MRI Basics

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imagination at work

Recipe for MRI

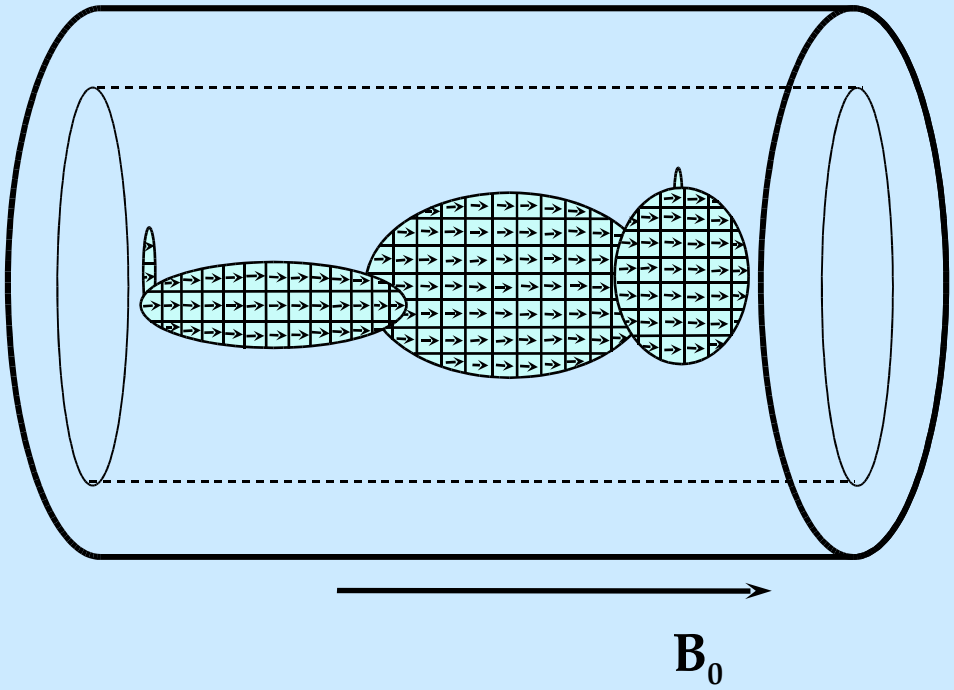
1) Put subject in big magnetic field
2) Transmit radio waves into subject (a few ms)
3) Receive radio waves re-transmitted by subject
   - Manipulate re-transmission with magnetic fields during this *readout* interval (10 -100 ms order : MRI is not a snapshot)
4) Store measured radio wave data vs. time
   - Now go back to 2) to get some more data
5) Process raw data to reconstruct images
6) Allow subject to leave scanner (this is optional)

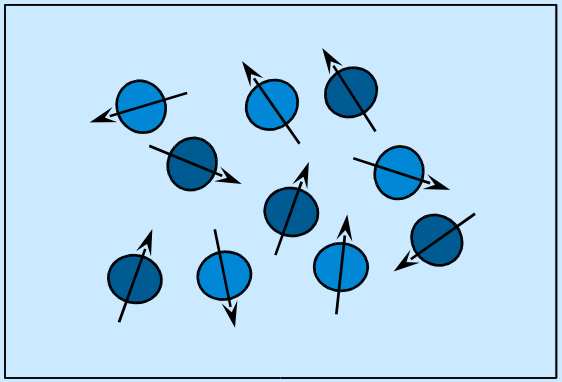
Source: Robert Cox's web slides

MRI Recipe

Step 1: Put the patient into a big magnetic field.

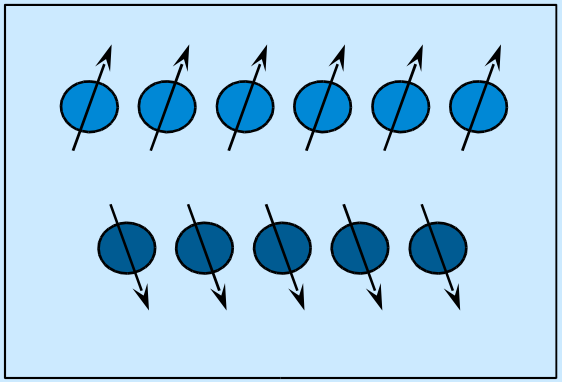
The magnetic field is used to align water molecules or “spins” within the body…





No Magnet Field

(Random Spin Orientation. Sum = 0)



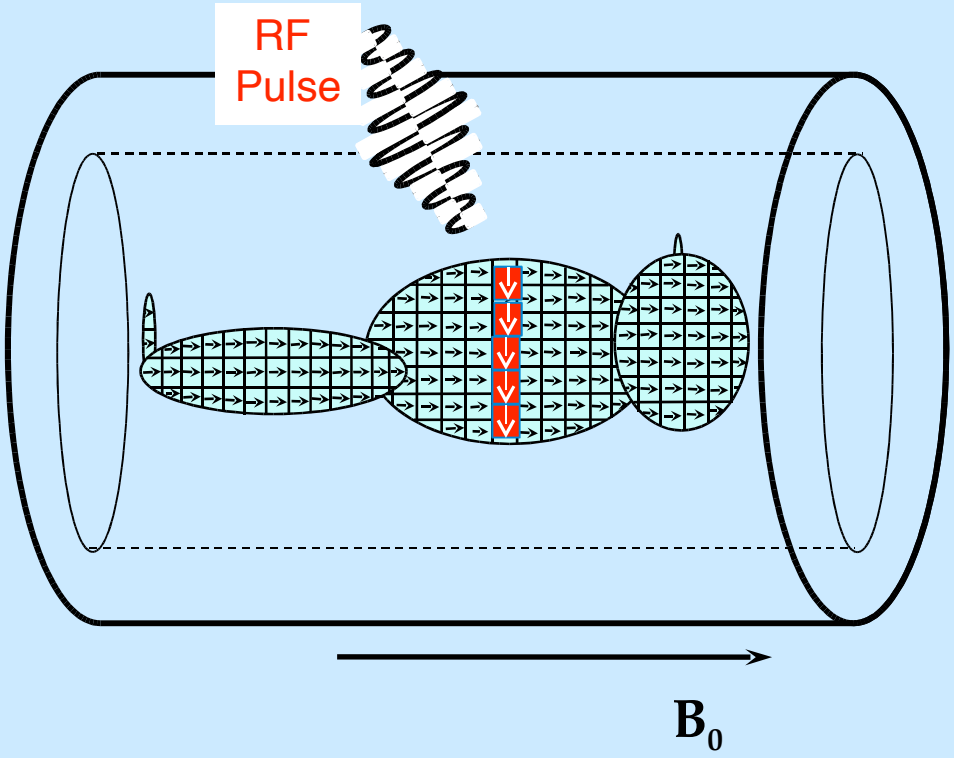
Bo = 1.5T, or 3T …

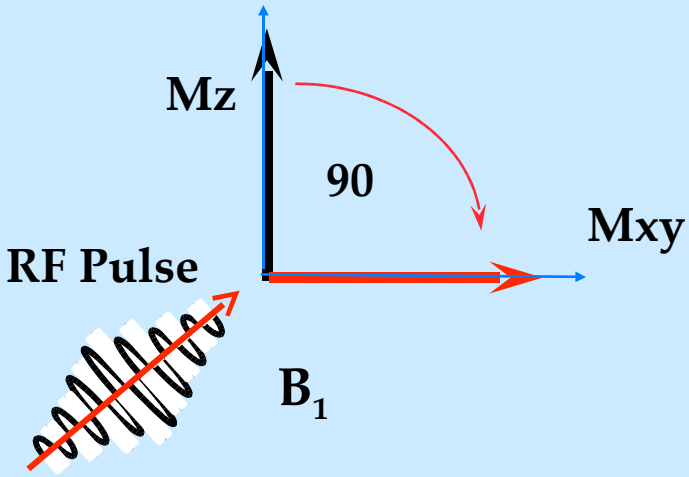
(Spins Align…Sum = **M**)

MRI Recipe

Step 2: Transmit radio waves into subject.

A pulse sequence is used to “excite” sections of spins using radio waves (RF excitation)…

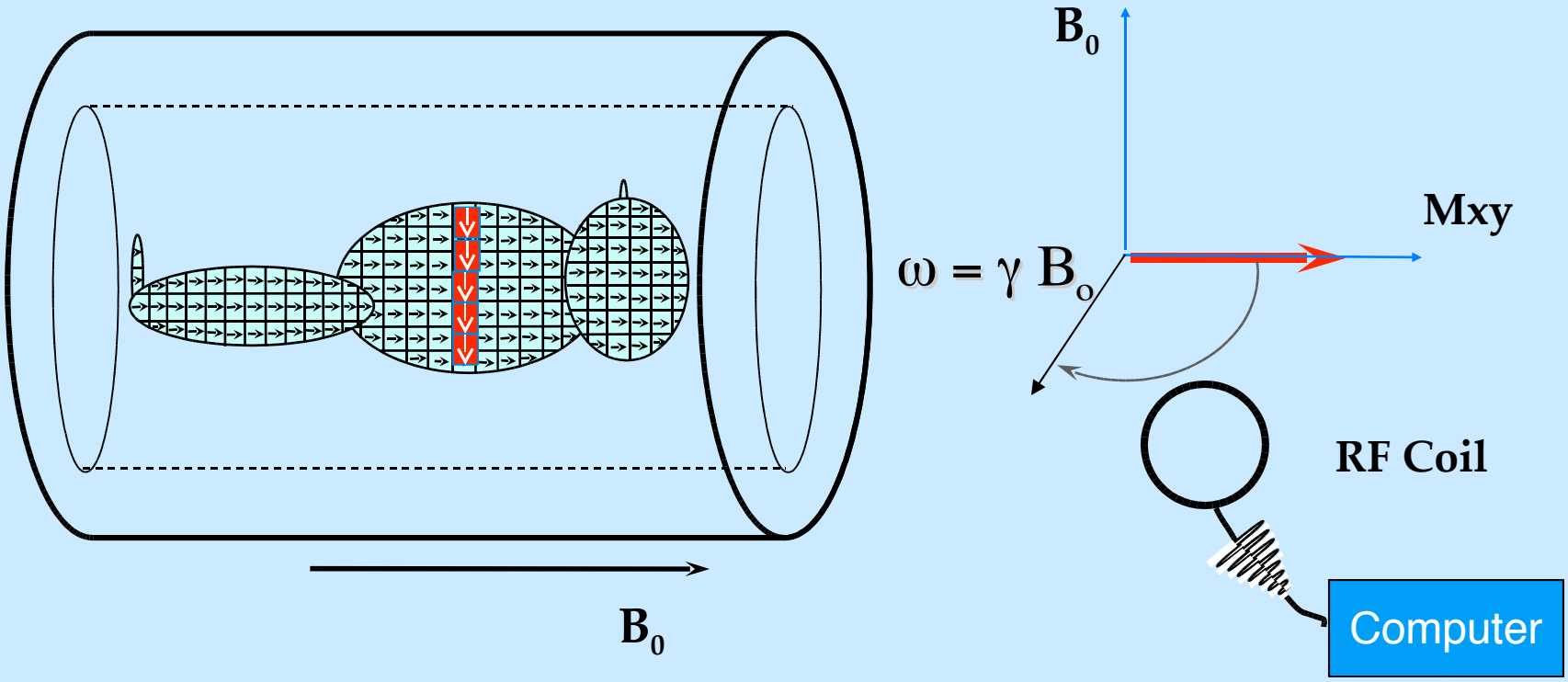




MRI Recipe

Step 3: Receive radio waves re-transmitted by subject.

