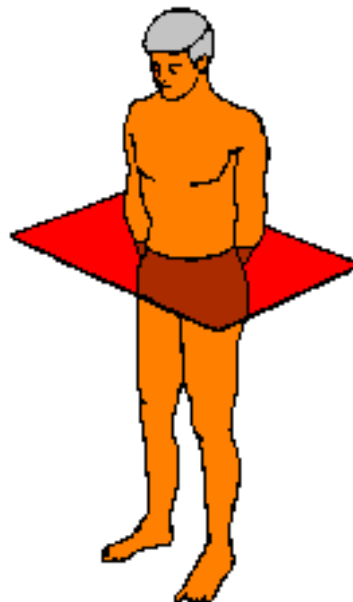


Body Array and Head Array Coils

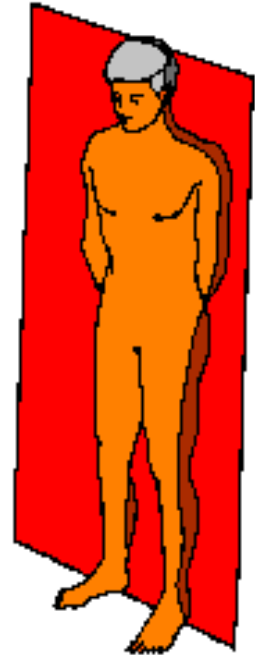
MRI hardware



SAGITTAL



AXIAL



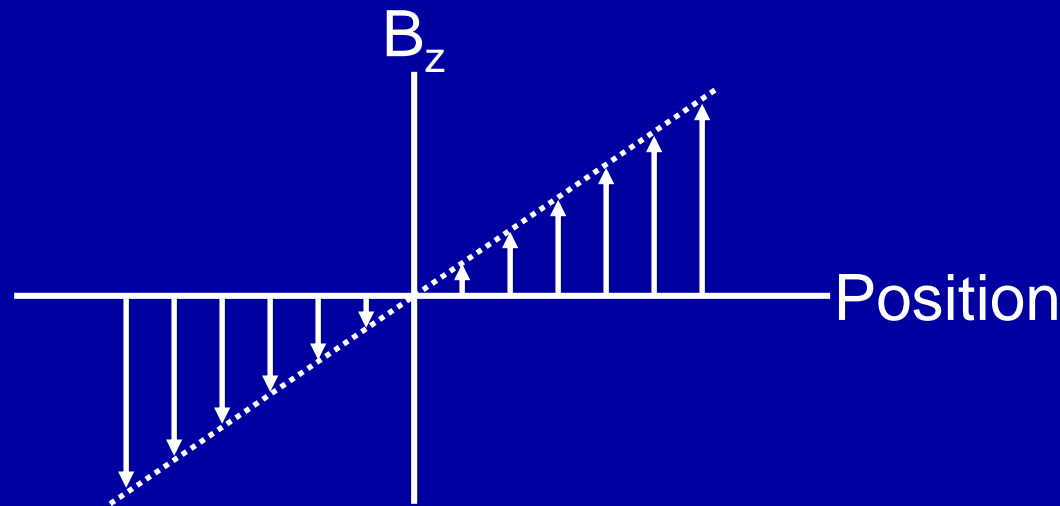
CORONAL

Topics

- MRI Physics
- Hardware
- MR Image Formation
- Contrast
- Applications of MRI

