Neuroimaging and mathematical modelling

Lesson 4: Basics of MRI

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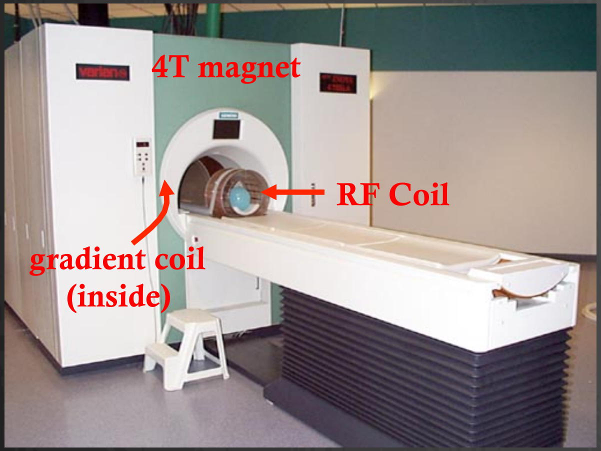
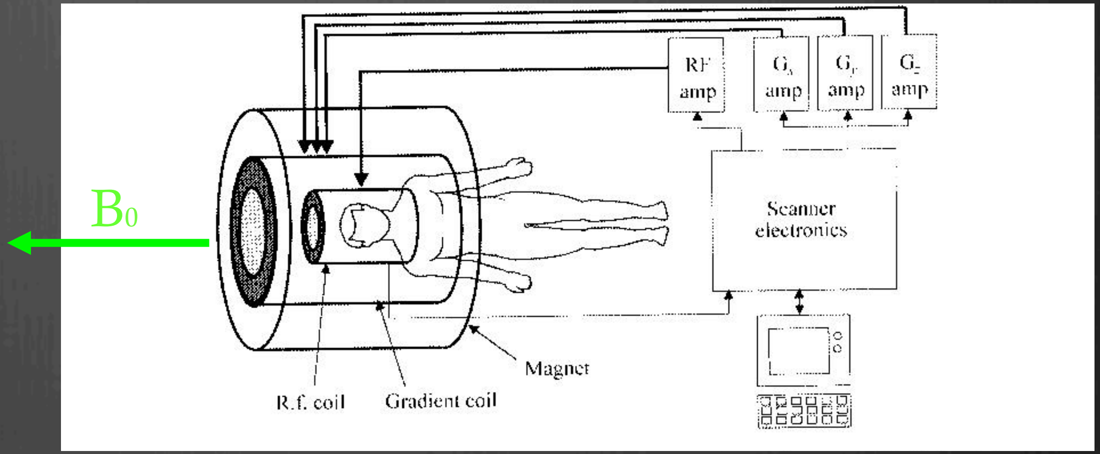
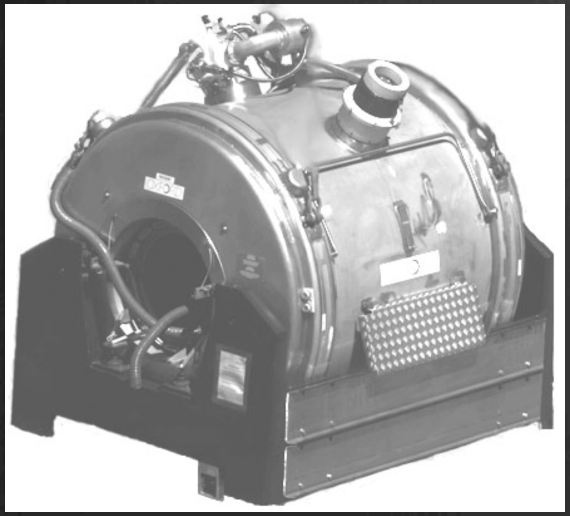
Equipment