After excitation, the magnetization precesses around the main field (B0). Any RF coil nearby will pick up the signal or "echo" as the magnetization spins around the main field…

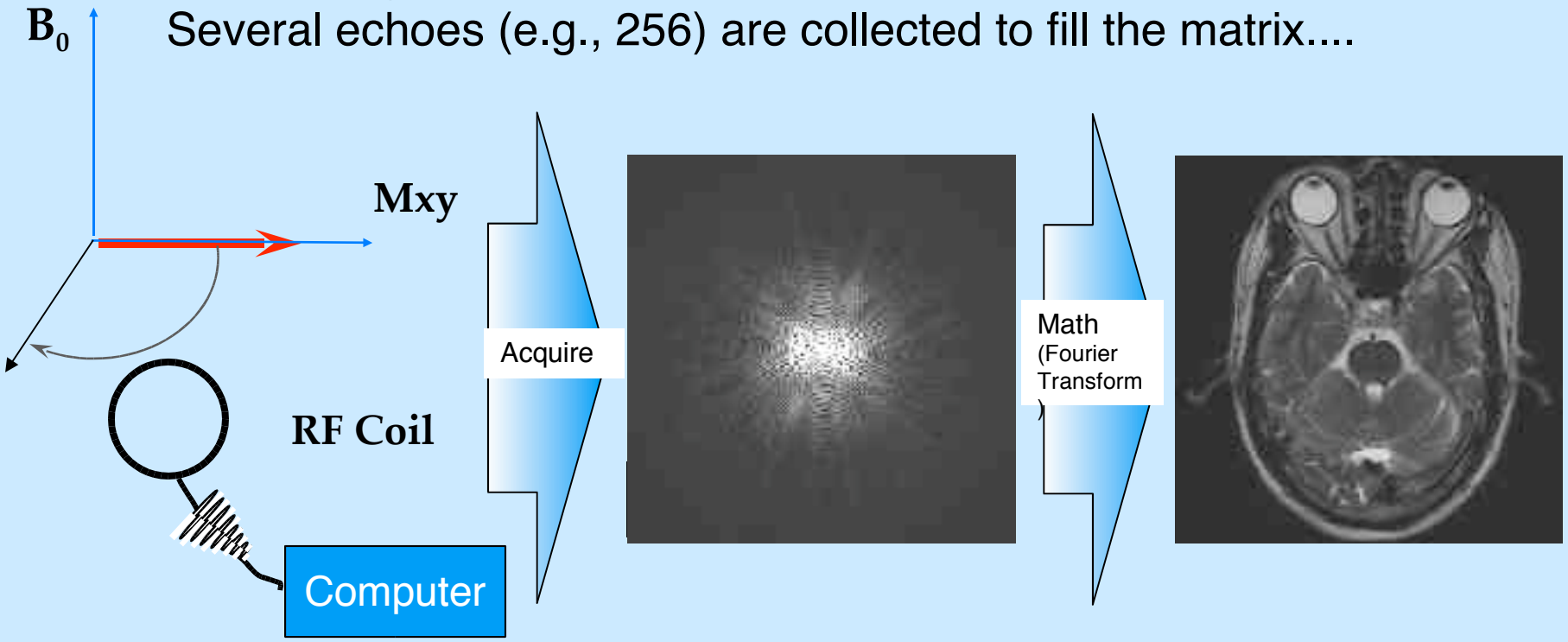


MRI Recipe

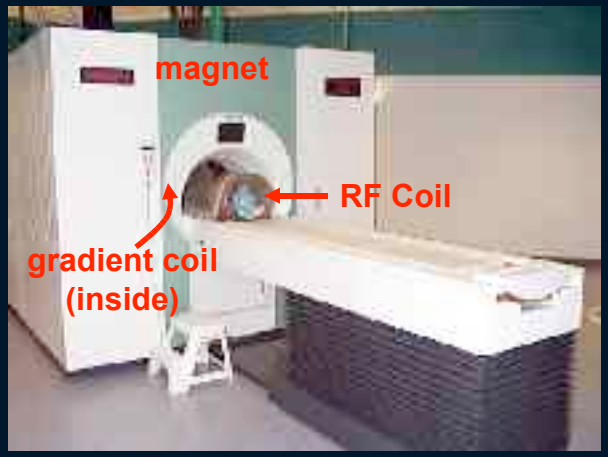
Step 4: Store measured radio wave data - Now go back to step 2 to get some more data

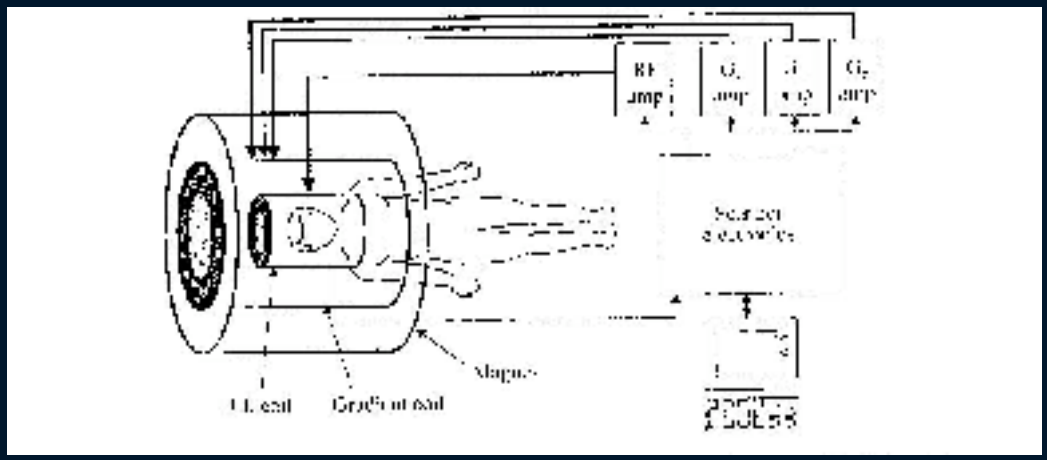
Step 5: Process raw data to reconstruct images.

The MR signal, or echo, is acquired and stored in a k-space matrix. Several echoes (e.g., 256) are collected to fill the matrix....



Necessary Equipment





Magnet

Gradient Coil

RF Coil

Source: Joe Gati, photos

MRI System Components

- The Magnet
- The Gradients
- The Data Pipeline
- RF Coil Portfolio
- Applications Portfolio

What it is
Why it matters
Why it matters to fMRI

The MR Imaging Chain

Any MR system and be dissected into 5 sub-systems…
The first four define the fifth

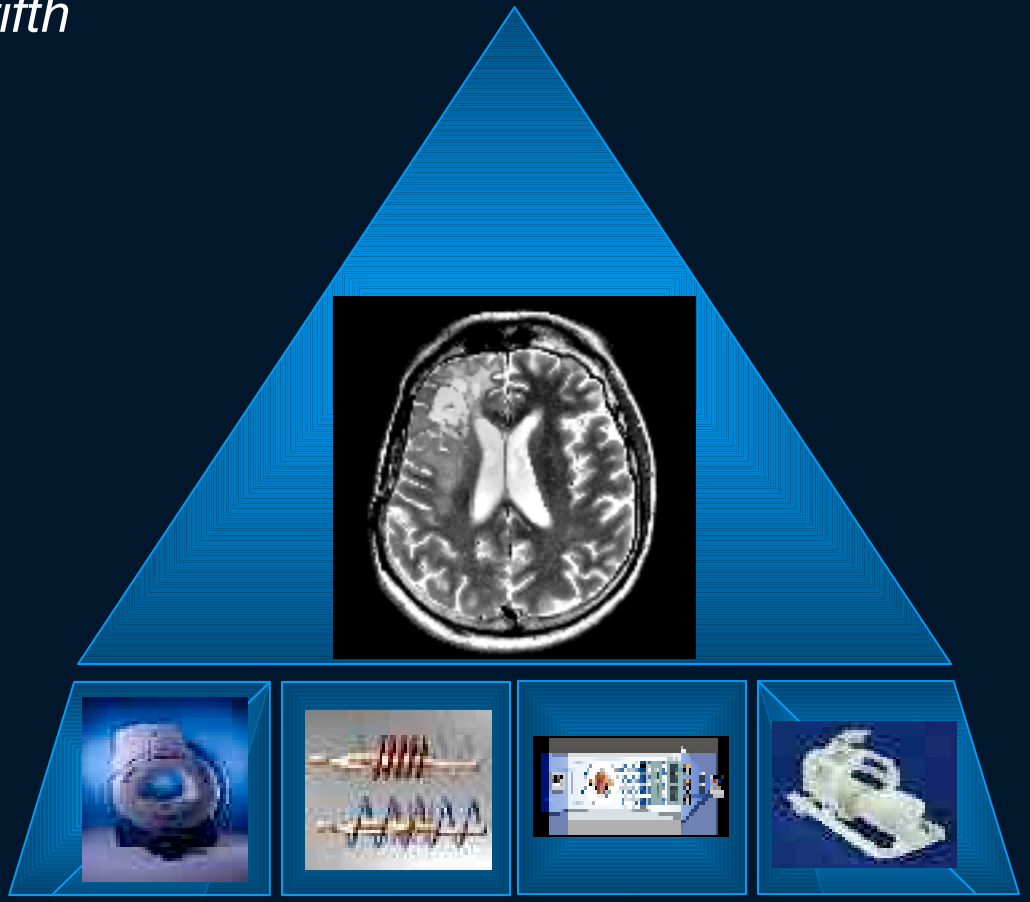
The Magnet

The Gradients

The Data Pipeline

RF Coil Portfolio

Applications Portfolio



The Magnet

The Magnet

The magnet is the heart of a MR scanner, which directly related to image quality and cost decision.

Field strength

Homogeneity

Shimming

Siting ease

Cryogen consumption

Magnetic Field Strength – What is it?

Magnetic Field Strength is the measured intensity of magnetic field.

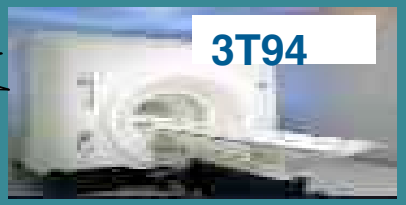
Magnetic field strength is measured in Tesla(T) or Gauss(G) (1T = 10,000G)