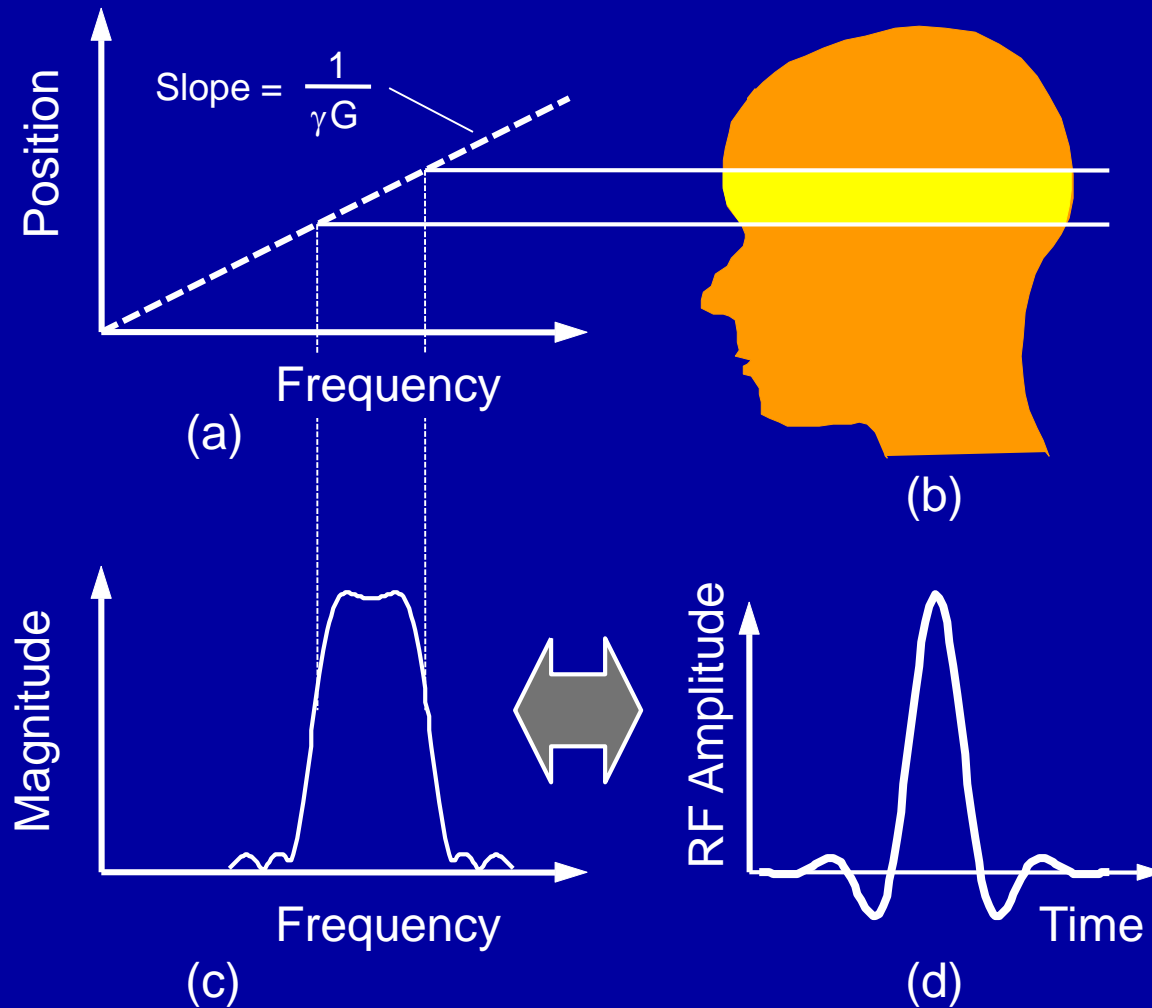
MR Image Formation

- Gradient coils provide a linear variation in B_z with position.
- Result is a resonant frequency variation with position.



MR Image Formation

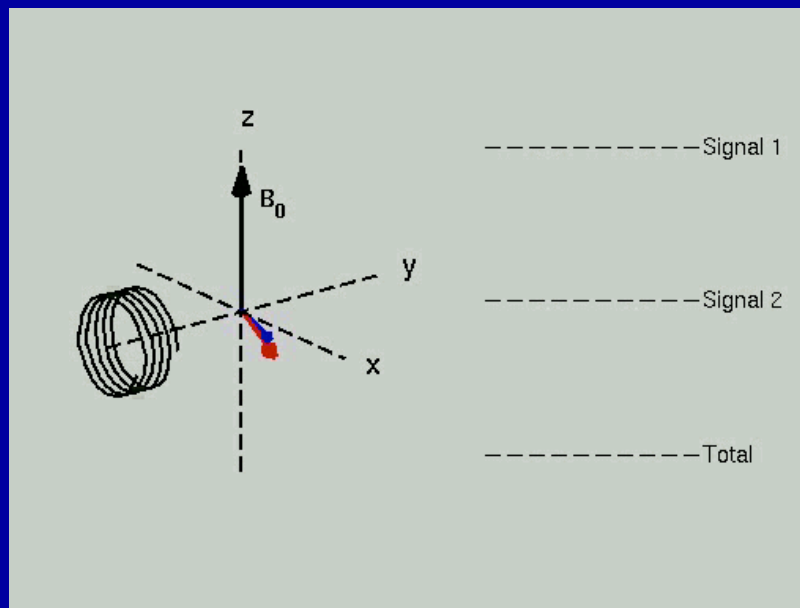
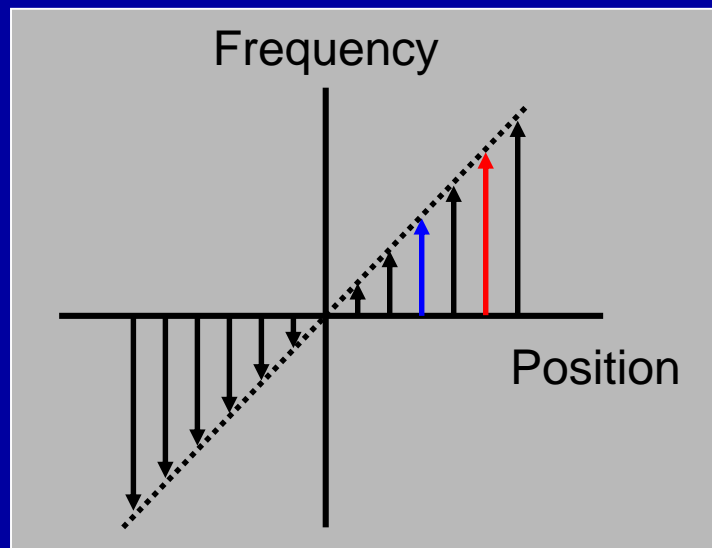
Selective Excitation



