2.1 Instrumentation

Magnetism & MR Magnets

& other MR system components: shim systems, RF system, gradient system, other components

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Outline

- Magnetism
- MR Magnets
  - -Permanent
  - -Resistive
  - -Super-conducting
- Shim System
- Gradient System
- RF System

Objectives

Upon completion of this course, the attendee should…

1. Have an understanding of magnetism & magnetic properties
2. Understand various MR imagers
3. Have an understanding various system components
4. Learn the difference between magnet, shim, gradients and RF systems
5. Understand various MR components, their "job" and operation.

Magnetic System Components

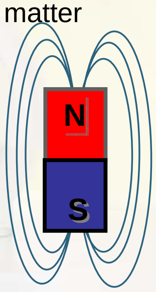
- The Main Magnet (Bo)
- The Shim Magnet
- The Gradient Magnet
- The RF Magnet (B1)


Image courtesy of Philips Medical

- And you thought that there was only one!

Magnetism

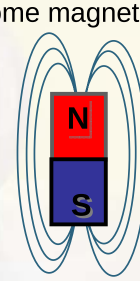
- Fundamental property of matter
  - –Like mass
  - –Like charge
- Magnetic Susceptibility
- Magnetic Properties



Magnetic susceptibility

The ability for a material to become magnetized

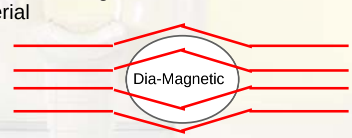
- Diamagnetic materials
- Paramagnetic materials
- Super paramagnetic materials
- Ferromagnetic materials



Diamagnetic Materials

Dia-Magnetic Characteristics
- Paired Electrons
- Electron Cloud protects nucleus
- Negative susceptibility
- Low susceptibility
- "D"oes not fly into the magnet

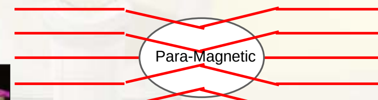
Dia-Magnetic Material
- -Wood
- -Glass
- -Plastic
- -Metals
  - gold
  - silver
  - Stainless Steel



Paramagnetic Materials

Para-Magnetic Characteristics
- Unpaired Electrons
- no protection for the nucleus
- Positive susceptibility
- Low susceptibility

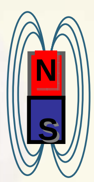
Para-Magnetic Material
- -Gadolinium contrast agents



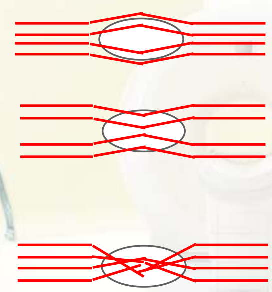
Ferromagnetic Materials

Ferro-Magnetic Characteristics
- ½ filled Electron shells
- no protection for the nucleus
- Positive susceptibility
- High susceptibility
- "F"lies into the magnet

Ferro-Magnetic Material
- -Iron
- -Steel



Magnetic Properties



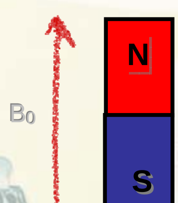
Dia-Magnetic
- **Wood**
- **Plastic**
- **Glass**

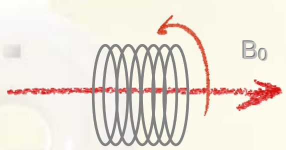
Para-Magnetic
- **gadolinium**
- **manganese**

Super Paramagnetic
- **Contrast agents**
- **Iron Oxide**
- **T2 agents**

Ferro-Magnetic
- **Iron**
- **Steel**

How to Make a Magnet

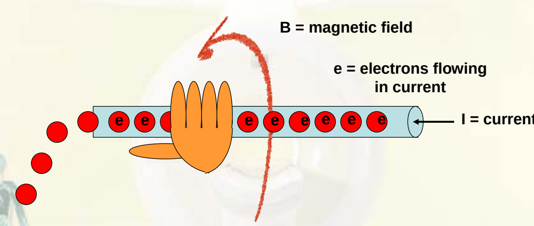




Permanent magnets
Magnetize ferromagnetic materials
Permanently magnetized

Electromagnets
Current in wires
Requires current to remain magnetized

Right Hand Thumb Rule



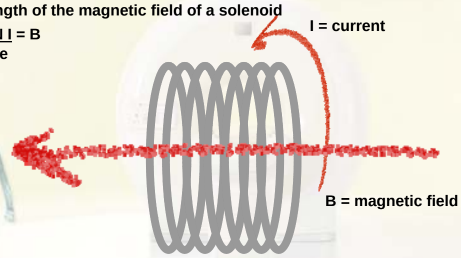
- Wrap fingers of right had around the wire
- Point thumb in the direction of current
- Fingers point in the direction of the magnetic field (B)