Earth's magnetic field = 0.6 Gauss

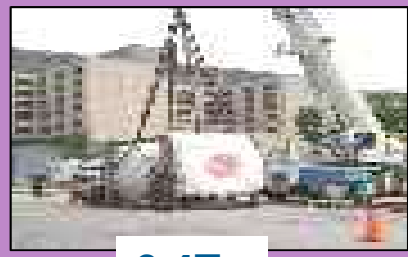
FDA approved clinical MRI scanner <= 3T

3T = 50,000 * earth magnetic field

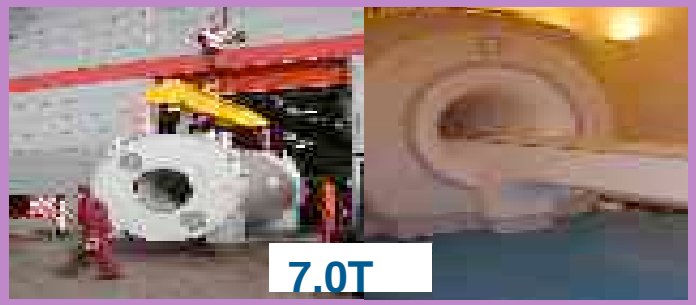
Clinical



from 0.2T to 9.4T



Research

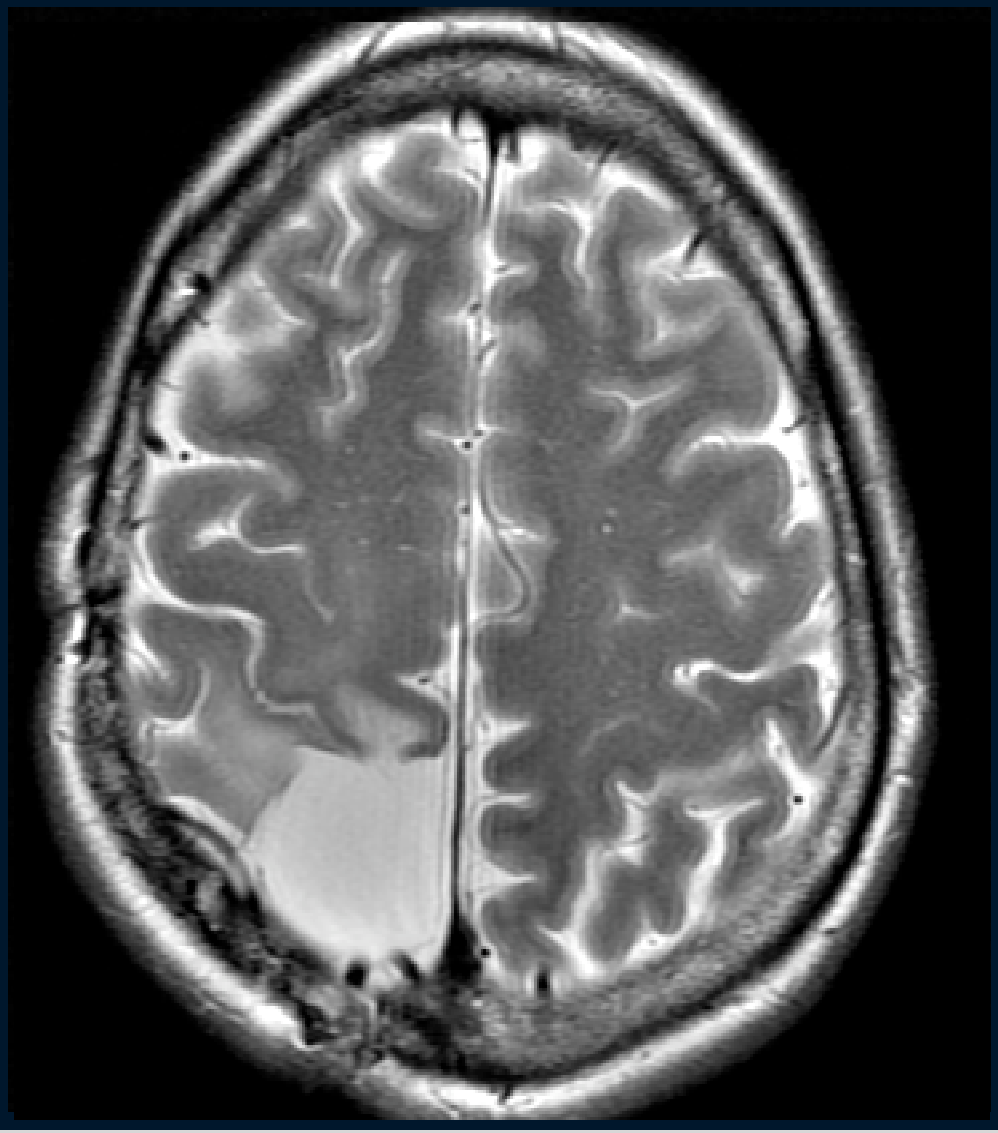


Effects of Increasing Field Strength

Parameter	Effect	Comments
SNR	↑	Linear i.e. SNR at 3.0T = 2X SNR at 1.5T
Spectral Dispersion	↑	Spectroscopy easier at higher fields – peaks are further apart
Fat Saturation	↑	Easier at higher field as fat and water peaks are further apart
Dielectric Effects	↑	Harder to get uniform RF field at higher magnet field strength… image shading
Acoustic Noise	↑	Higher field strength magnets exert more force on conductors thereby generating more acoustic noise
Patient Physiological Effects	↑	Vertigo, visual effects, metallic implant sensitivity increases
Magnetic Susceptibility	↑	Better fMRI studies -higher BOLD signal;more artefacts
T1	↑	Longer T1 relaxation time means scan protocols change with field strength
Chemical Shift	↑	Higher chemical shift means scan protocols change with field strength

Effects of Increasing Field Strength…
SNR

1.5 T
Excite



3.0 T
Excite

Images courtesy of Edison Imaging

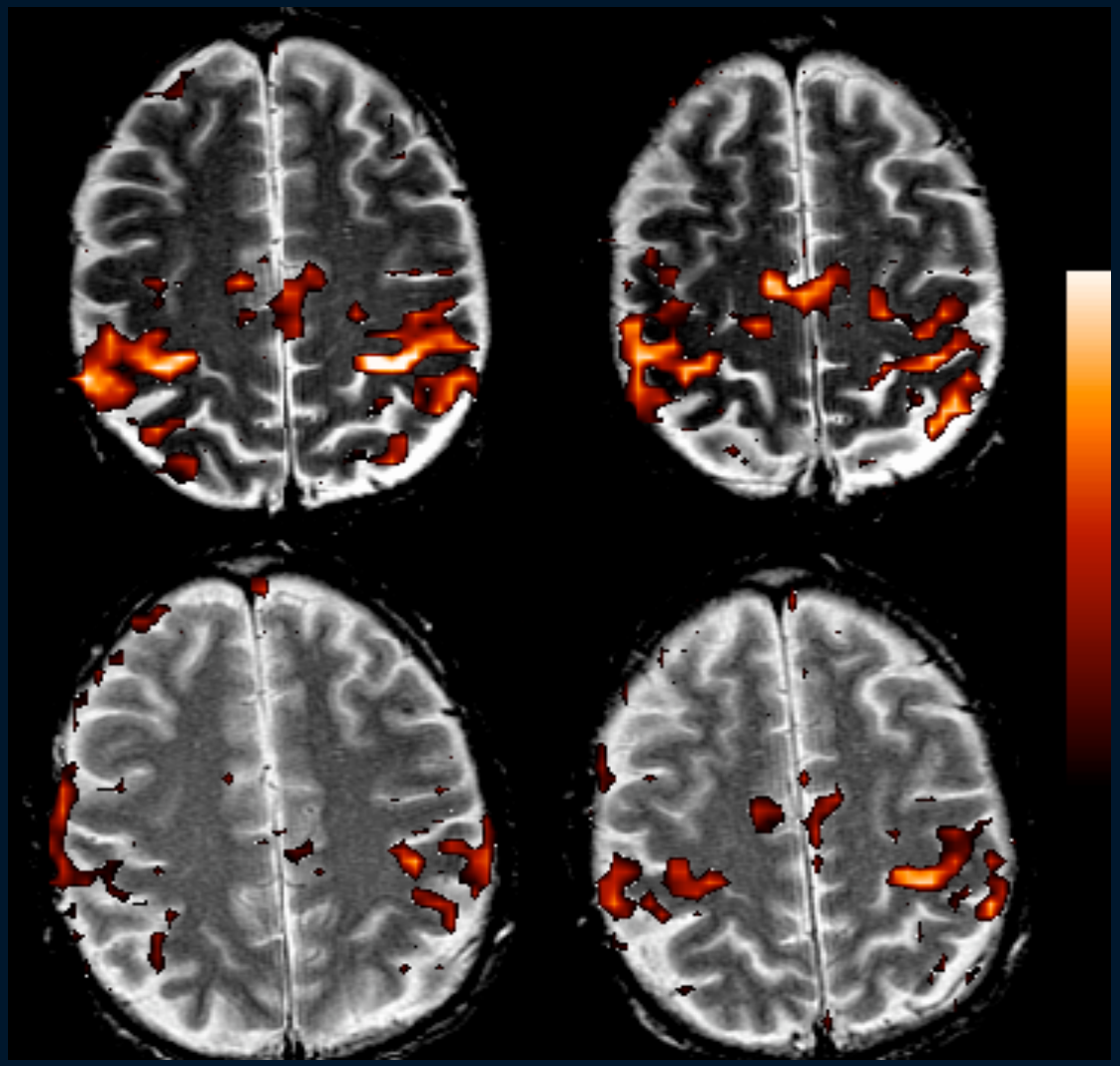
Effects of Increasing Field Strength…

BOLD effect

3.0T

fMRI

1.5 T



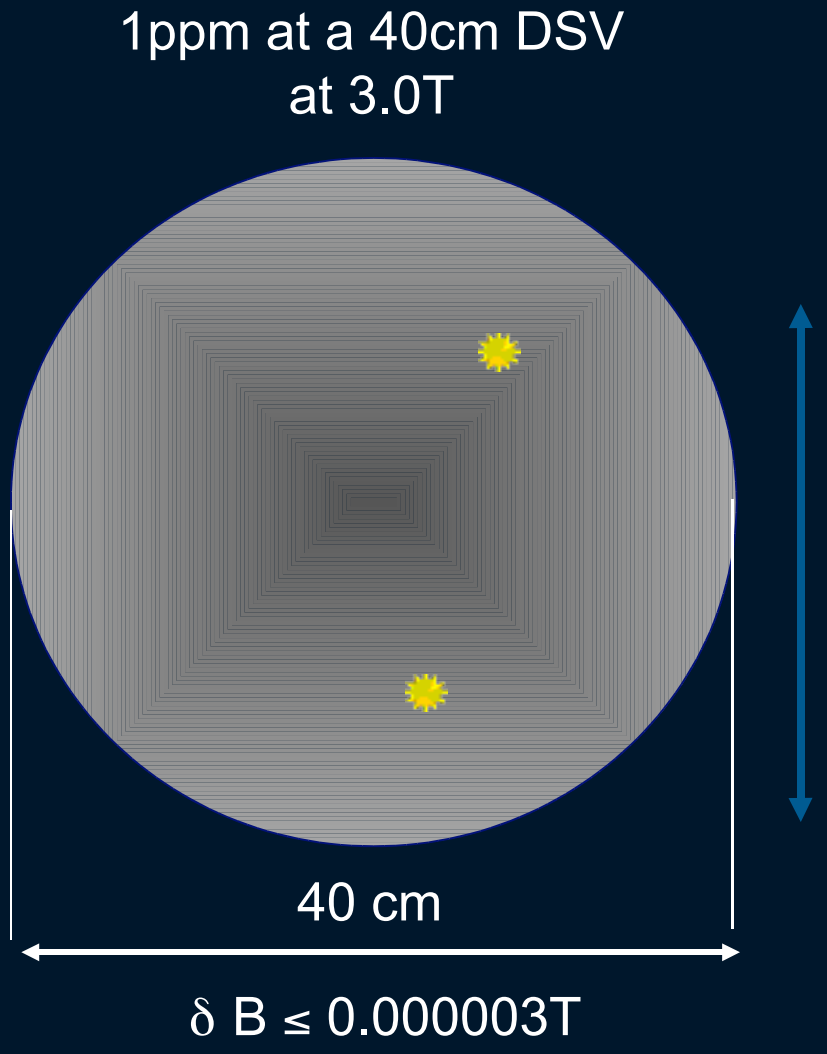
Images courtesy of Stanford University

Homogeneity – What is it?

Homogeneity is defined as “part per million variation of the magnetic field over a given volume--DSV”

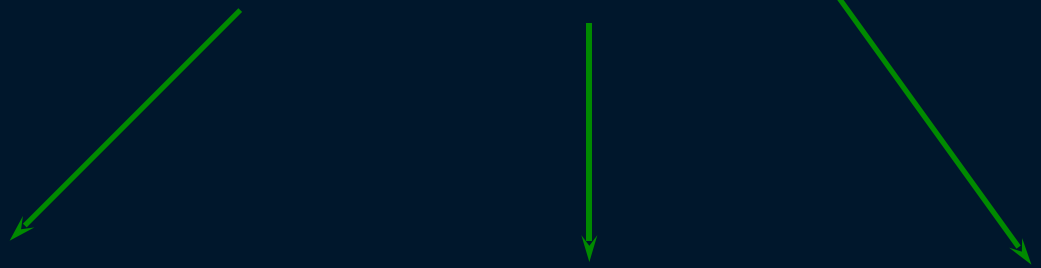
For example, at 1ppm homogeneity there is 1 part per million in the volume, that is not at the specified field strength

The significance of homogeneity increases as field strength increases.



Larmor Equation

$$\omega = \gamma Bo$$



Precessional Frequency

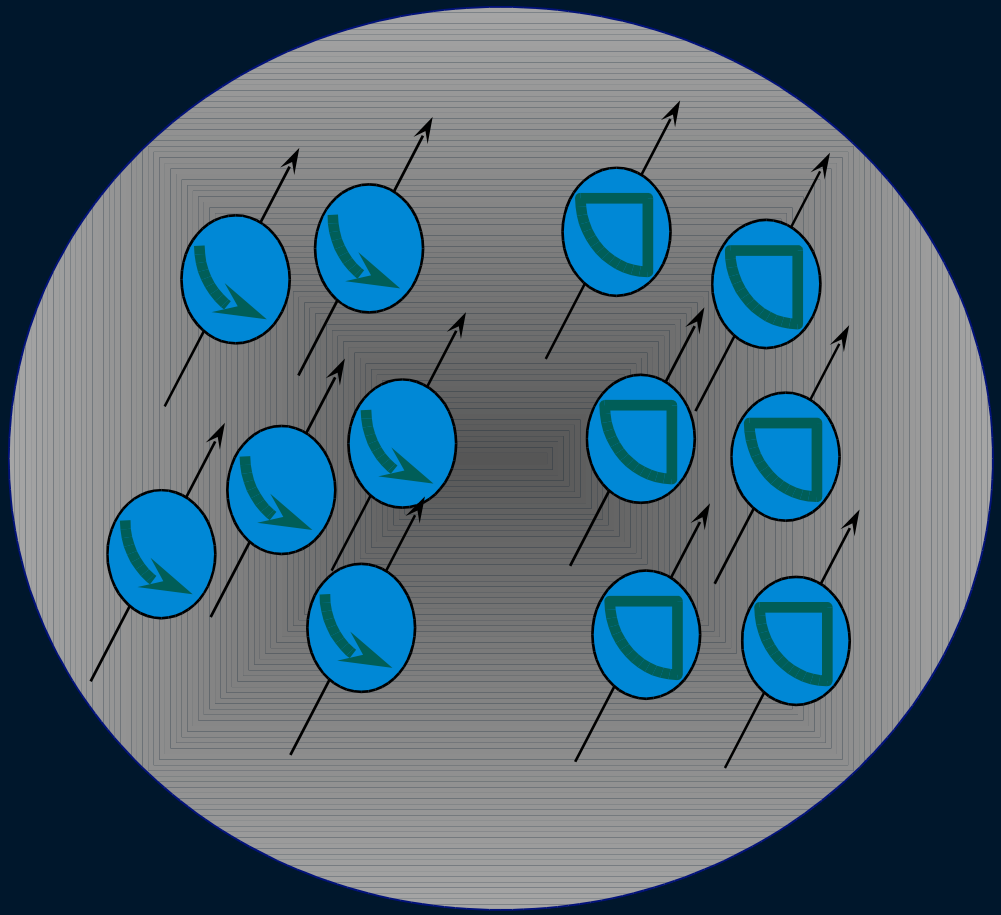
HYDROGEN (42.6)

Magnet Field Strength

Homogeneity – Why Does it Matter?