MR Image Formation

Image Acquisition

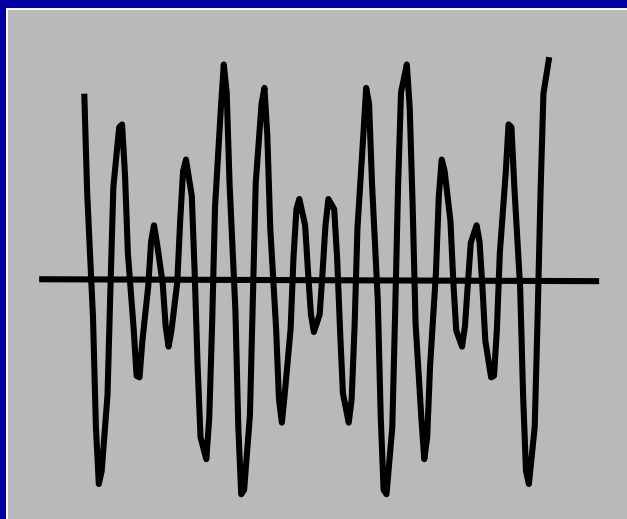
- Gradient causes resonant frequency to vary with position.
- Receive sum of signals from each spin.



MR Image Formation

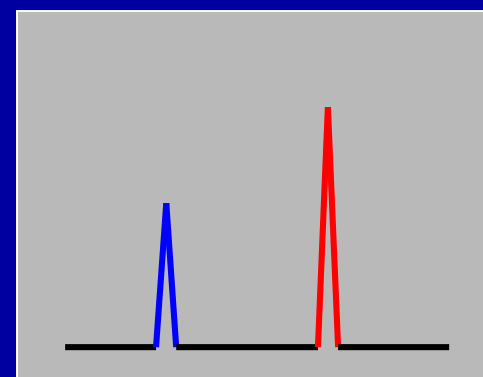
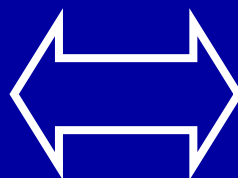
Image Reconstruction

- Received signal is a sum of “tones.”
- The “tones” of the signal are the image.
- This also applies to 2D and 3D images.



Received Signal

Fourier
Transform



Image

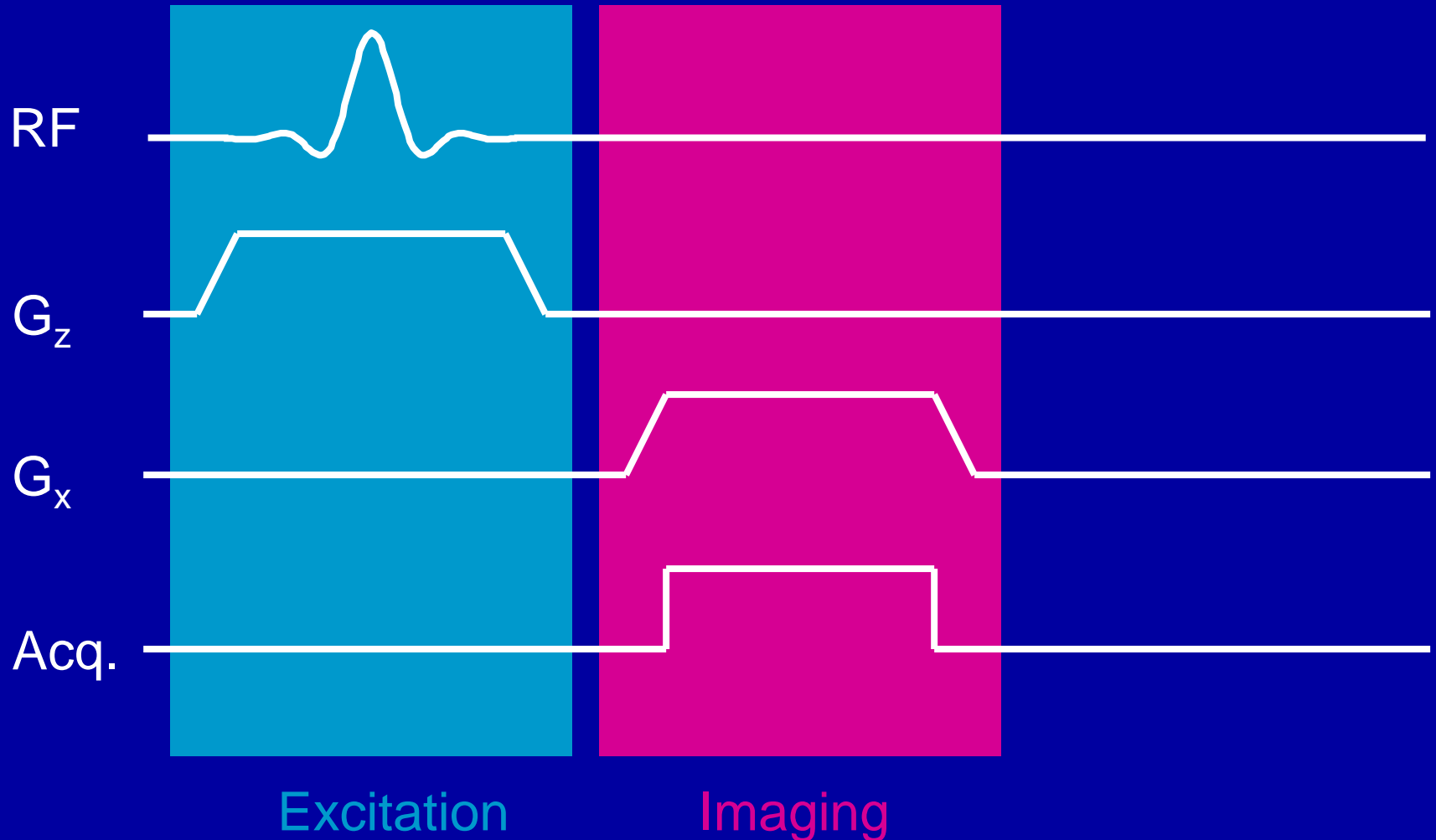
MR Image Formation

Pulse Sequences

- Excitation and imaging are separated.
- Pulse sequence controls:
 - RF excitation
 - Gradient waveforms
 - Acquisition
 - Reconstruction information as well.