Solenoid Electromagnet

Strength of the magnetic field of a solenoid

$\underline{2 \pi N I} = B$

space



Magnetic Field Strength

- Tesla (T)
  - Within the bore
- Gauss (g)
  - Outside the imager
- 1T = 10,000 g

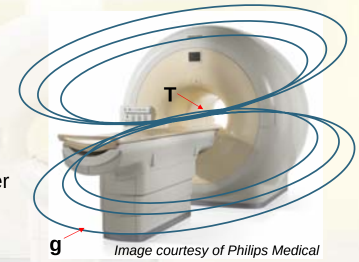


Image courtesy of Philips Medical

"Magnetic"

- The Main Magnet (Bo)
  - Static magnetic field
  - Magnetize the proton spins
- The Shim Magnet
- The Gradient Magnet
- The RF Magnet (B1)


Image courtesy of Philips Medical

Magnet Configurations


Image courtesy of Hitachi Medical

Permanent Magnet 0.3T


Image courtesy of Philips Medical

Resistive Magnet 0.3T


Image courtesy of Siemens Medical

Superconducting Magnet 1.5T

Simple Permanent Magnet Configurations

- Horseshoe Magnets
- Face – to- face
- Vertical field
- "Open"

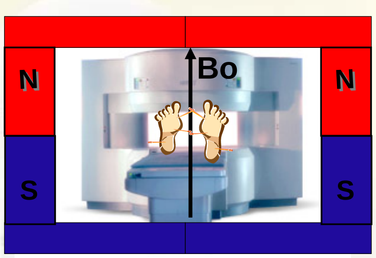
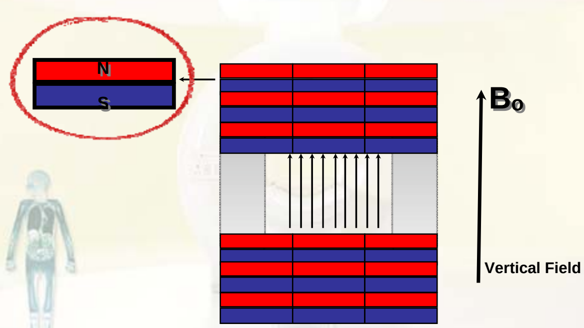


Image courtesy of Hitachi Medical

Permanent Magnet



Permanent Magnet Imager

- Magnetic material magnetized
- Permanently magnetized
  - –Always on
- Temperature sensitive
- Heavy in weight
- Low field strength
- Vertical field

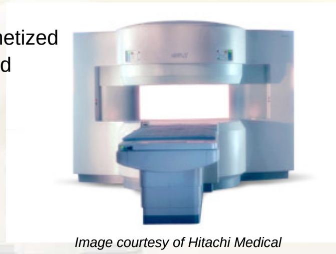


Image courtesy of Hitachi Medical

Permanent Magnet 0.3T

Permanent Magnet Imagers

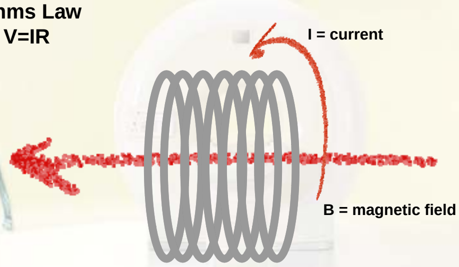
Hitachi Airis (0.3 T)

GE Profile (0.2 T)

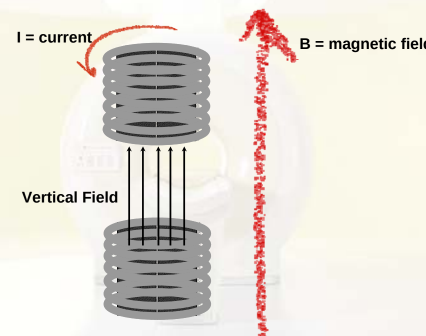
Images courtesy of Hitachi and GE Medical Systems