In a homogeneous volume of tissue all spins (of the same type) have the same MR frequency

“Everybody’s radio is tuned to the right station” resulting in optimum signal and minimized artifacts

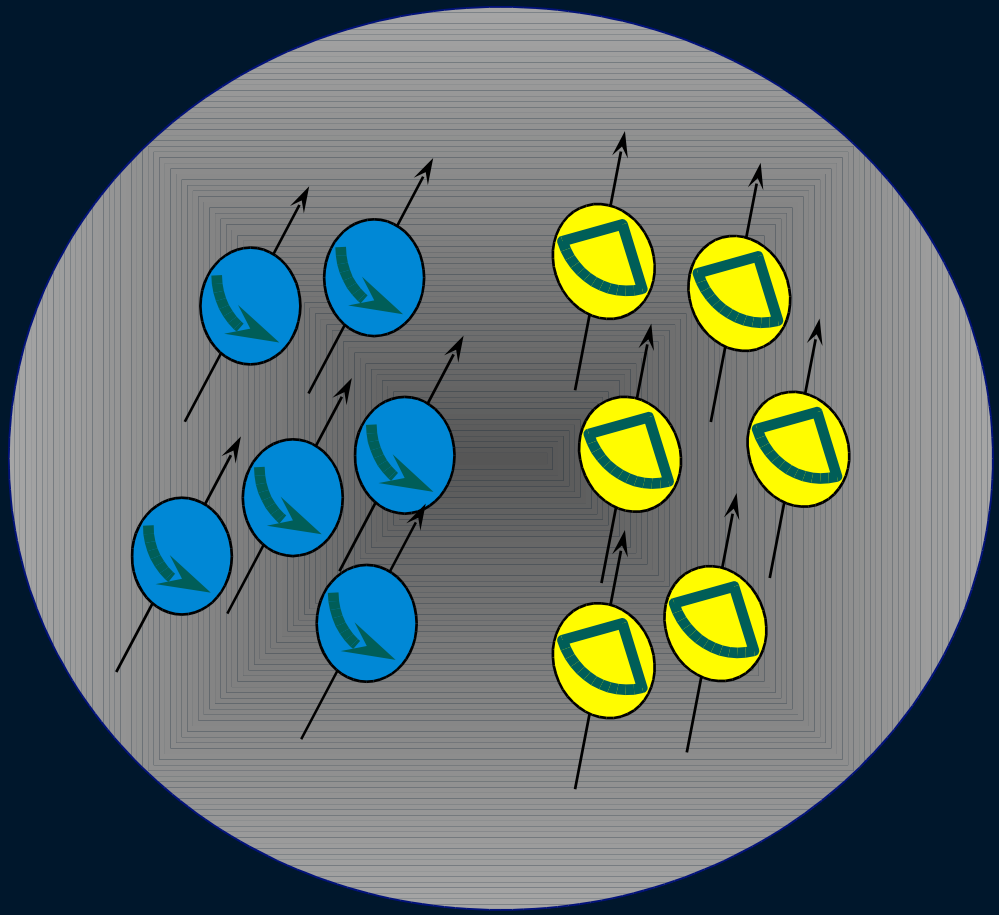


Homogeneity – Why Does it Matter?

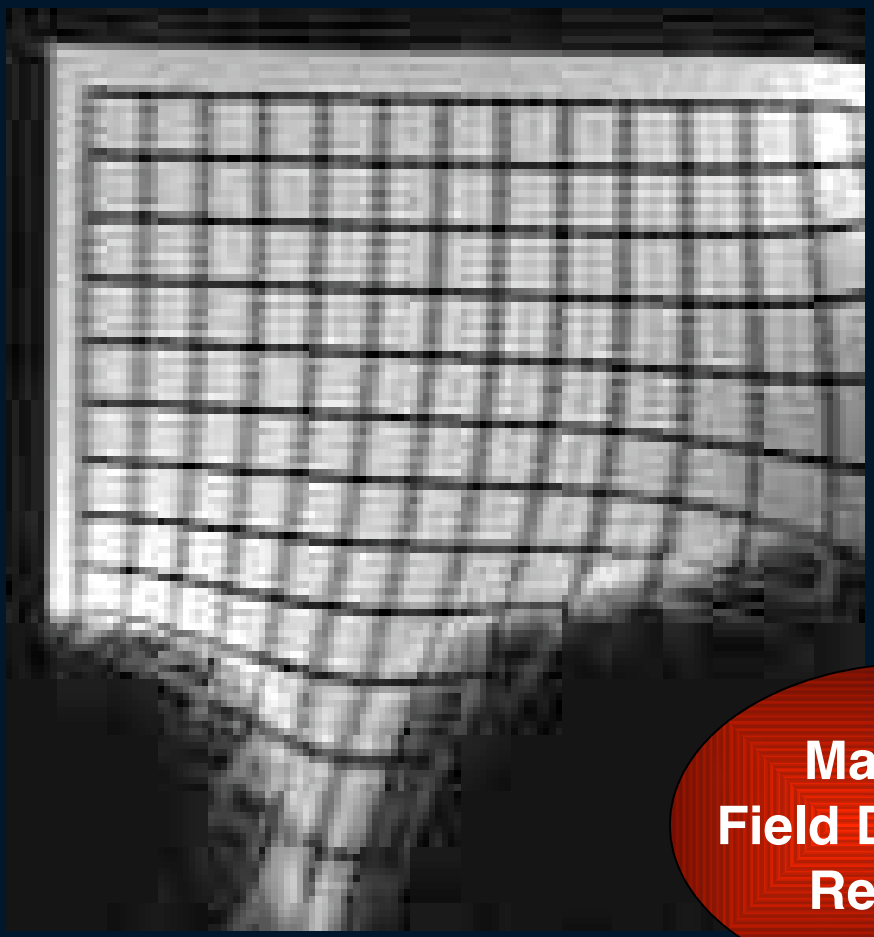
In an inhomogeneous volume of tissue spins have a different MR frequency

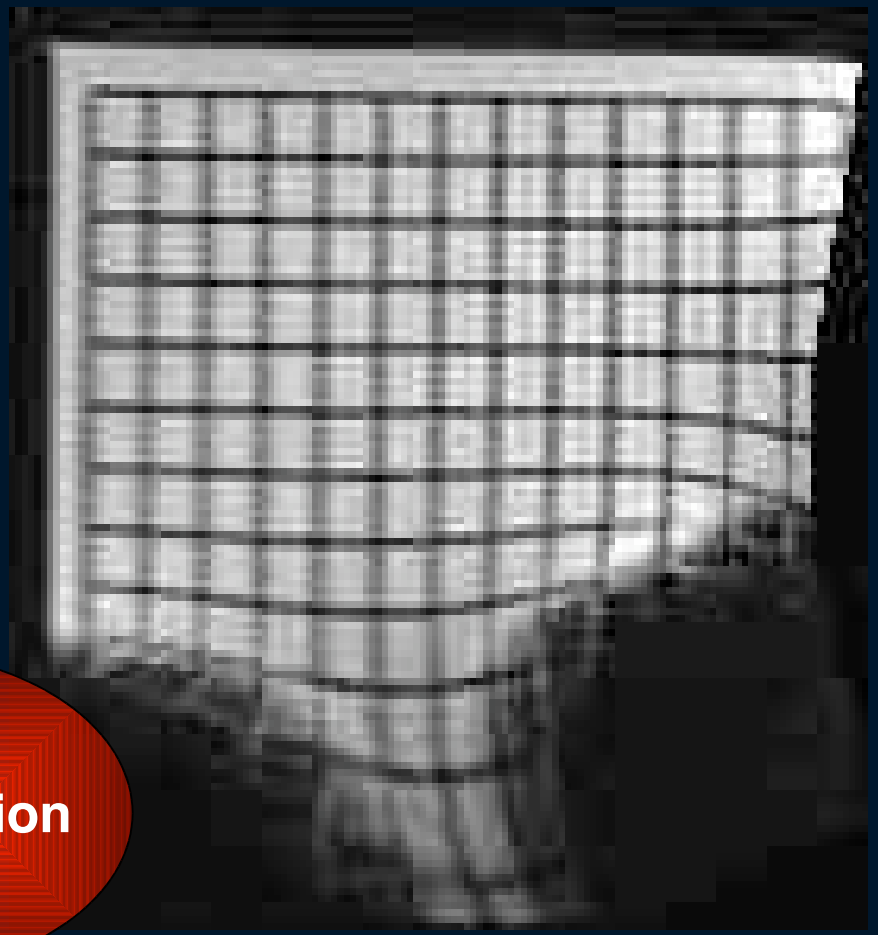
"Some radios are tuned to the wrong station"

- SNR degrades
- FOV degrades
- Off-center IQ degrades
- Resolution degrades
- FatSat is poor



Homogeneity – Why Does it Matter?

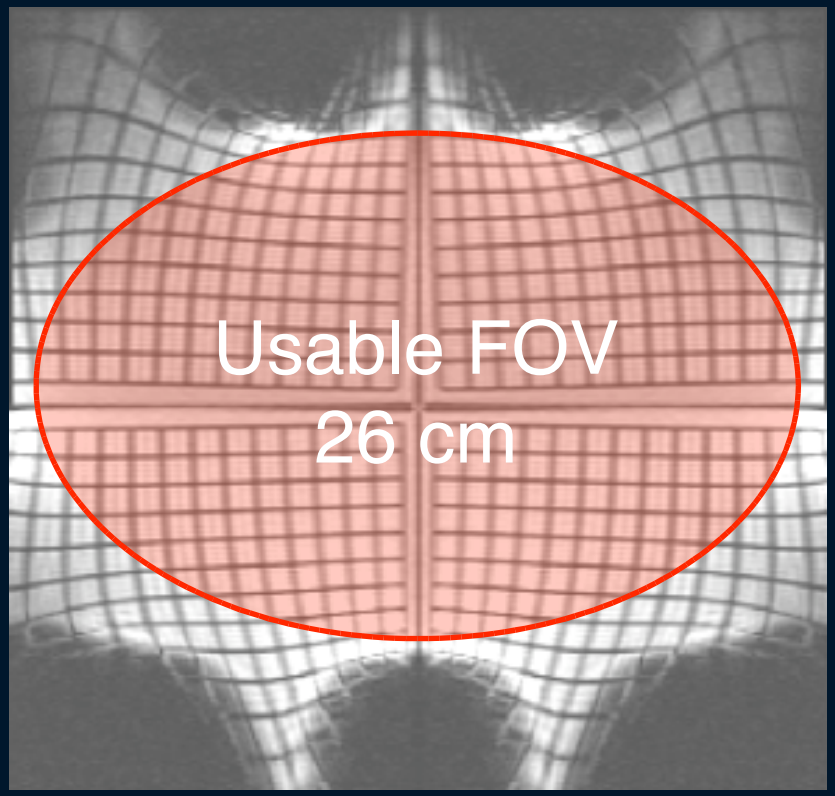


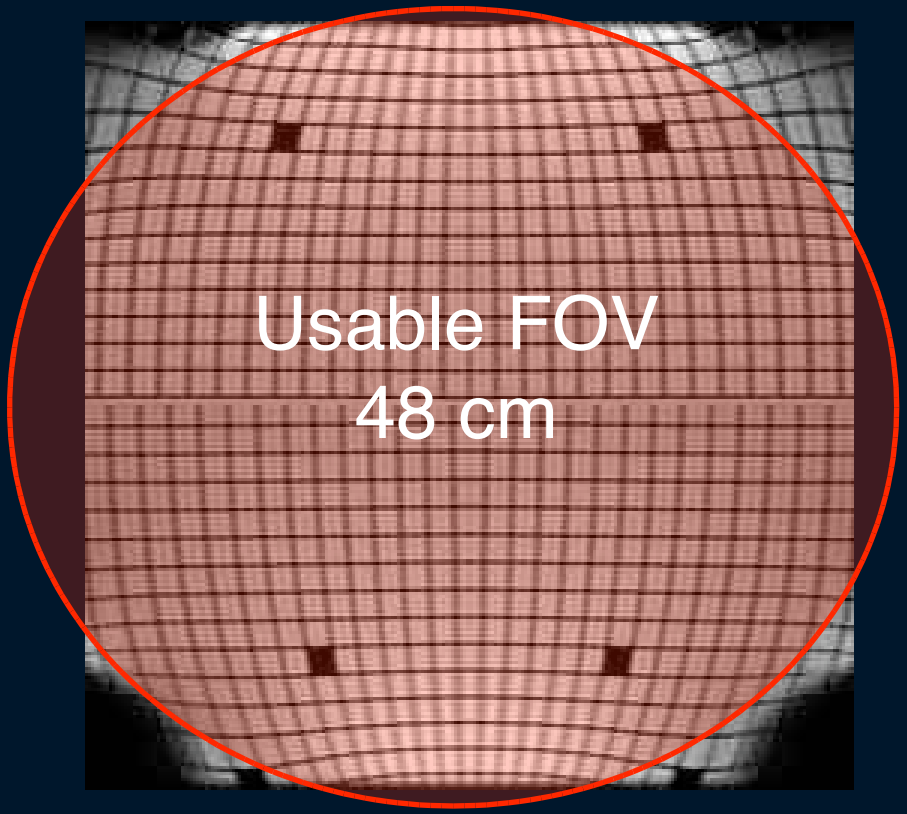


Magnetic Field Distortion Remains

Artifacts caused by magnet inhomogeneity cannot be corrected completely

Homogeneity – Why Does it Matter?