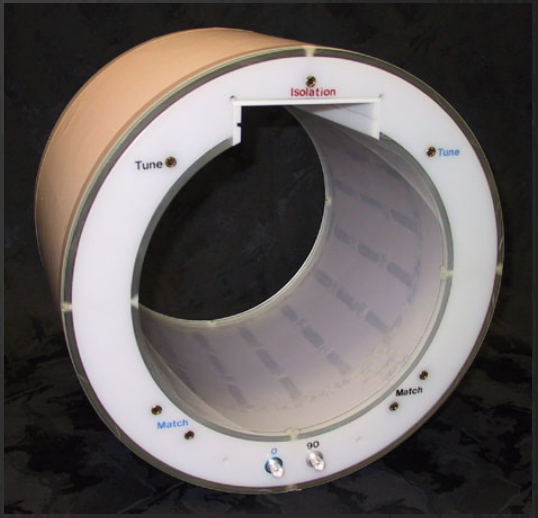


Magnet

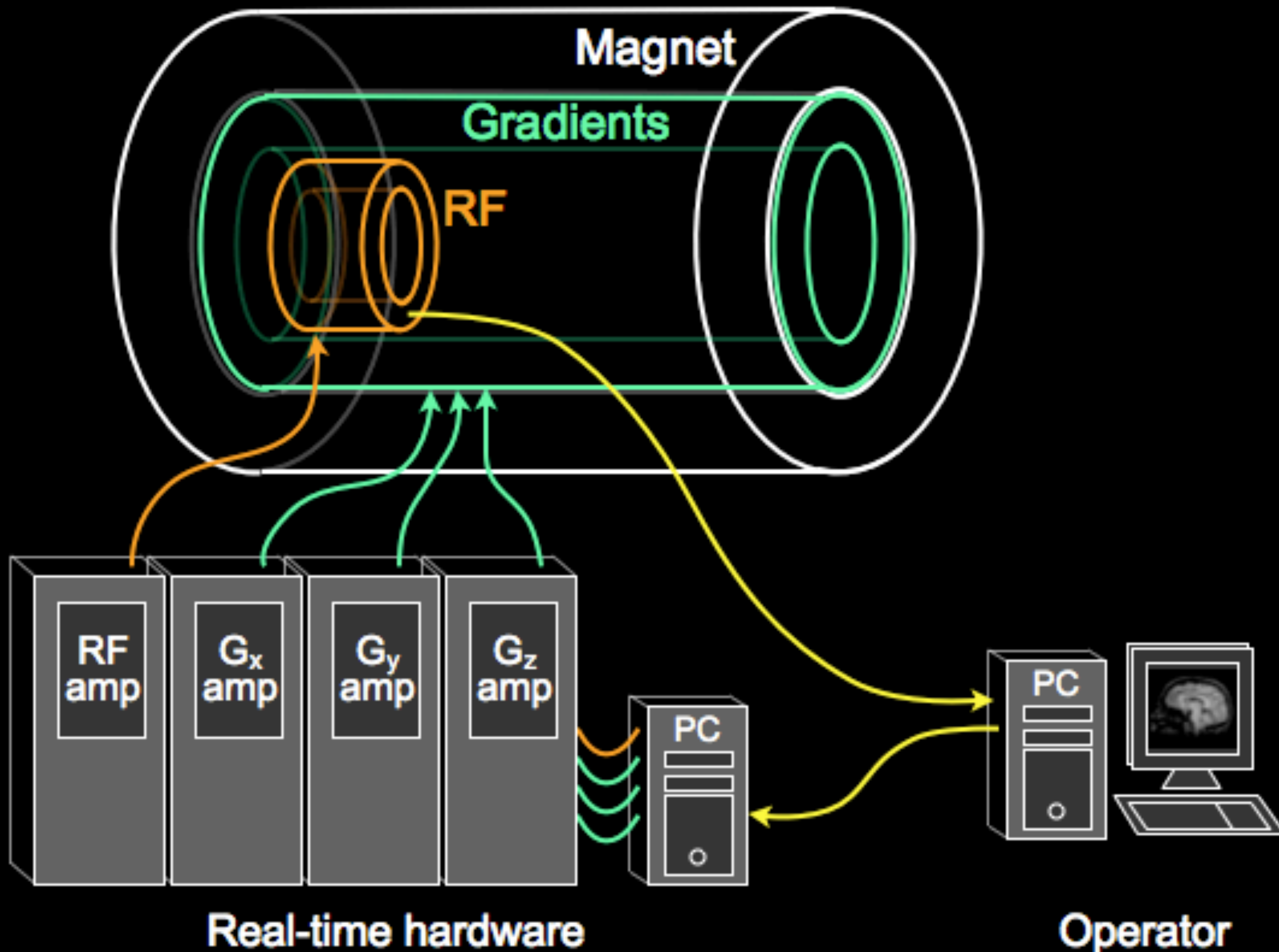


Gradient Coil

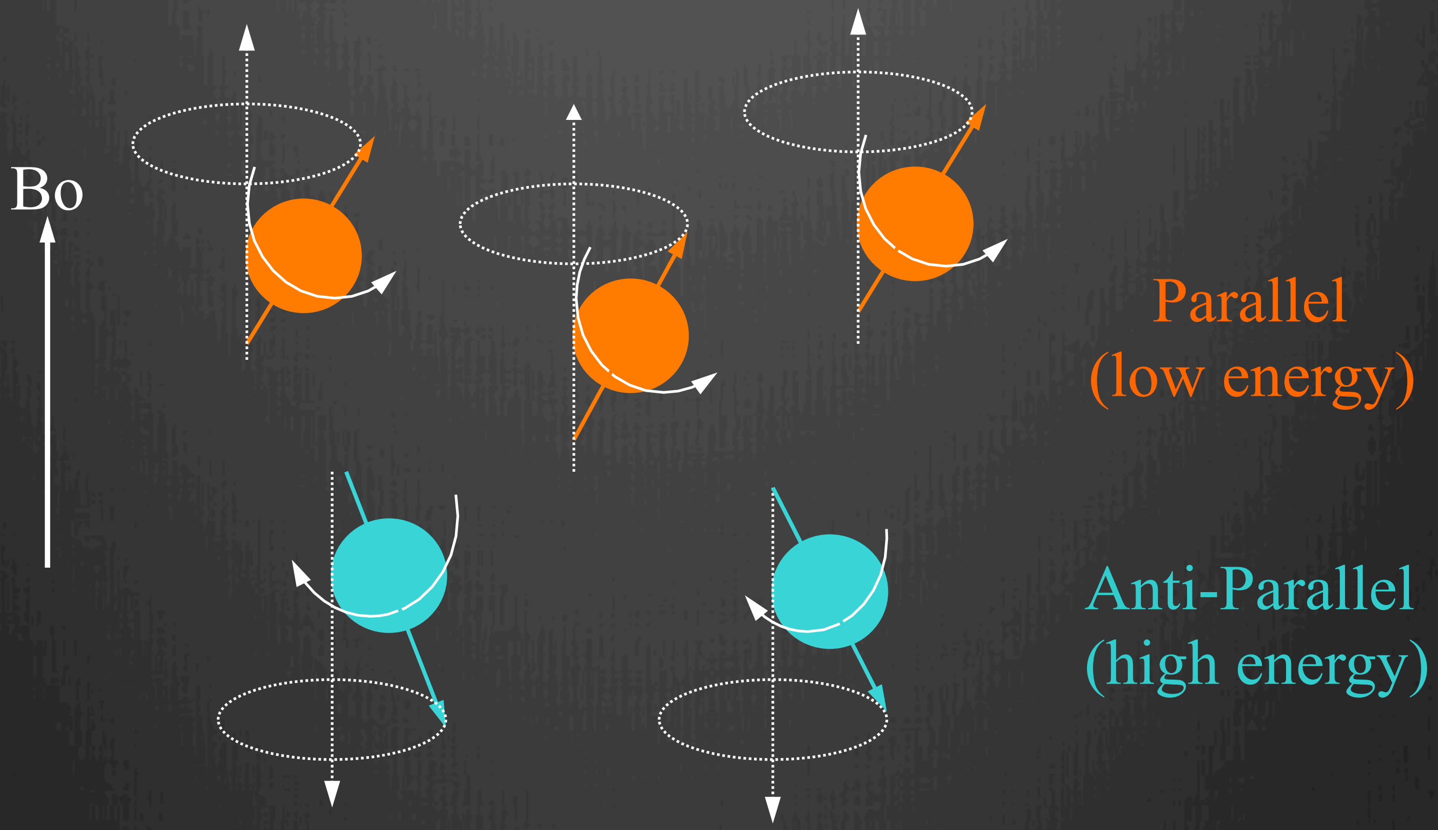
RF Coil



And lots of other bits...



Protons in a Magnetic Field

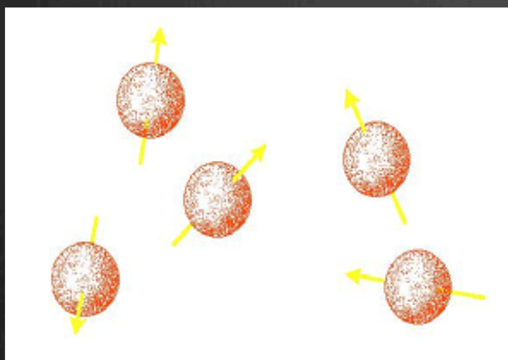


Spinning protons in a magnetic field will assume two states.
If the temperature is 0^{o} K, all spins will occupy the lower energy state.