Resistive Magnet

Ohms Law
V=IR



Iron Core Resistive Magnet



Resistive Magnet Imager

- Electro-Magnet
  - –Current within conductors
  - –Resistance within the conductors
- Requires current to be on
  - –Can be turned off
- Light in weight
- Low field strength
- Vertical or Horizontal field

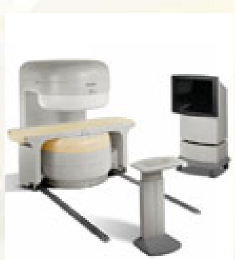


Image courtesy of Philips Medical

Resistive Magnet 0.3T

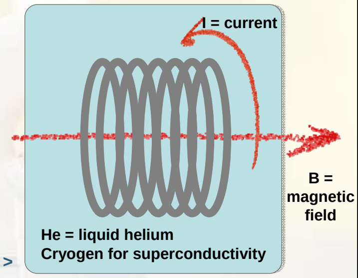
Upright System

Transverse field

Image courtesy of Fonar

Superconducting Magnet


Image courtesy of Siemens Medical



Clinical Imagers with field strengths up to 3.0 T
Research systems at 7.0 T and >

Superconducting Magnet Imager

- Superconducting Electro-Magnet
  - –Current within conductors
  - –Supercooled to remove resistance
  - –Needs cryogens (liquid helium)
- Always on
- High field strength
- Horizontal field
  - –Rare exceptions

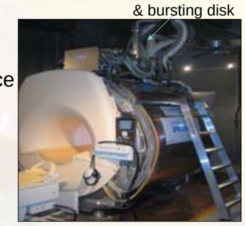


Image courtesy of Philips Medical

Superconducting Magnet
1.5T

High Field Extremity Magnet



Images courtesy of ONI Medical Systems

Whole Body Superconducting Hybrid Magnet


Images courtesy of GE

Magnetic Field Shielding

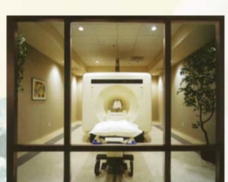


Image courtesy Lindgren

- Passive
  -Metal in scan room walls
- Active
  -Implies current
  -Other magnets within
- 5 g within the wall

Magnetic System Components

- The Main Magnet (B_0)
- The Shim Magnet
- The Gradient Magnet
- The RF Magnet (B_1)


Image courtesy of Philips Medical

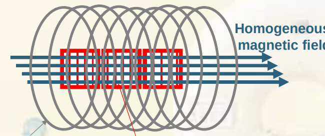
•And you thought that there was only one magnet in the MR Imager!

Magnetic – Shim System

- The Main Magnet (Bo)
- The Shim Magnet
  - Maintain homogeneity
    - Units of PPM
    - Parts per million
  - Passive or active
    - Passive
      (shim plates, no current)
    - Active
      (shim coils, requires current)
- The Gradient Magnet
- The RF Magnet (B)

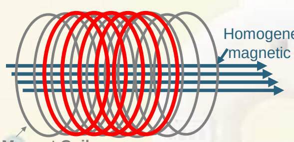
Image courtesy of Philips Medical

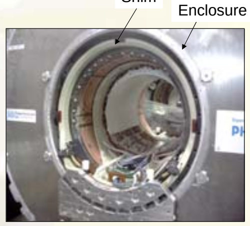
Passive Shim



- Passive shim = NO current
- Shim plates within the imager near the magnet
- Shim plates are installed during imager manufacturing

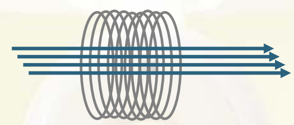
Active Shim





- Active shim implies current
- Shim coils within the imager near the magnet
- Shim coils are resistive magnets and require current in order to run
- Systems typically shimmed by the service engineer

Homogeniety



- Homogeniety is expressed in units of ppm
- PPM = parts per million or one 1/1,000,000
- 1T = 10,000 g
- 1 ppm inhomogeniety = + or - .01 gauss
- Field strength can be 10,000.01 g to 10,000.00 g
- if the frequency is 42 megahertz (million hertz)
- then the homogeniety is 42 Hz