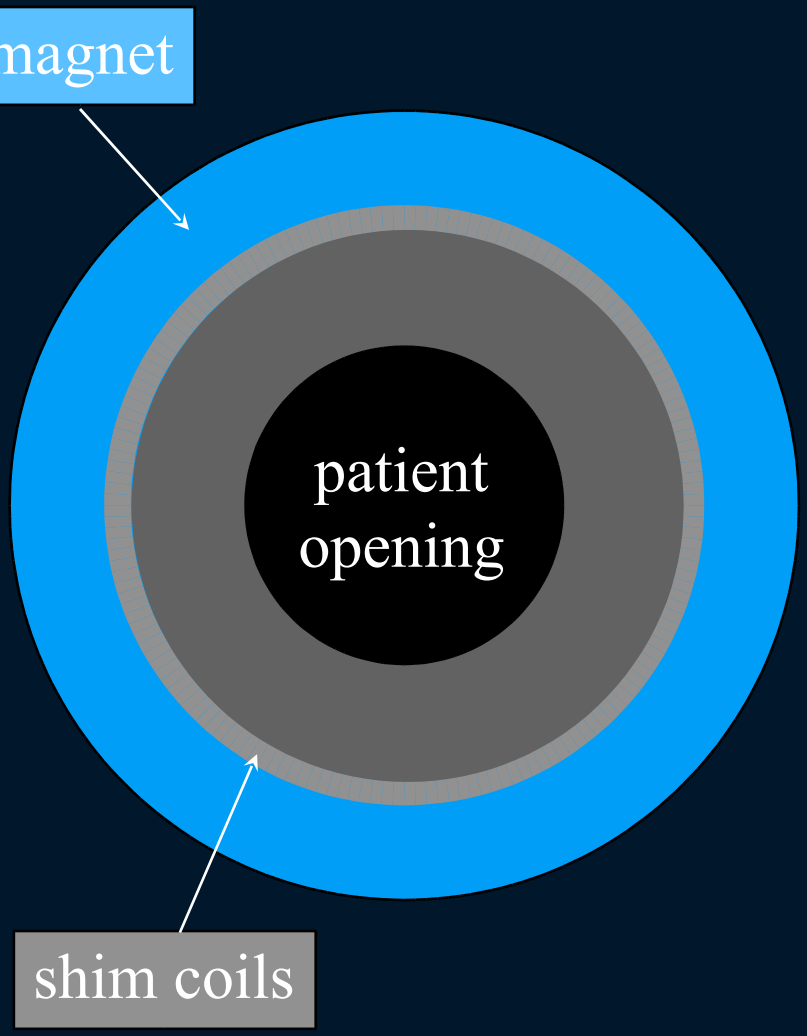




Usable FOV Is Reduced

Shimming – What is it? Why Does it Matter?

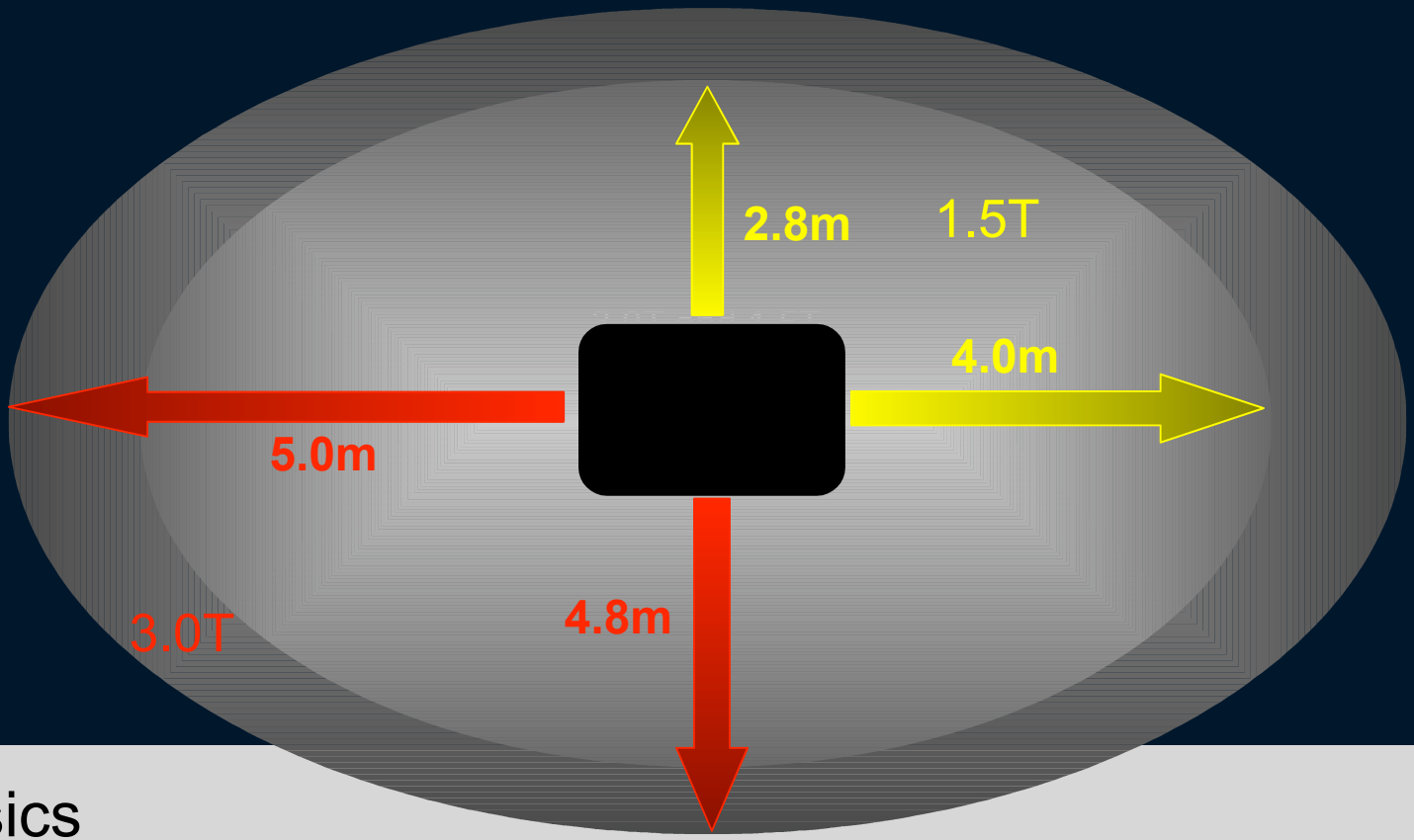
- Shimming is the process of balancing the main magnetic field
- GE uses 18 super-conducting shim coils in order to provide the most stable environment
- Shimming is critical to the maintenance of homogeneity – it reduces residual inhomogeneity as well as patient induced inhomogeneity



Fringe Field – What is it? Why Does it Matter?

Fringe field is the extension of the magnet field beyond the magnet and is a significant factor in siting.

- ✓Pacemakers outside 5 Gauss
- ✓Color monitors outside 1 Gauss
- ✓Nuclear Medicine outside .5Gauss

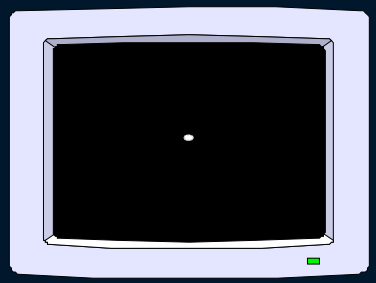


The Gradients

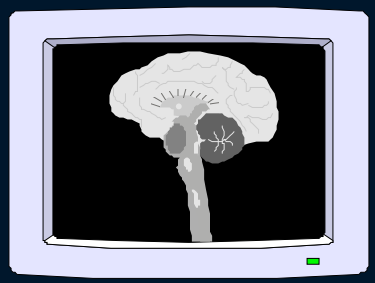
The Gradients - What is it?

Current-carrying coils designed to produce a desired gradient magnetic field which changes strength in a given direction.

No gradients (single resonant frequency)



Large gradient (highly resolved image)



$$\omega = \gamma \, Bo$$

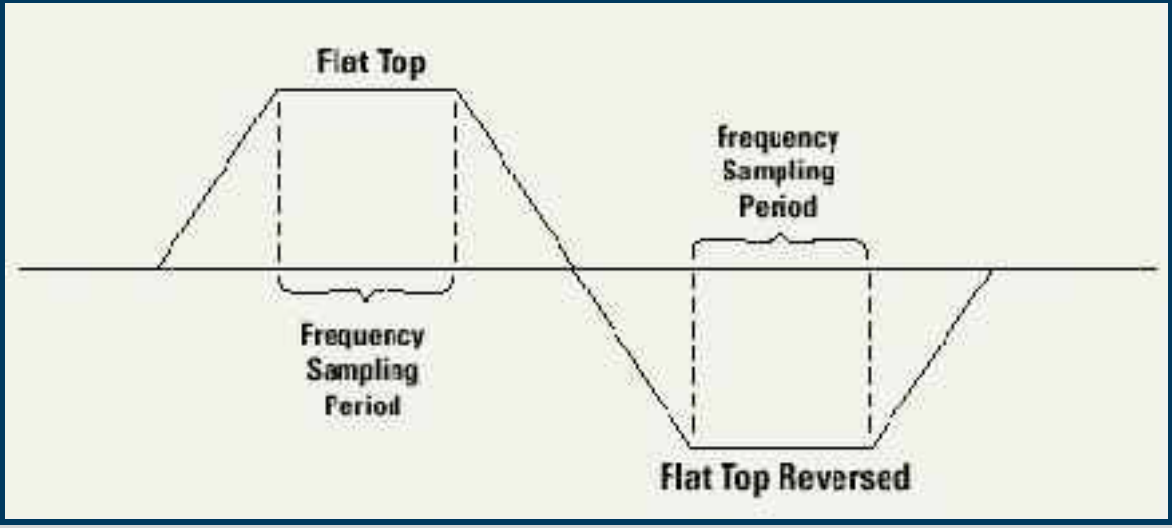
Major Gradients Specification

- Amplitude

  Amplitude is measured as mT/m it reflects the rate of increase in the magnetic field – also known as the height of the gradient flat top

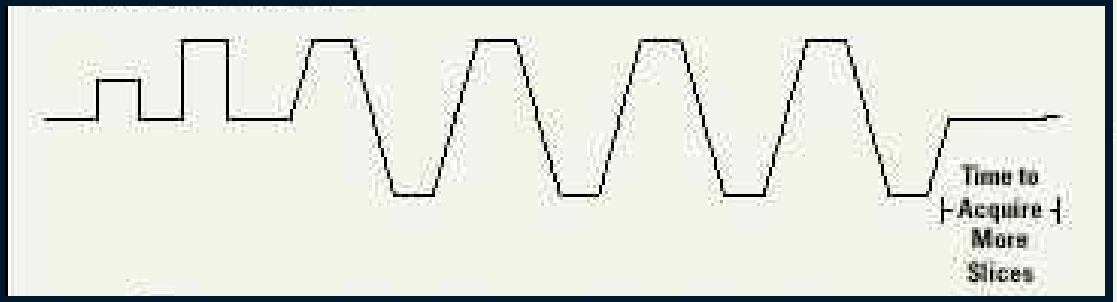
- Slew Rate

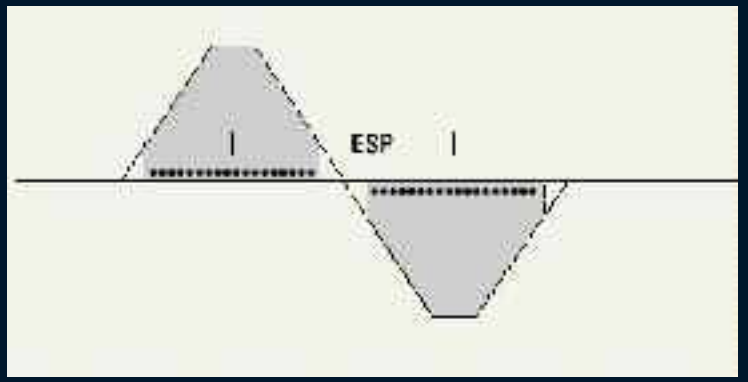
  Slew Rate is measured as T/m/s it reflects how rapidly the gradient can be ramped to the height of the gradient flat top



Why do Gradient Amplitude and Slew Rate Matter?