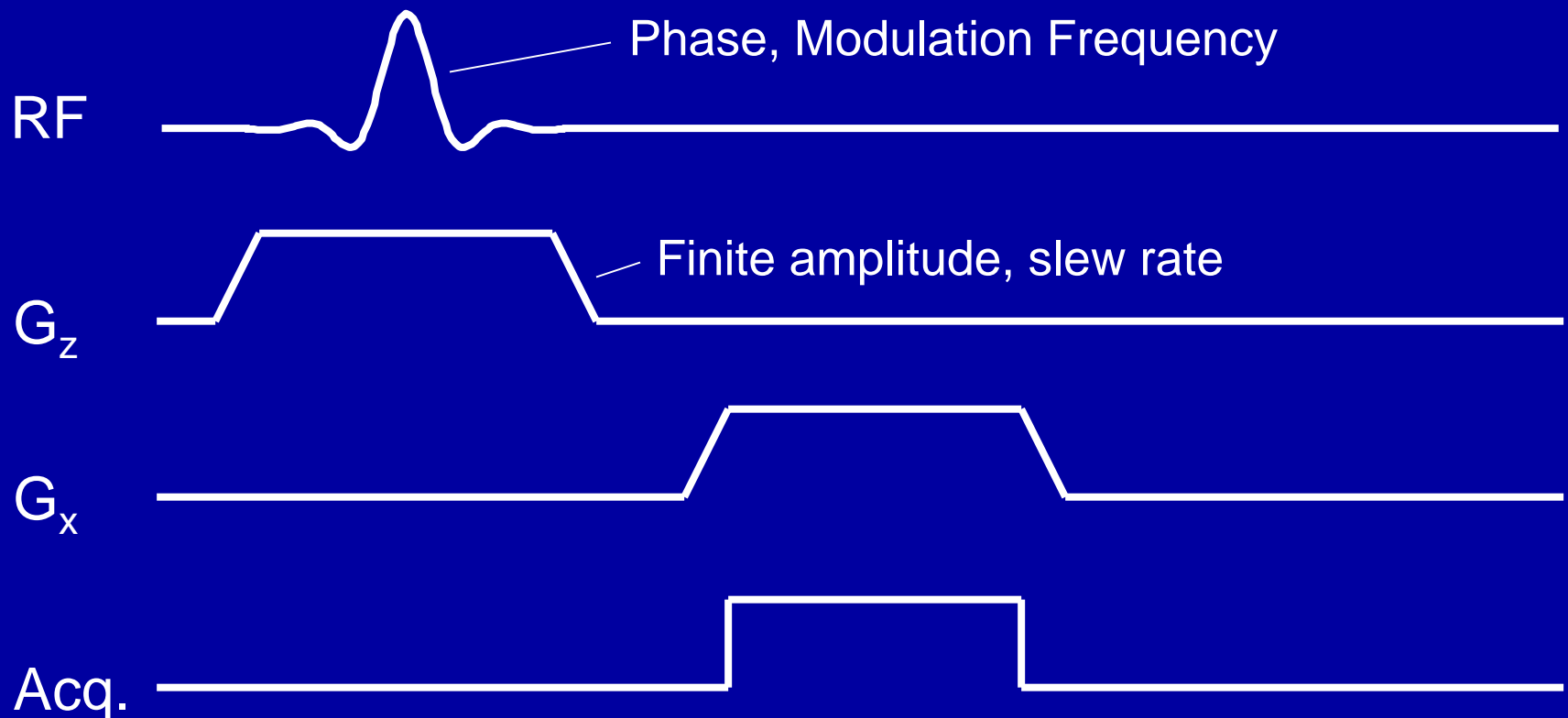
MR Image Formation

1D-Pulse Sequence



MR Image Formation

1D-Pulse Sequence – Detailed!