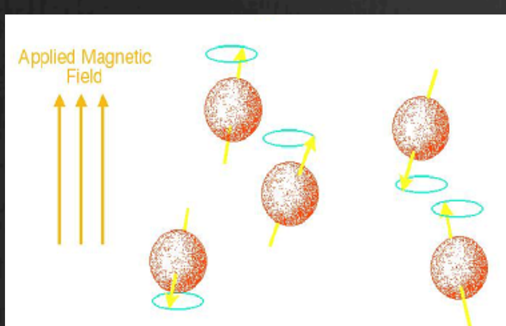
Protons align with field

Outside magnetic field

randomly oriented



Inside magnetic field

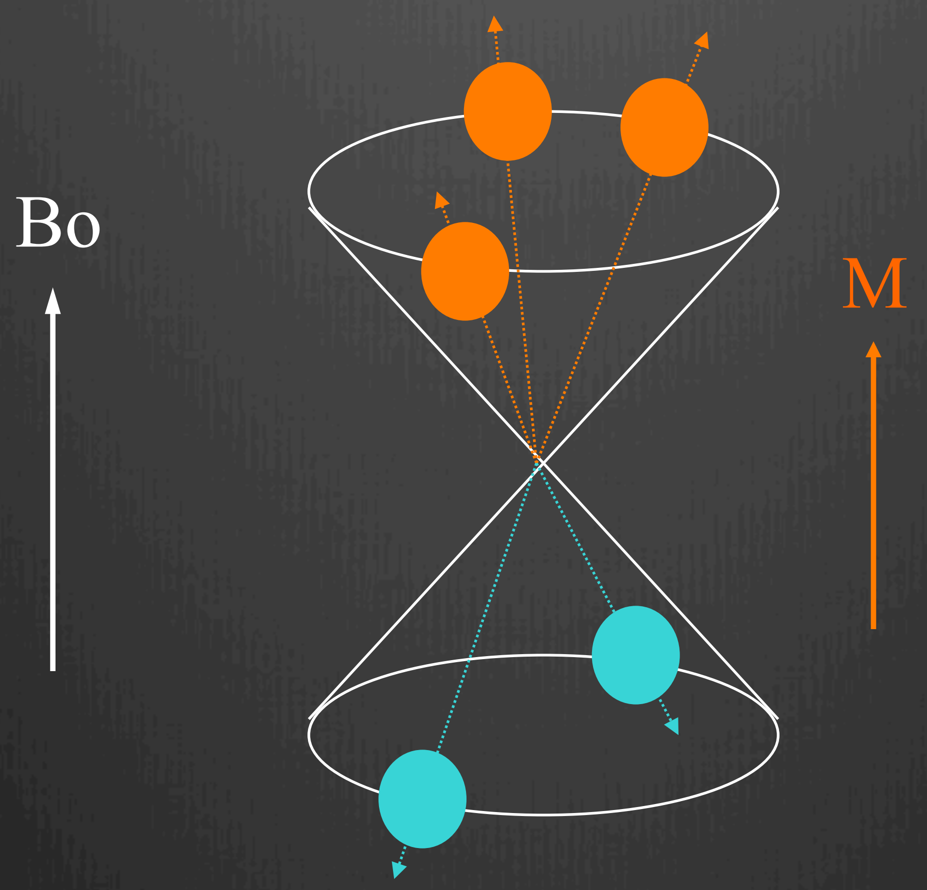


- spins tend to align parallel or anti-parallel to B_0
- net magnetization (M) along B_0
- spins precess with random phase
- no net magnetization in transverse plane
- only 0.0003% of protons/T align with field