Shim Power Supply

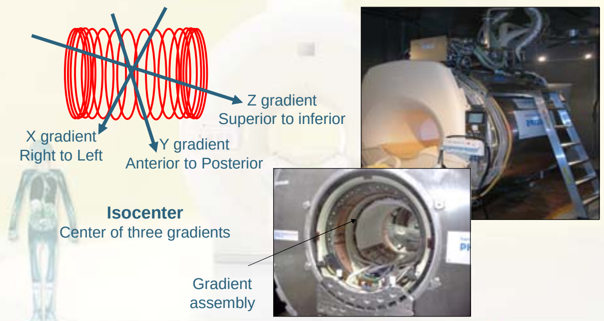
- Located within the equipment room
- Must be "on" for the shim system to work
- Otherwise homogeneity suffers
- Image quality is compromised

Gradient "Magnetic" System

- The Main Magnet (Bo)
- The Shim Magnet
- **The Gradient Magnet**
  - Spatial localization
  - Refocus Signals
  - Linear gradation (slope)
  - Time varied magnetic field
  - Units
    - Millitesla per meter (Mt/m)
    - Gauss per centimeter (g/cm)
    - 10 Mt/m = 1 g/cm
- The RF Magnet (B1)

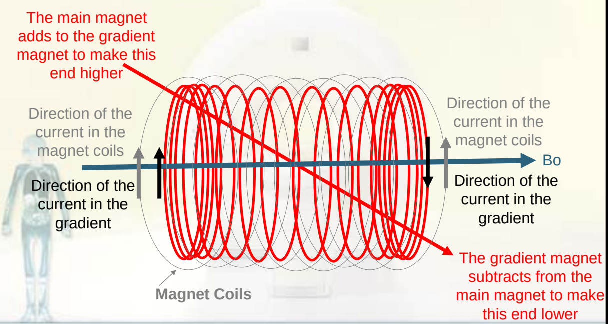
Image courtesy of Philips Medical

Gradient Configurations



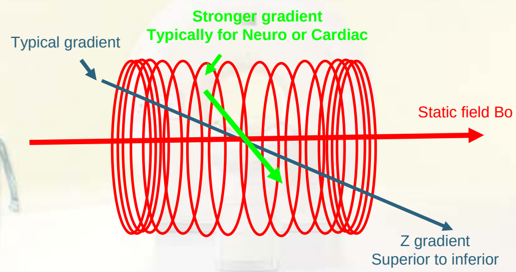
Slide # 37

Wire Configurations for Gradient Coils



Slide # 38

Dual Gradients



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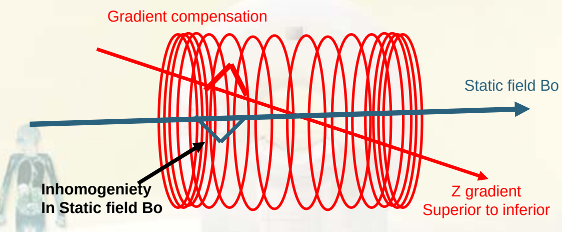
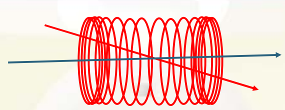
Gradient Shim



Slide # 40

Gradient Units



Gradients can be expressed in several units of measure including:

- Strength (amplitude)
  - mT/M (millitesla per meter)
- Strength (amplitude)
  - g/cm (gauss per centimeter)
- 10 mT/M = 1 g/cm
- Rise Time µ (microseconds)
  - (time to reach maximum amplitude)
- Slew Rate (combines rise time with strength)
  - Tesla per meter per second (T/M/s)

•Duty cycle (% of time the gradient can "work")

Slide # 41

Gradient Amplifiers

- X, Y, Z gradient amps
- Each has master/slave configuration
- Located in the computer room
- Uses resistive components
- Requires current

Slide # 42

Electromagnetic Radio Wave

- The Main Magnet (Bo)
- The Shim Magnet
- The Gradient Magnet
- **The RF Magnet (B1)**
  - To excite the proton spins
  - B1 field
  - Oscillating magnetic field
  - Larmor Frequency

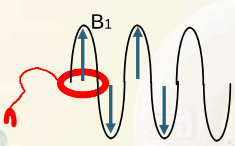
Image courtesy of Philips Medical

Resonance

- RF coils
  - Transmitters
  - Receivers
- Body coil
- Local coils
  - Linear
  - Quadrature
  - Phase array
  - Coil elements