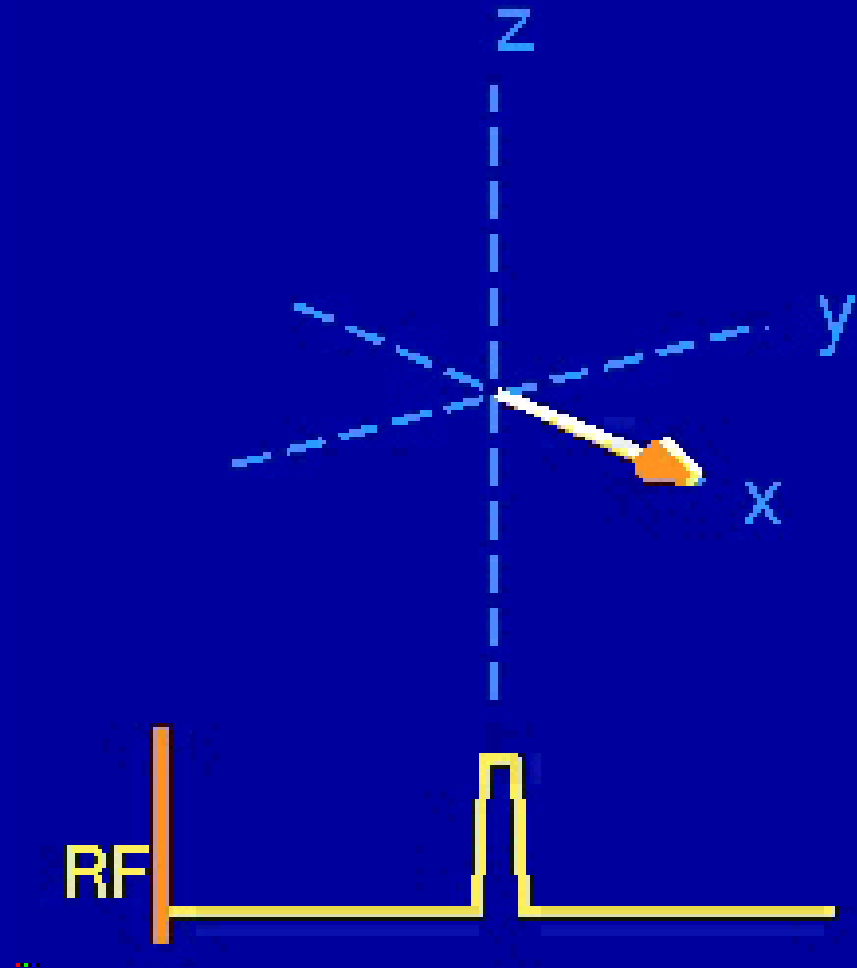


- Demodulation frequency, phase
- Sampling rate and duration

MR Image Formation

Spin Echoes

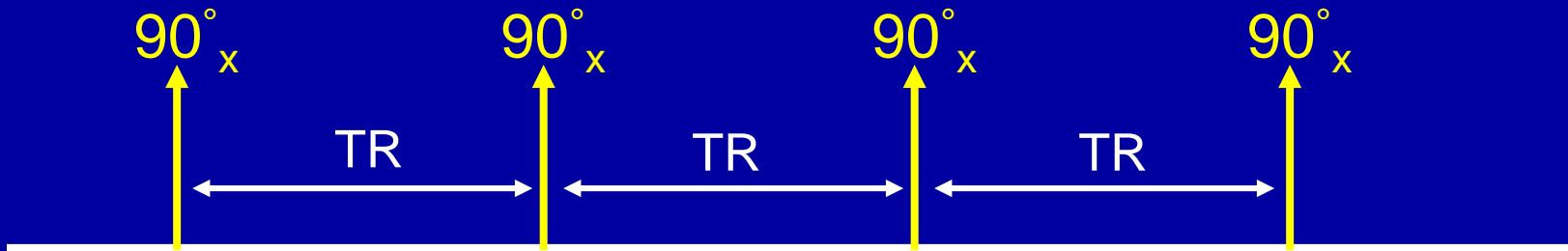
- 180° RF tip can reverse the dephasing effects of off-resonance.
- Spins realign at some time to form a *spin echo*



MR Image Formation

Imaging Sequences

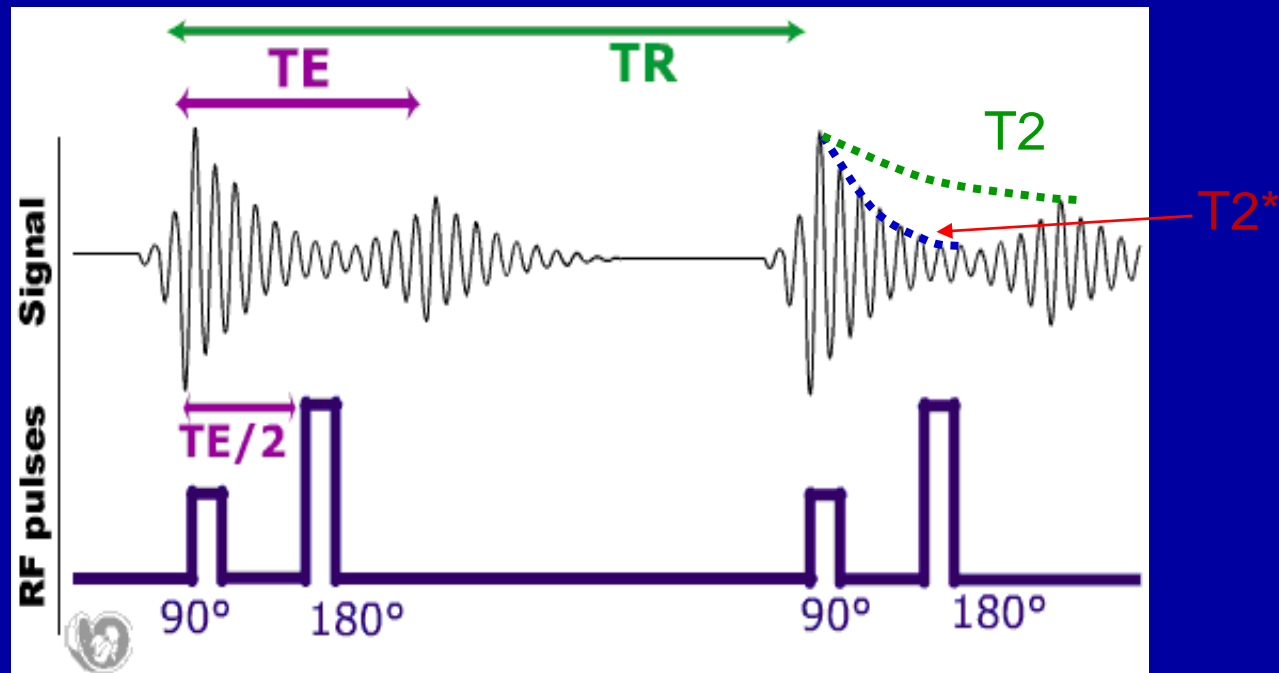
- Image acquisition usually requires multiple repetitions.