-Gradient Specs Must Translate to Performance





Powerful Gradient

Weak Gradient

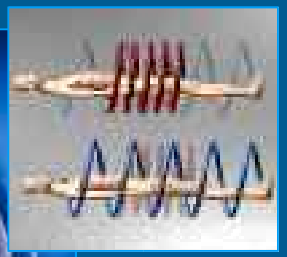
Gradient Platform

Gradient Performance

SmartSpeed
23mT/m SR50

HiSpeed+
33mT/m SR77
Min TR 1.3, Min TE .05

EchoSpeed+
33mT/m SR120
Min TR 1.2, Min TE 0.4



TwinSpeed
40mT/m SR150
23mT/m SR80
Min TR 1.1, Min TE 0.4
Dual Gradient
Quiet Technology

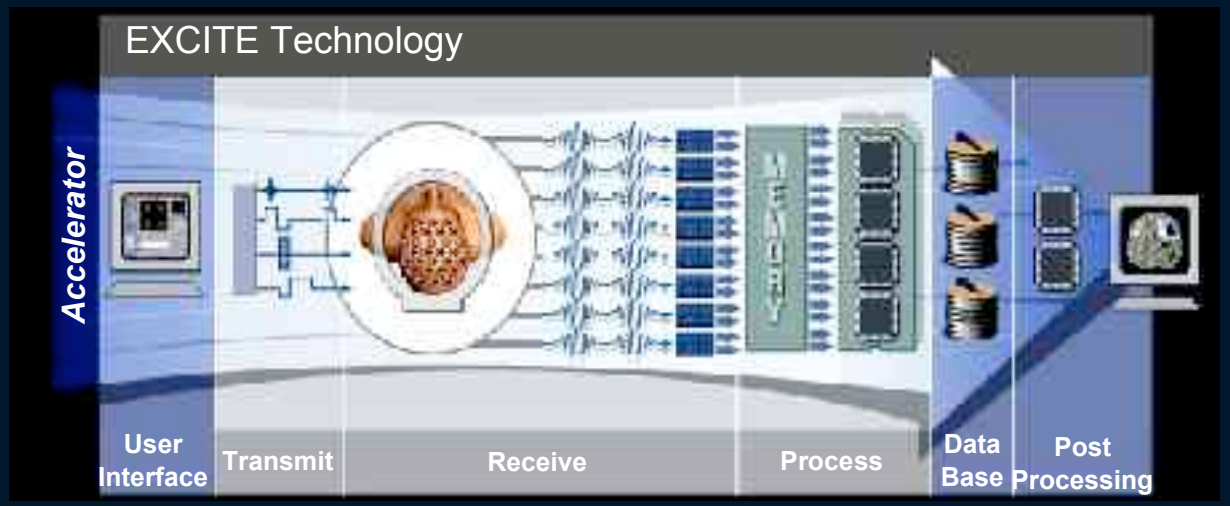
Applications Performance

The Data Pipeline

The Data Pipeline

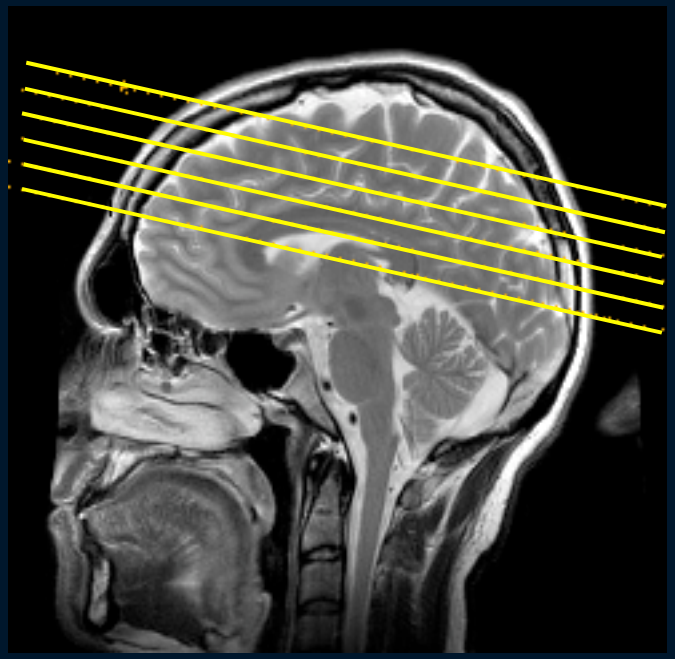
The Data Pipeline is a matter of being able to use technology to it's fullest extent to deliver more image quality and optimized applications

- Balanced – no bottlenecks for full performance and capability
- Broadband performance
- Delivers more image quality to the area of interest
- Delivers advanced applications capability



Need for Data Management

2001



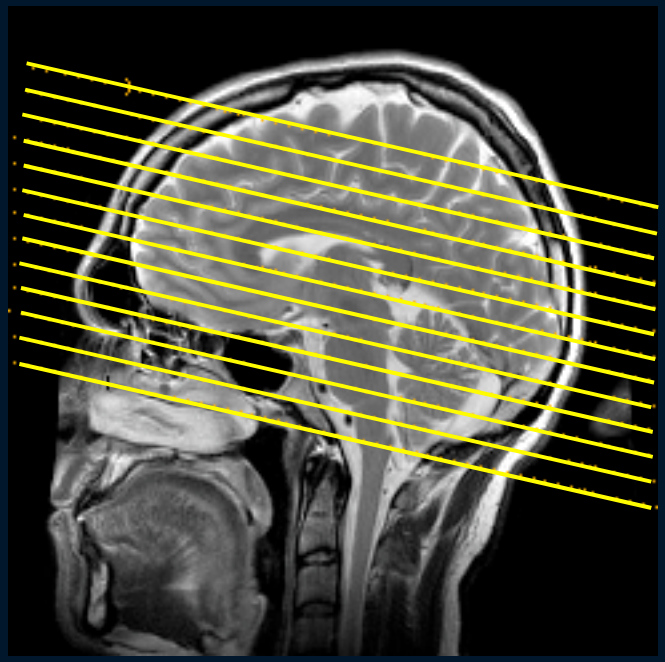
Single-element head coil
6 slices

0.4 MB/sec

128x128 EPI
24 cm FOV
TR 1000 ms

16X Increase

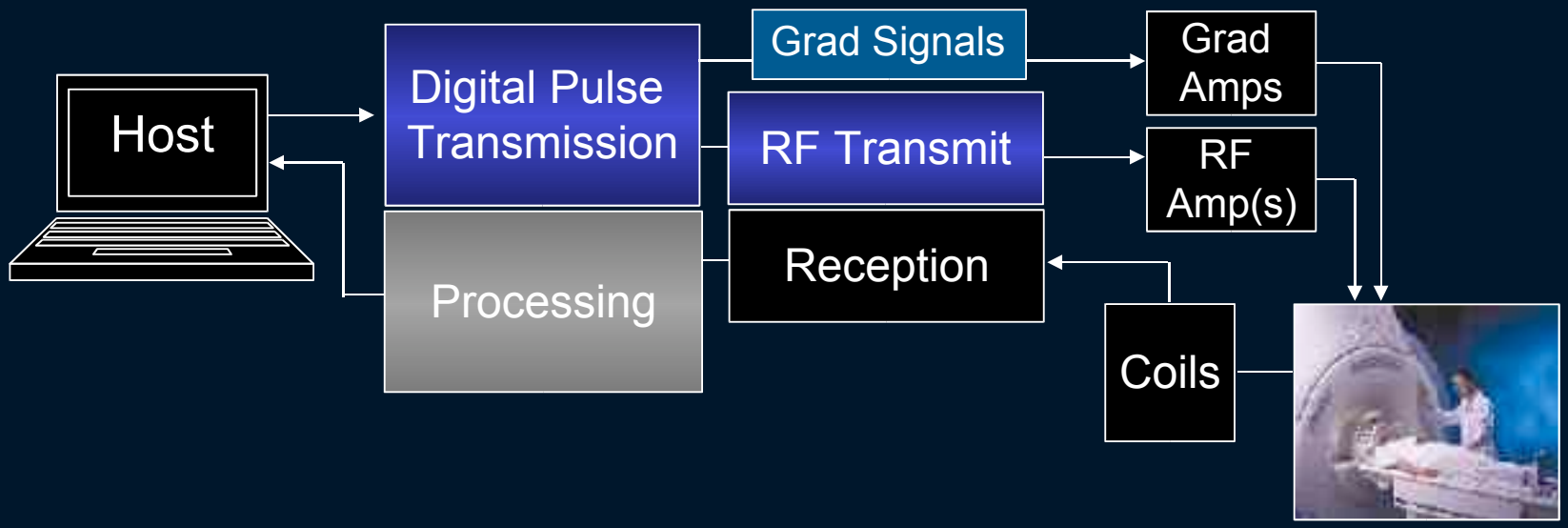
2004



8-channel brain coil
13 slices

6.8 MB/sec

EXCITE - Expandable Channel Integrated Technology



Transmission	Reception	Processing
Pulse Sequence Control	Open Coil Interface	High Speed Recon Engine
RF Control Electronics	Massively Parallel Channel Capability	Scalable to Support Massively Parallel Applications
Fast Play-out Pulse Sequence Memory	High Bandwidth & Dynamic Range	

RF Coil Portfolio

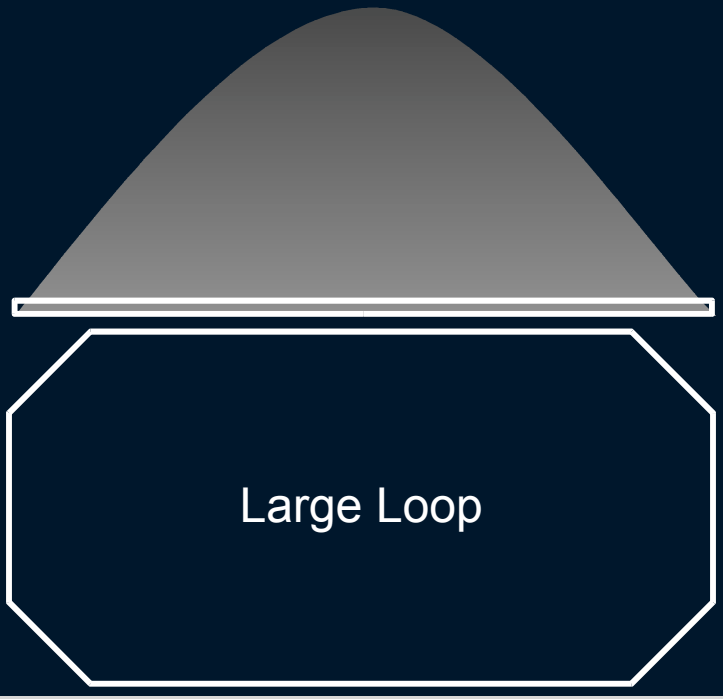
1. What is the difference between fMRI scanner and MR scanner? can we use fMRI for other applications ?
2. What is a RF coil ?
3.. Why need difference coil ?

1 or 3 inch coil

How does coil geometry affect image quality?