Images courtesy of Philips Medical

RF Transmitter Configurations



RF Transmitters
Transmit signals at the Larmor frequency

Body coil

Transmit Coil Configurations

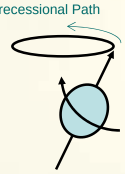
Vertical Field

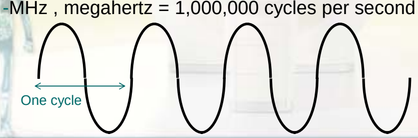
Transmit coils on the "face" of the magnet poles

The RF Frequency

The Larmor Equation
-calculates the precessional frequency based on B_0

- Precessional Frequency or Larmor frequency
  -The rate at which the spins wobble, or precess
- Wobble or precess in cycles per second
  -One cycle is once around the processional path
  -One cycle is one sine wave
  -One cycle per second = I Hertz (Hz)
  -MHz , megahertz = 1,000,000 cycles per second





Larmor Frequency

In order to calculate the precessional (Larmor) frequency
- The magnetic moment of the proton
- The spin angular momentum of the proton

Gyro-magnetic ratio = γ
Magneto-gyric ratio = γ

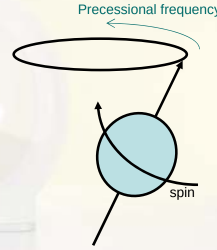
- The field strength of the magnet

Magnetic field strength = Bo

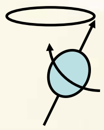
This is known as the Larmor equation

$$\omega_o = B_o \gamma$$

Larmor or Precessional Frequency = ω | Magnetic field strength = B | Gyro-magnetic ratio = γ Magneto-gyric ratio = γ



Calculating the Larmor Frequency



$$\omega_o = B_o \gamma$$

ω for 1H (hydrogen) = 42.6 MHz/T
If the Field strength (Bo) is 1.0 Tesla

Then...

ω_o = (1.0T) x (42.6 MHz/T)

ω_o = 42.6 MHz (Megahertz)

ω for 1H (hydrogen) = 42.6 MHz/T
If the Field strength (Bo) is 1.5 Tesla

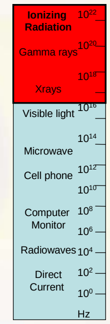
Then...

ω_o = (1.5T) x (42.6 MHz/T)

ω_o = 63.9 MHz (Megahertz)

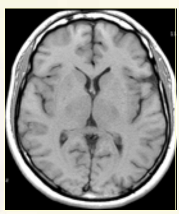
Radiofrequency Energy?

- Do we use radiation in MR?
- Electromagnetic spectrum
- X-rays
  - High energy
  - Ionizing radiation
- MR Radiofrequency
  - Low energy
  - Non-ionizing



At 1.5T the frequency is roughly 64 MHz.
In most cities, channel 3 broadcasts at roughly 64 Mhz.

Head Coil



Images courtesy Philips

RF Coils

MAGNETOM Concerto

Special coil kit

Body Spine Array Coil is available in S, M, L, XL. The Coil Kit includes size M and L.

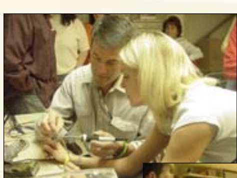
CP Head/Neck Array Coil
2 channel array receive coil
2 additional neck coil elements

Extremity Array Coil, small and large
Dual phased array receive coils with 2 coil elements each
Internal dimensions (WxHxD):
Small coil:
6 x 6.3 x 8.3 in
Large coil: 7.8 x 8.3 x 8.3 in

Multipurpose Coil 4.3 in
Single channel receive coil

Shoulder Array Coil
Dual Phased Array receive coil
Inner vertical opening 7.6 in

Building Coils



Coil tuning

Oscilliscope

RF Amplifiers

- Generates RF
- Amplifies signals
- Uses resistive components
- Requires power

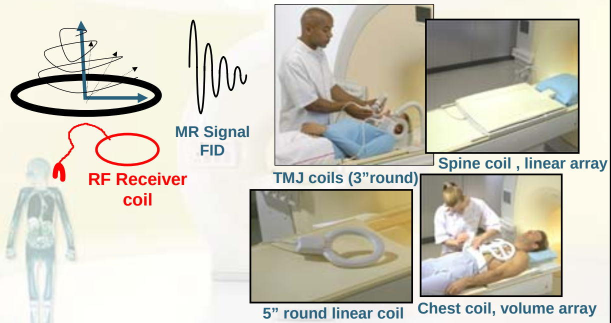
RF Shielding

Image courtesy Lindgren

Use of copper to construct a Faraday Cage around the system

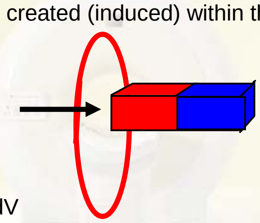
Eliminate RF noise from the environment

RF Receiver Configurations



Faraday's Law of Inducation

- Drag a magnet across a conductor, a voltage is created (induced) within the conductor