MR Image Formation

Basic Spin Echo Sequences (SE)

- The refocusing pulse allows us to recover true T2.



Topics

- MRI Physics
- Hardware
- MR Image Formation
- Contrast
- Applications of MRI

Contrast

Image Noise and SNR

Low Signal-to-Noise Ratio



High Signal-to-Noise Ratio



Contrast

- Contrast is the difference in appearance of different tissues in an image.

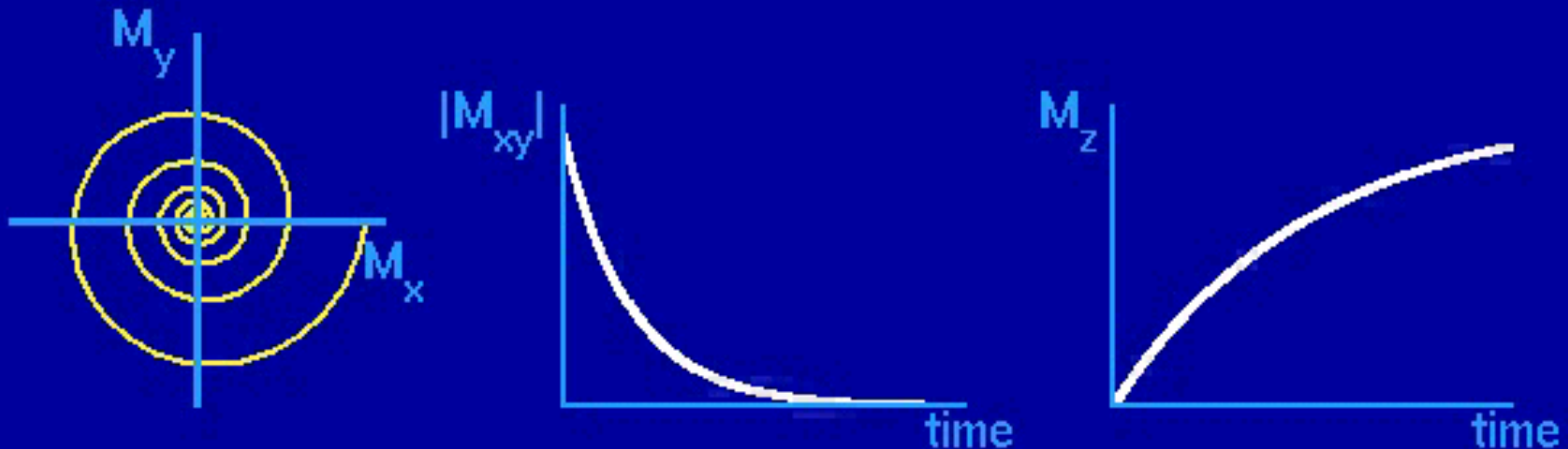


X-ray contrast is based on transmission.

Contrast

Contrast in MRI

- Hydrogen (water) density results in contrast between tissues.
- Many other mechanisms, some based on relaxation.