Longitudinal magnetization

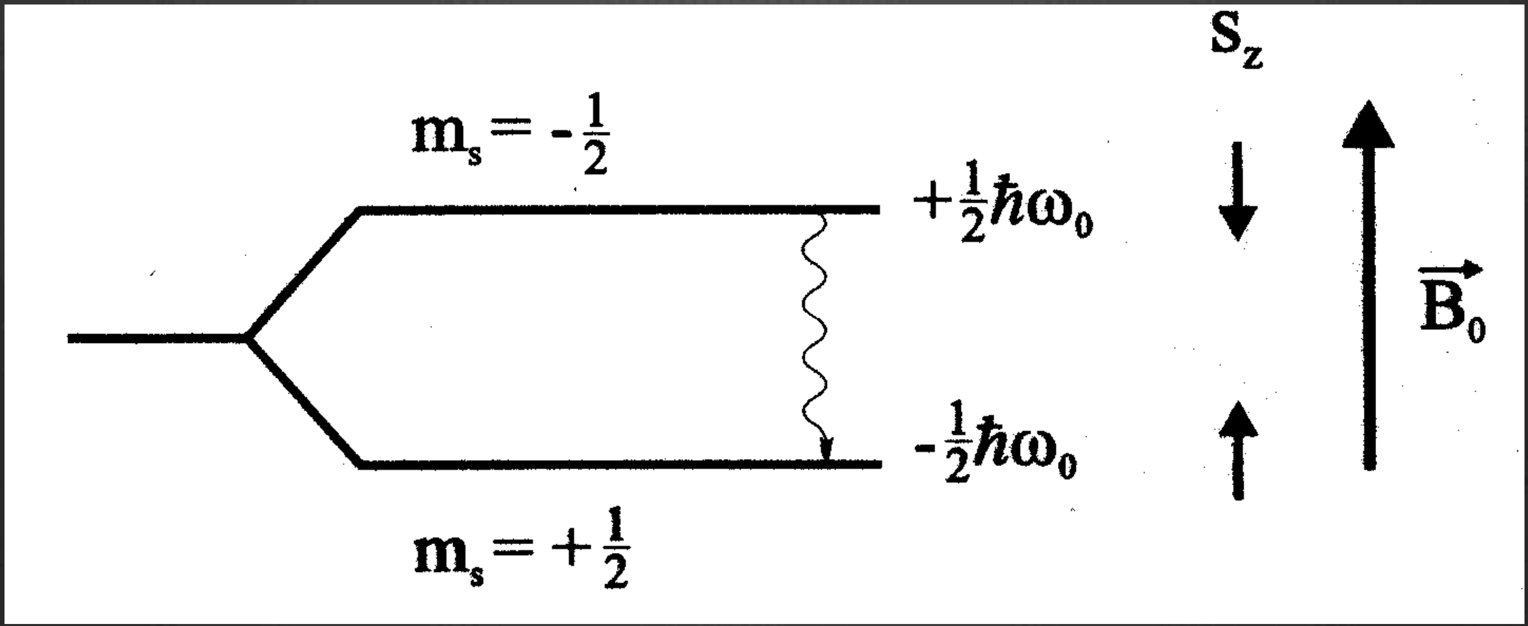
Transverse magnetization

Net Magnetization



$$M = c\frac{B_o}{T}$$

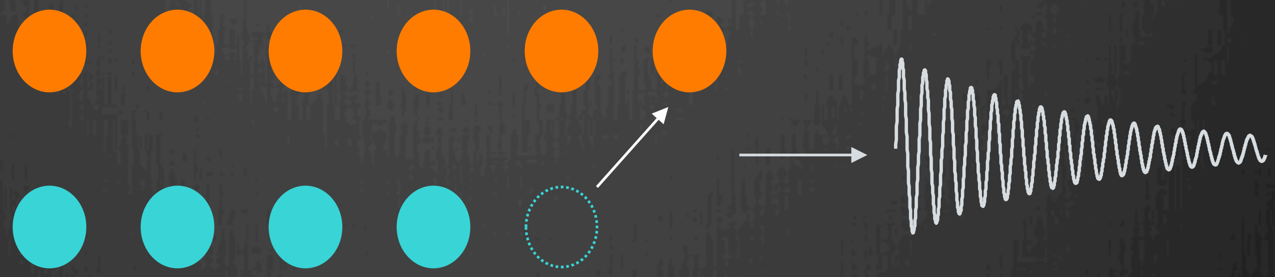
Energy Difference Between States



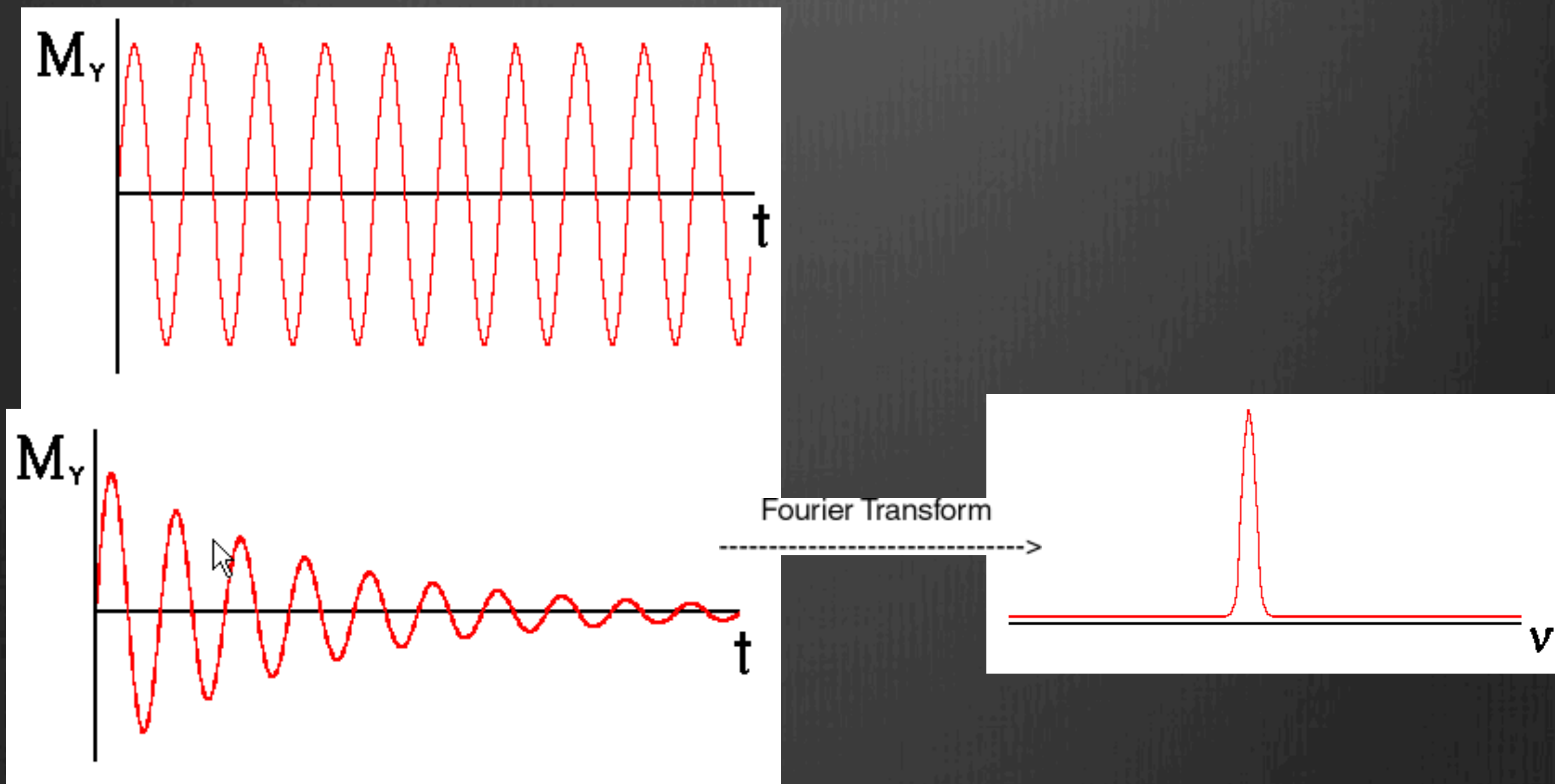
Spin System Before Irradiation