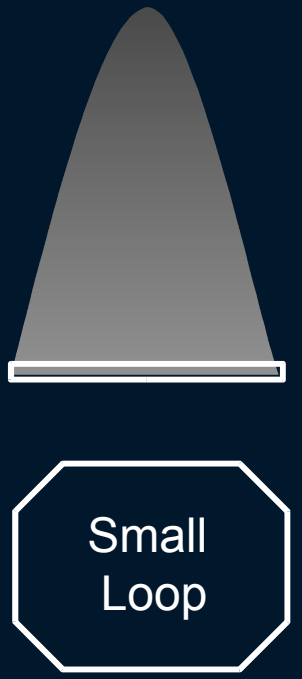
Larger Diameter-Loop
More Penetration
Less SNR

Smaller Diameter-Loop
More SNR
Less Penetration



Side View

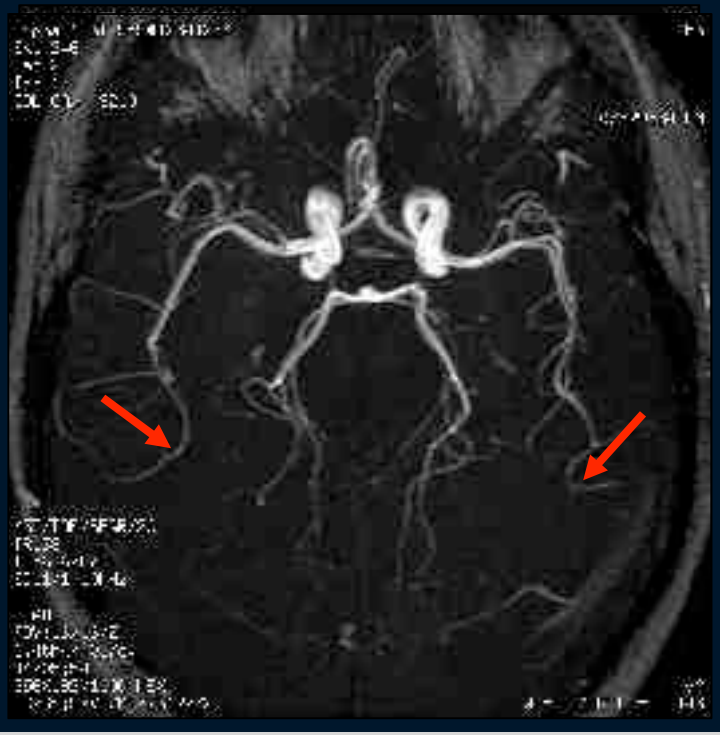
Top View

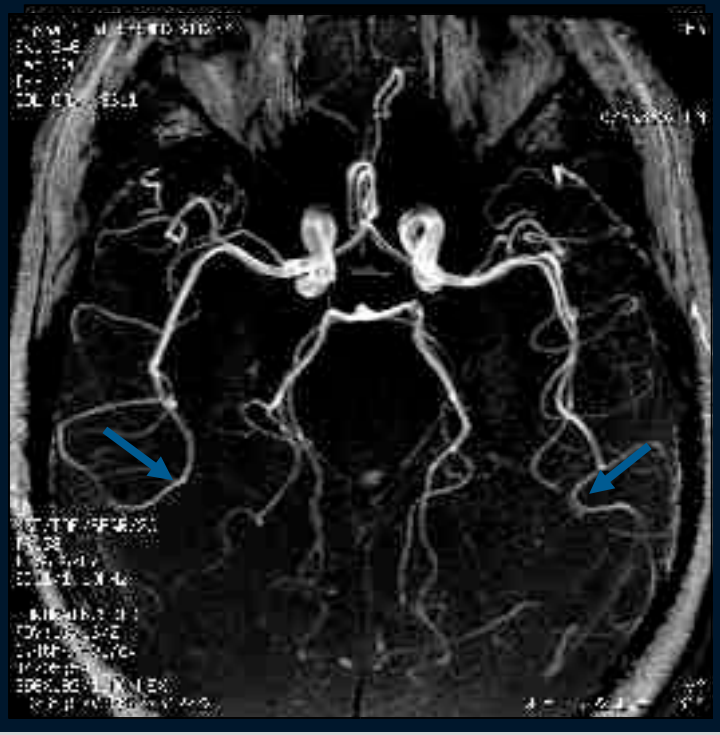


The RF Coil Portfolio

The RF portfolio determines what applications you do and how well you do them

1ch T/R Head Coil vs 8ch Brain Coil





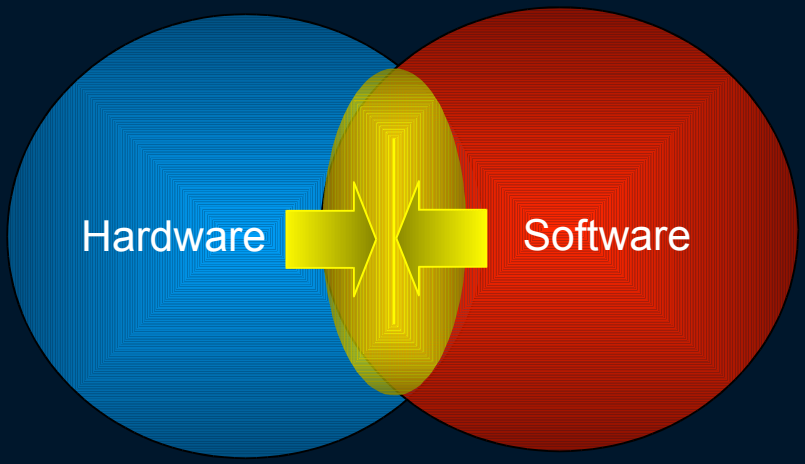
EXCITE 8ch… for 40% higher SNR

High Definition Spine Array

Transmit and Receive Knee and Foot Coil

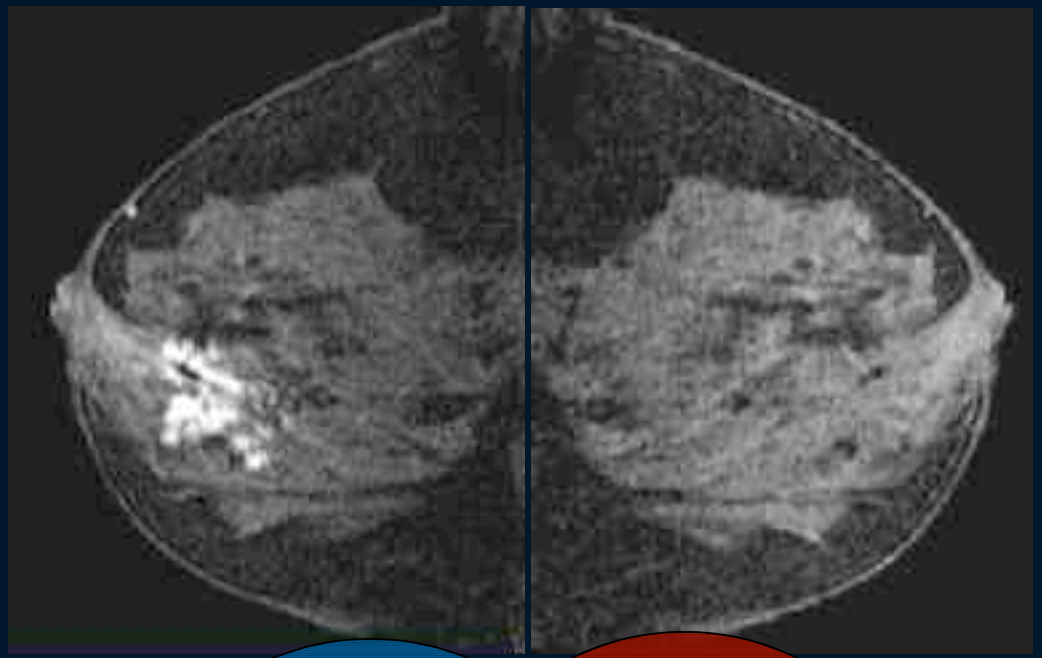
Applications Portfolio

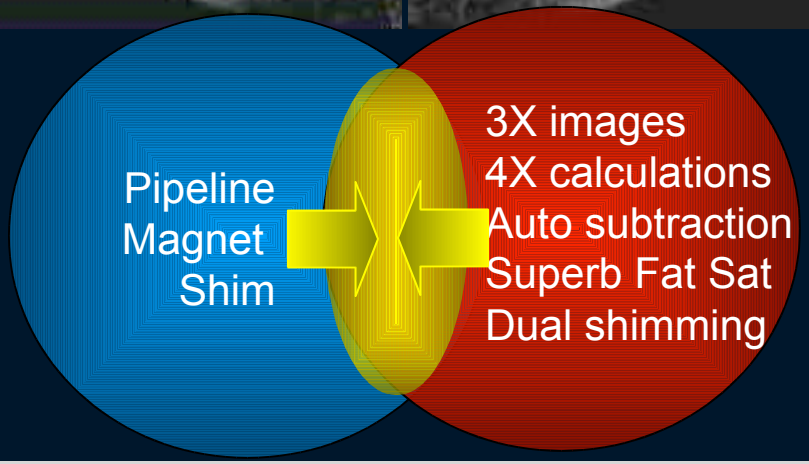
Good RF Coil Portfolio alone does not guarantee good applications. Complete application requires good software package together with good RF portfolio.



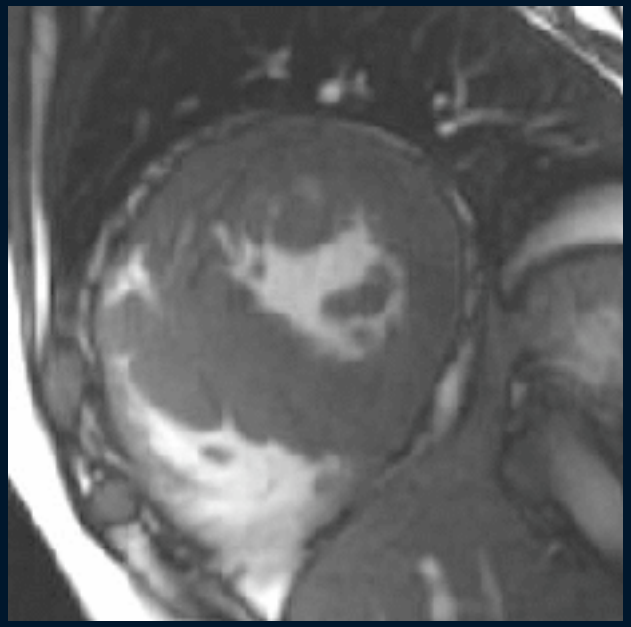
Signature Value – VIBRANT – Optimized Breast Imaging

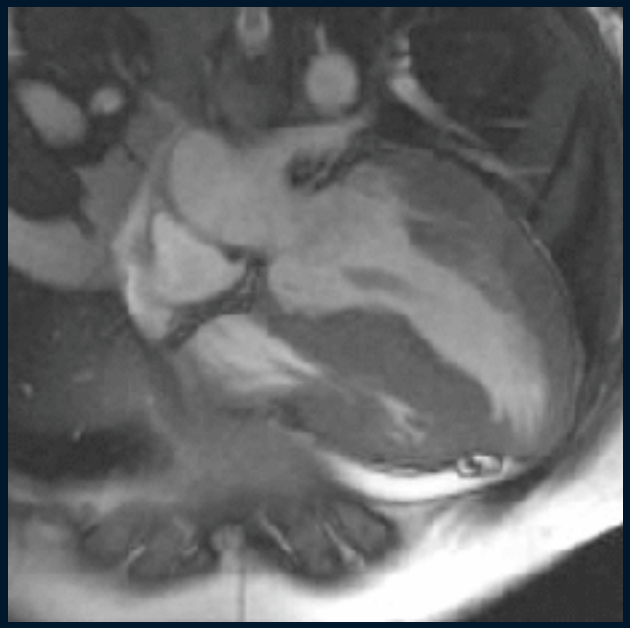
- High Spatial Resolution—Imaged not Interpolated
- High Temporal Resolution—Matched not Toggled
- Optimized Fat Suppression
- Dual Shimming
- Inline Subtraction
- No Workflow Penalty