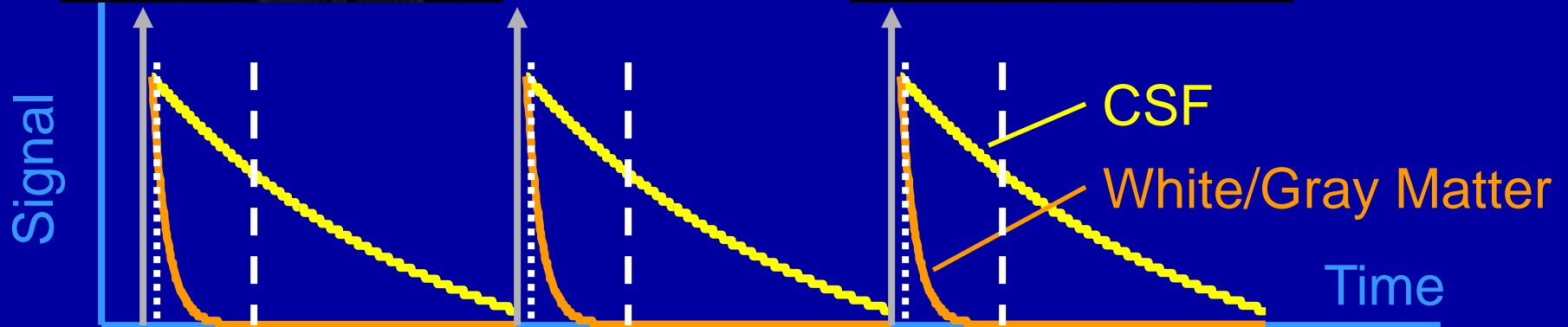
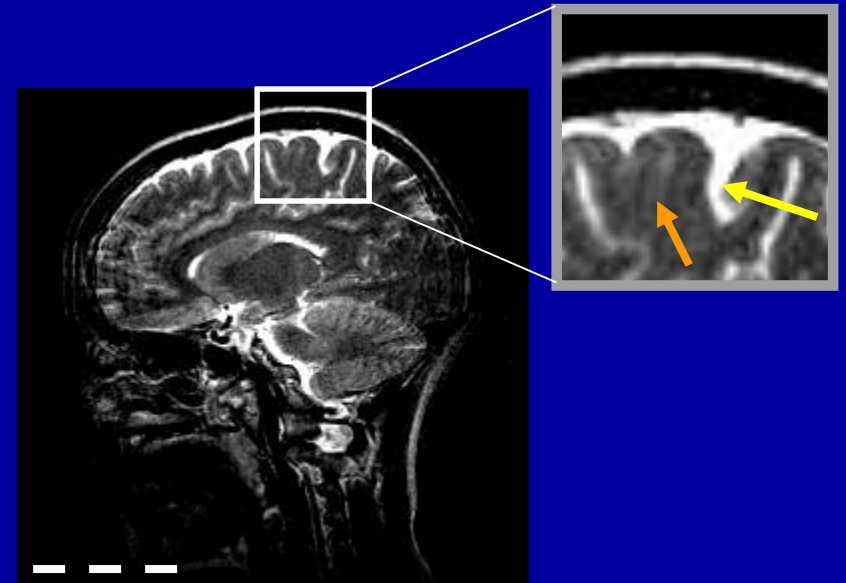
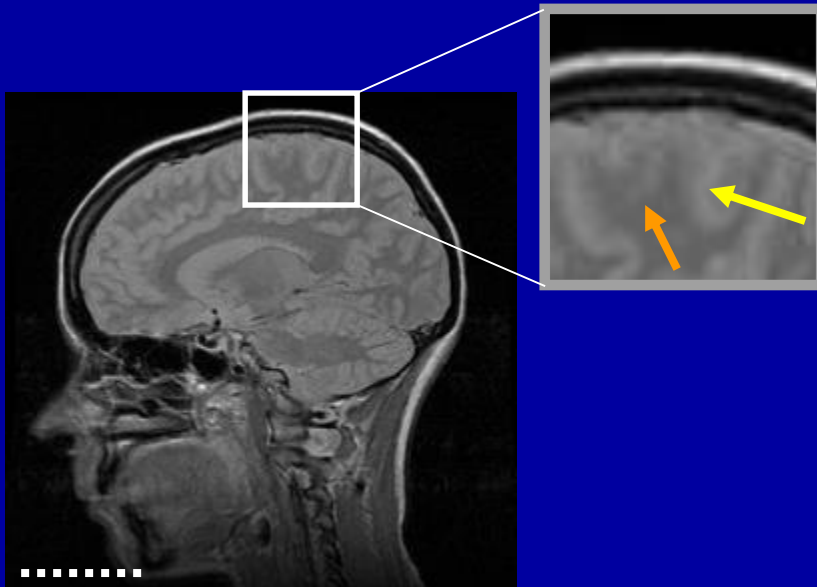


Contrast

T_2 Contrast

Short Echo-Time

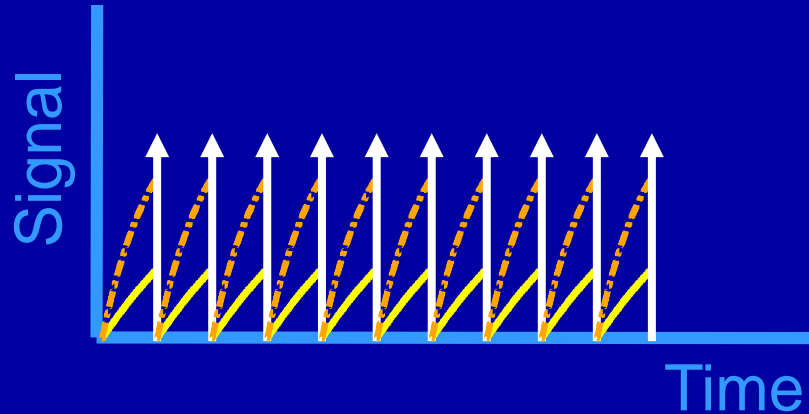
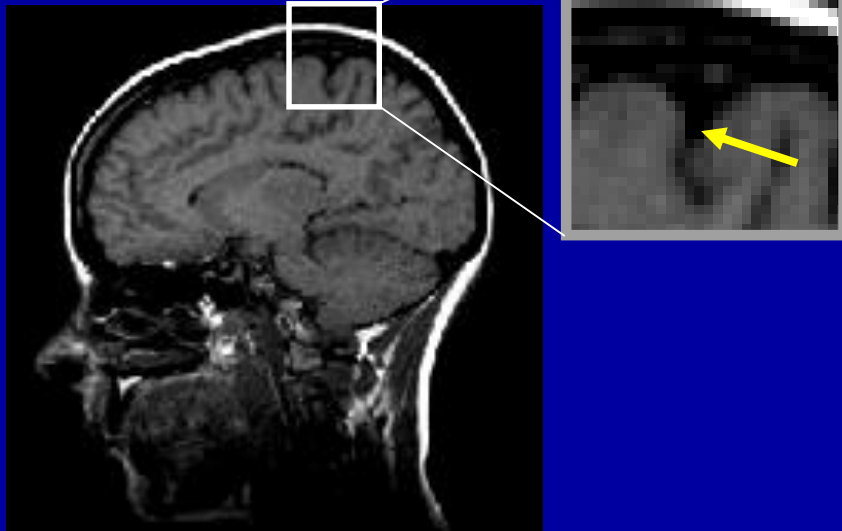
Long Echo-Time