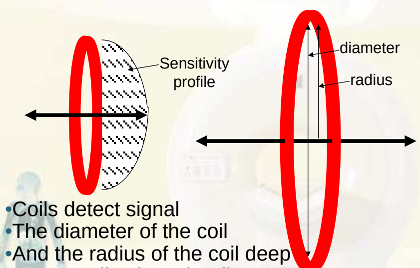


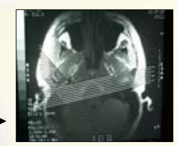
- dB / dt = dV

Change of magnet divided by time = voltage

- $\Delta B / \Delta t = \Delta V$

Sensitivity Profiles for Coils





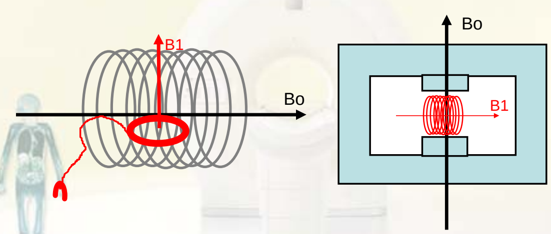
- Coils detect signal
- The diameter of the coil
- And the radius of the coil deep

Radius is ½ the diameter

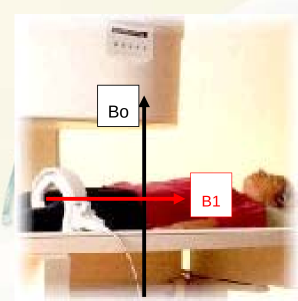
Sensitivity profile

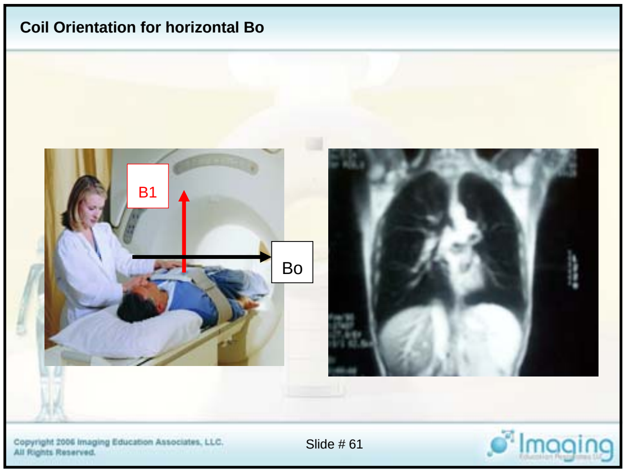
the area that signal can be detected

Magnet / Coil Configurations



Coil Orientation for vertical Bo




Coil Orientation for horizontal Bo
B1
Bo
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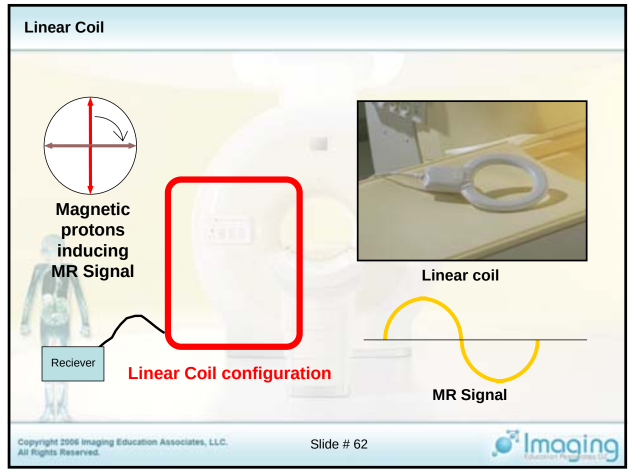
Slide # 61
Imaging