The Effect of Irradiation to the Spin System

Spin System After Irradiation

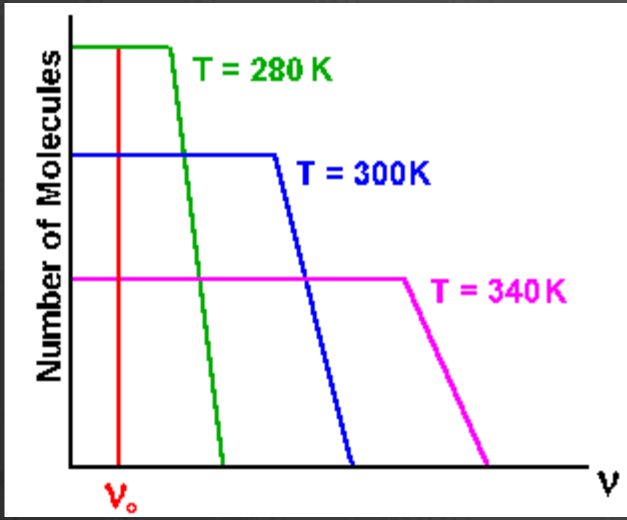


Signal Detection

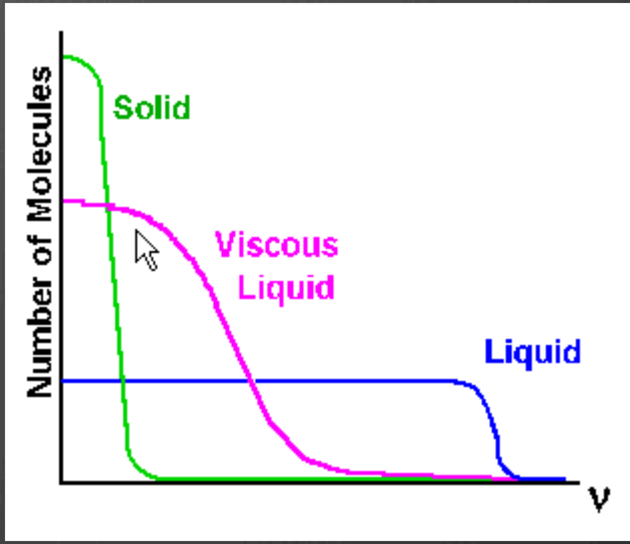


Signal is damped due to relaxation

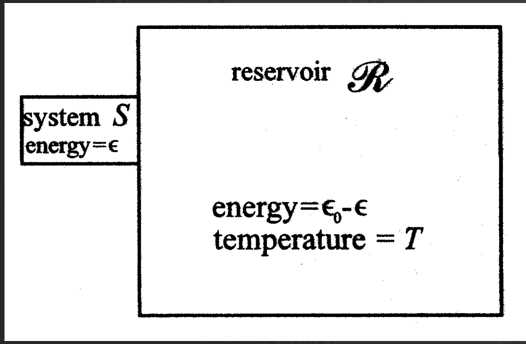
Spin-Lattice (T_1) relaxation via molecular motion