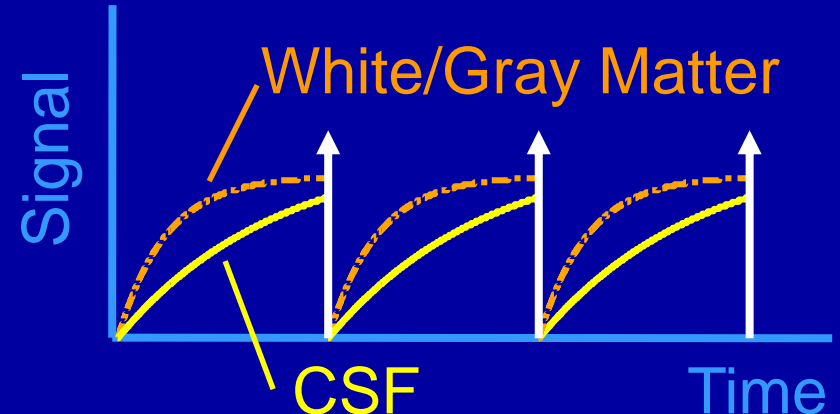
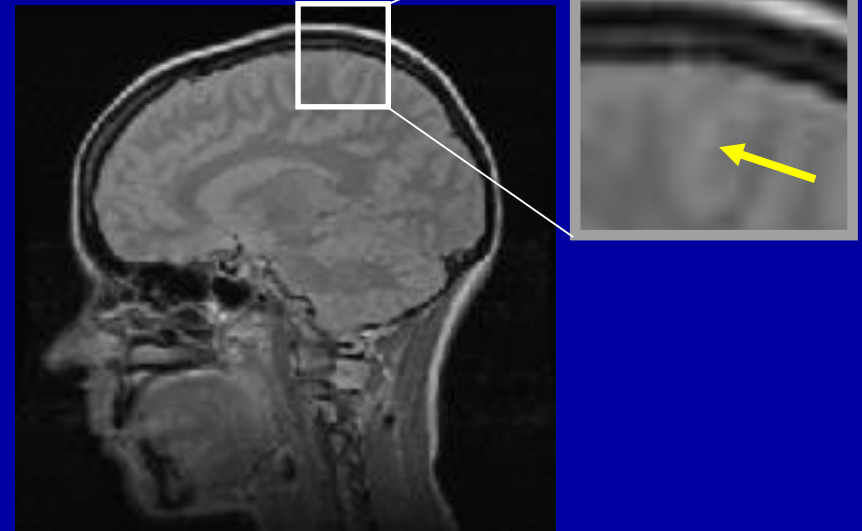
Contrast

T_1 Contrast

Short Repetition



Long Repetition



Contrast

Static Contrast Images

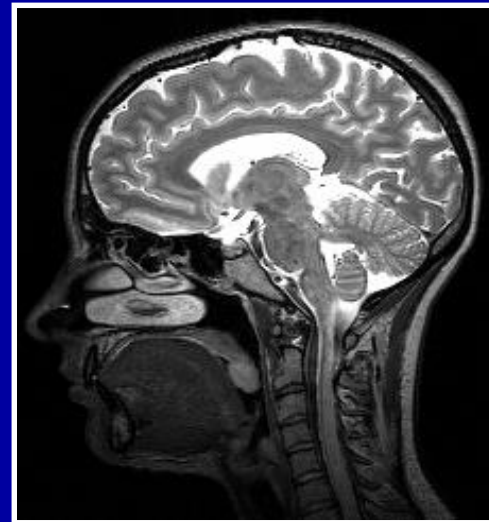
- Examples from the Siemens 3T

□ T1 and T2 Weighted Images

T1 Weighted Image (T1WI)
(Gray Matter – White Matter)



T2 Weighted Image (T2WI)
(Gray Matter – CSF Contrast)



Topics

- MRI Physics
- Hardware
- MR Image Formation
- Contrast
- Applications of MRI

Some Applications of MRI

- Brain / Spine imaging
- Knee Imaging
- Cardiac Imaging

Some Applications of MRI

Real-Time Interactive MRI

- Shows “live” images.
- Useful when there is motion, such as in the chest.
- Imaging is very fast, but SNR is lower.
- Interactive imaging allows us to move the scan plane in real-time.