Linear Coil
Magnetic protons inducing MR Signal
Reciever
Linear Coil configuration
Linear coil
MR Signal
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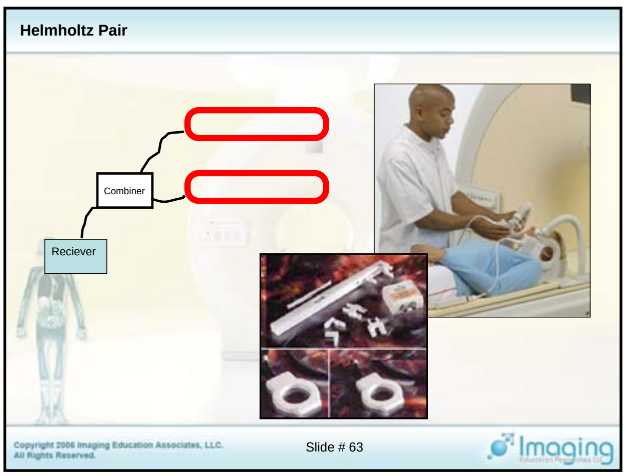
Slide # 62
Imaging


Helmholtz Pair
Combiner
Reciever
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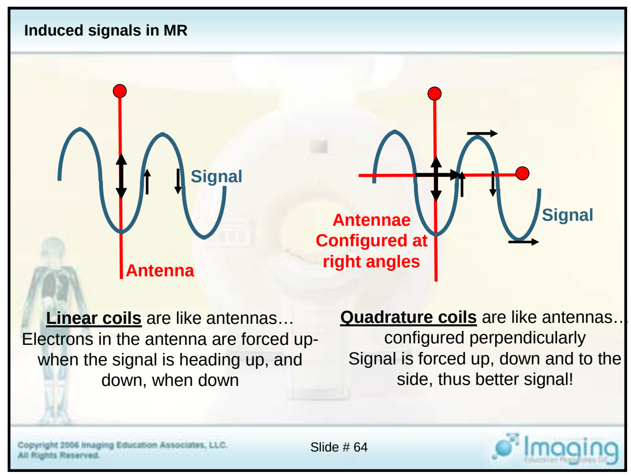
Induced signals in MR
Signal
Antenna
Antennae Configured at right angles
Signal
Linear coils are like antennas… Electrons in the antenna are forced up-when the signal is heading up, and down, when down
Quadrature coils are like antennas… configured perpendicularly Signal is forced up, down and to the side, thus better signal!
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Slide # 64
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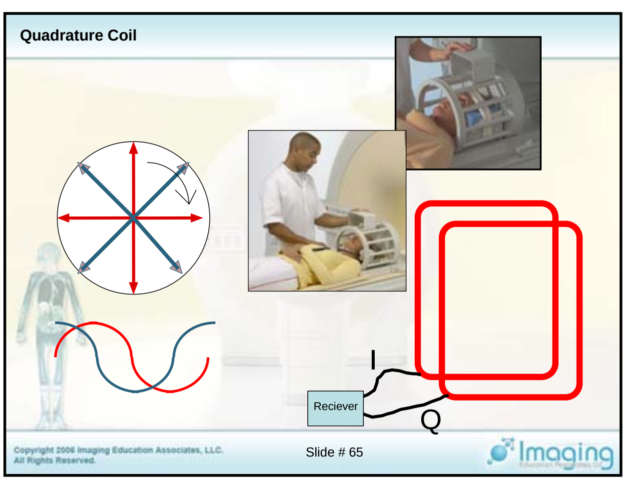
Quadrature Coil
I
Reciever
Q
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Slide # 65
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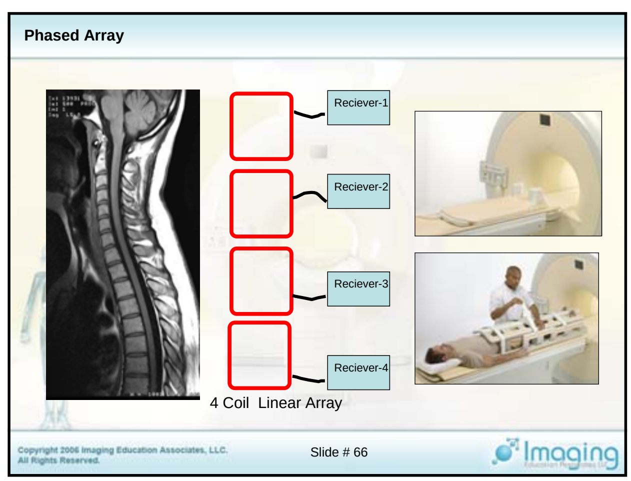
Phased Array
Reciever-1
Reciever-2
Reciever-3
Reciever-4
4 Coil Linear Array
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Slide # 66
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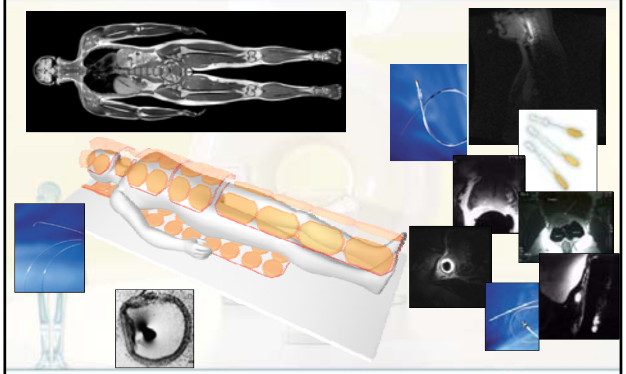
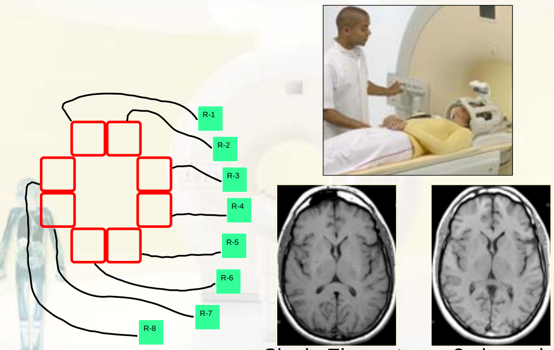
Coils, Coils, Coils