Cardiac Cine – ECG, multiphase



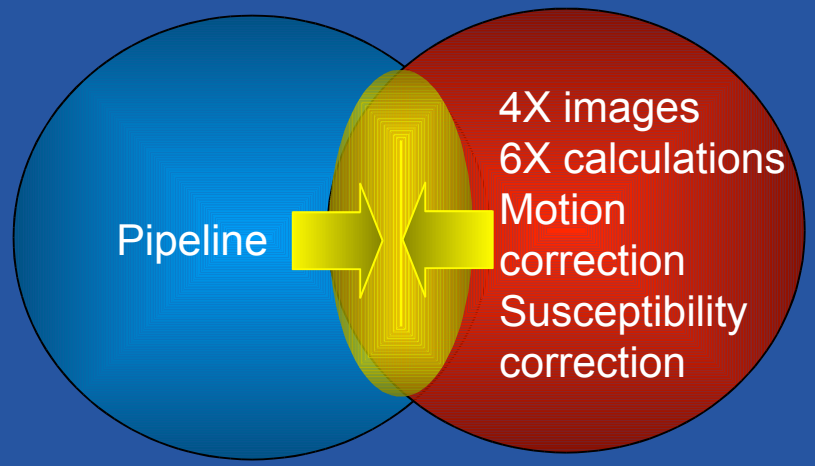


Myocardial hypertrophy case from Hong Kong Sanatorium

Applications …

1-in-6 pediatric *patients do not respond adequately to sedation;* ***1-in-14*** *fail to respond at all.*

PROPELLER
- Insensitive to Patient Motion



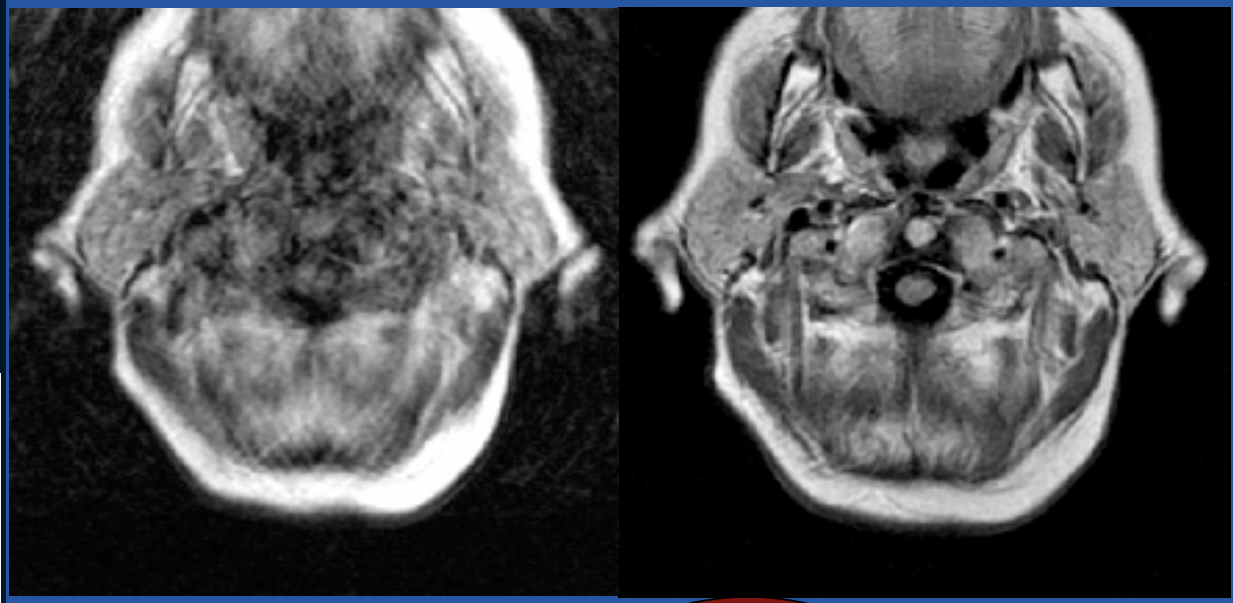
HD Applications .

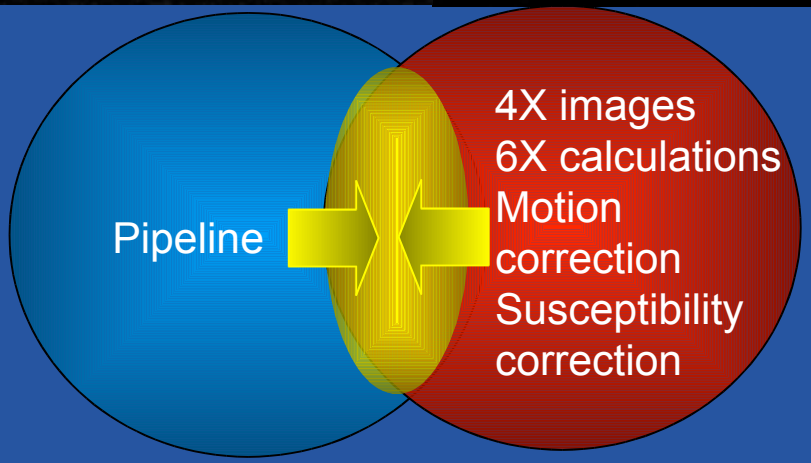
Additional Challenges:

- Uncooperative patients

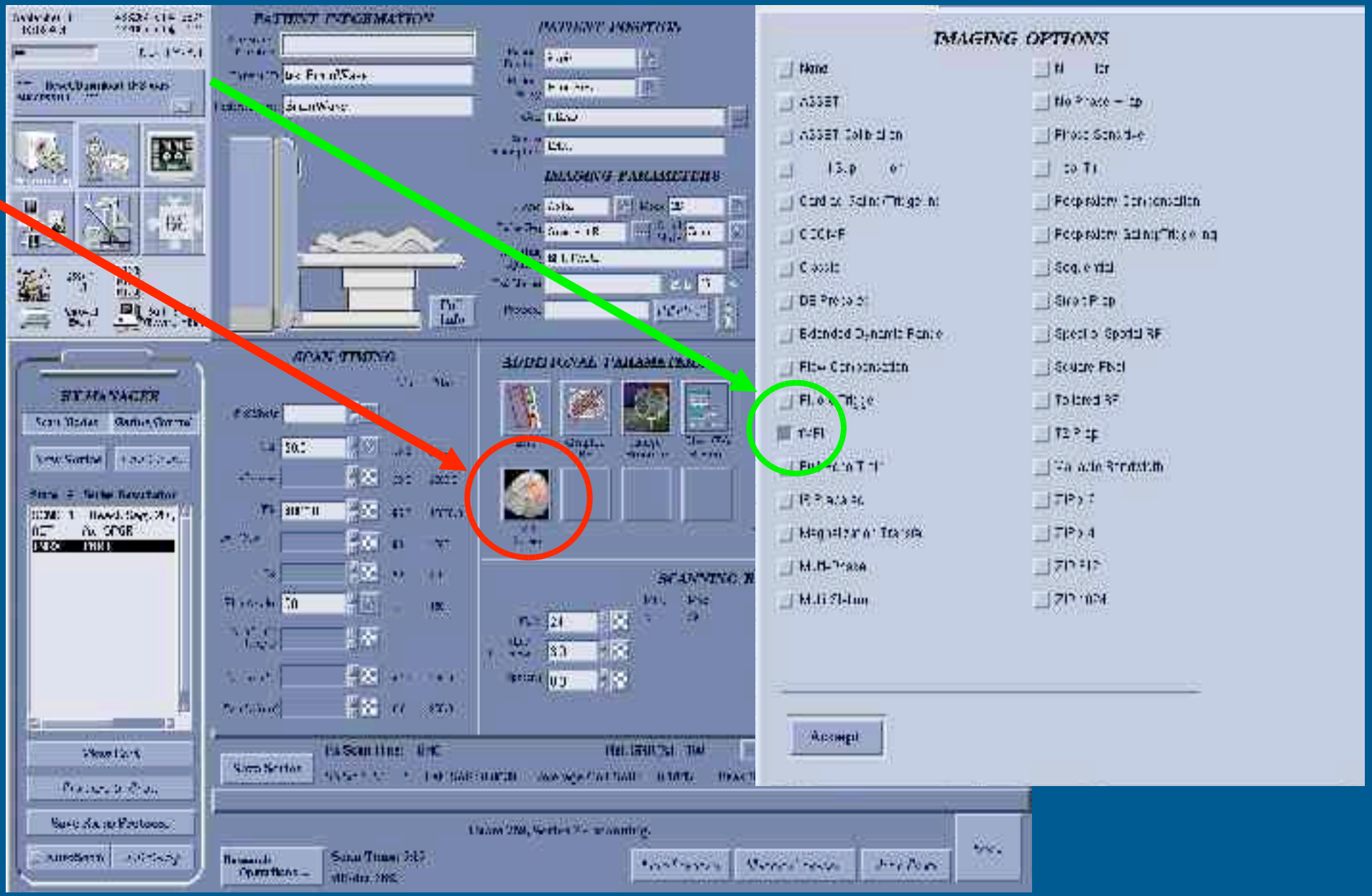
PROPELLER

Motion artifact → High resolution

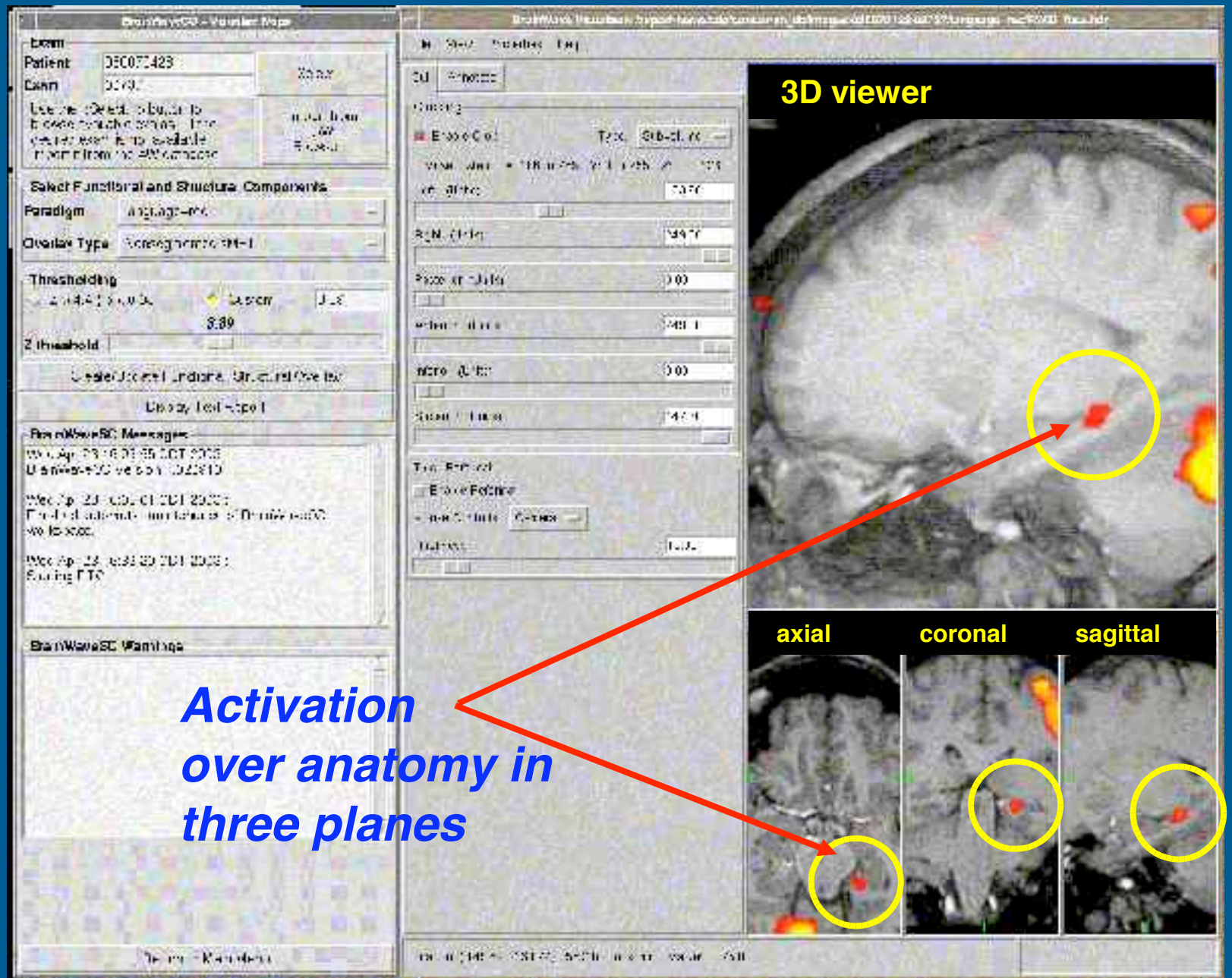




Brainwave RT



Brainwave PA



Summary

- MRI Recipe
- Important Components of MR System

Thank-you !