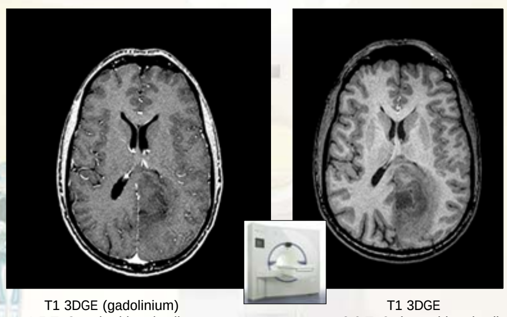


8 Channel Array



Single Element   8-channel

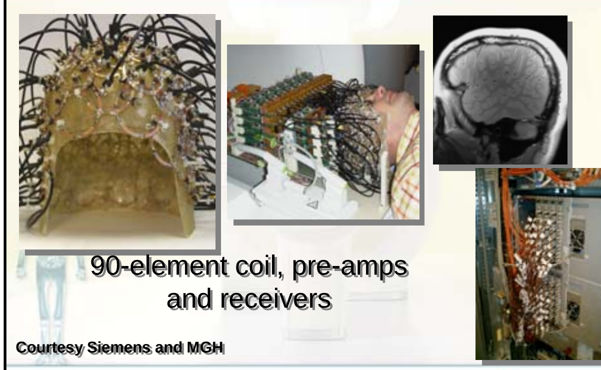
Image Quality for field strength and Coils



T1 3DGE (gadolinium)
1.5 T Standard head coil

T1 3DGE
3.0 T 8 channel head coil

On the Horizon?



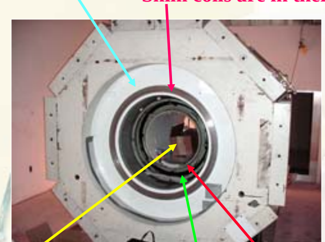
90-element coil, pre-amps and receivers

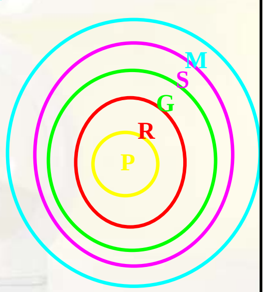
Courtesy Siemens and MGH

All the coils in the MR imager

Magnet enclosure (with cryogens)

Shim coils are in there





This is not a patient!

Gradient & RF coil assembly

2.1 Instrumentation

Magnetism & MR Magnets
other MR system components: shim systems,
RF system, gradient system, other components

Thank you for your attention!

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Carolyn Kaut Roth, RT (R)(MR)(CT)(M)(CV) FSMRT
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