Effect of temperature

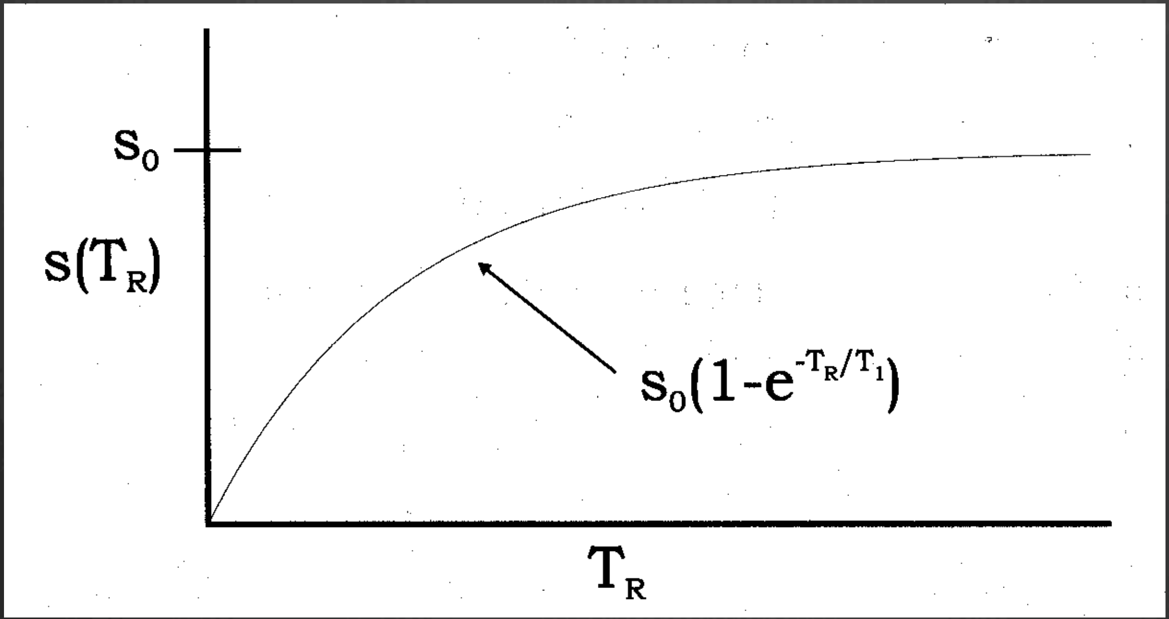


Effect of viscosity

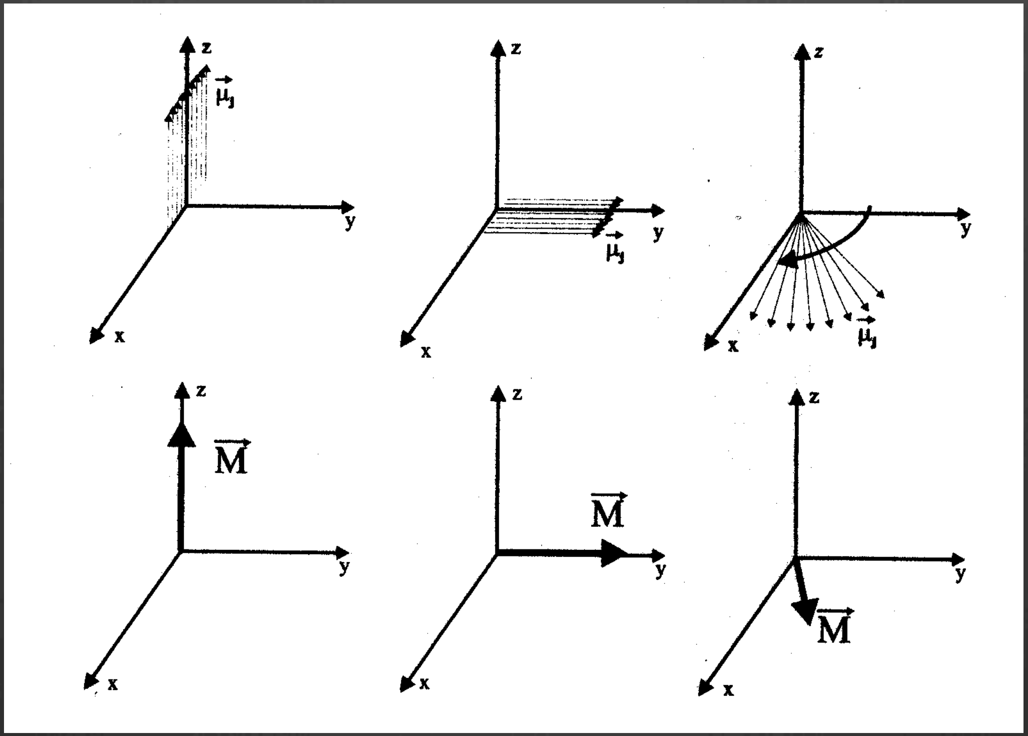


T_1 Relaxation efficiency as function of freq is inversely related to the density of states

Spin-Lattice (T1) relaxation



Spin-Spin (T_2) Relaxation via Dephasing



Relaxation

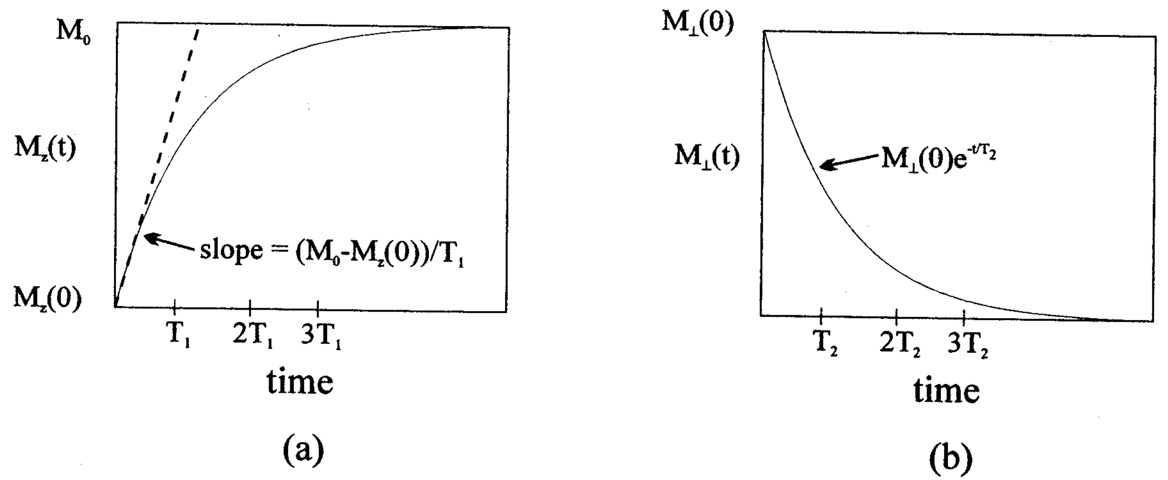


Fig. 4.1: (a) The regrowth of the longitudinal component of magnetization from the initial value $M_z(0)$ to the equilibrium value M_0. (b) The decay of the magnitude of the transverse magnetization from an initial value.

Tissue	T_1 (ms)	T_2 (ms)
gray matter (GM)	950	100
white matter (WM)	600	80
muscle	900	50
cerebrospinal fluid (CSF)	4500	2200
fat	250	60
blood	1200	100-200[3]

Relaxation

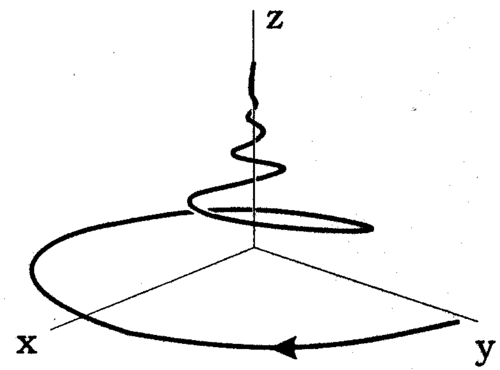
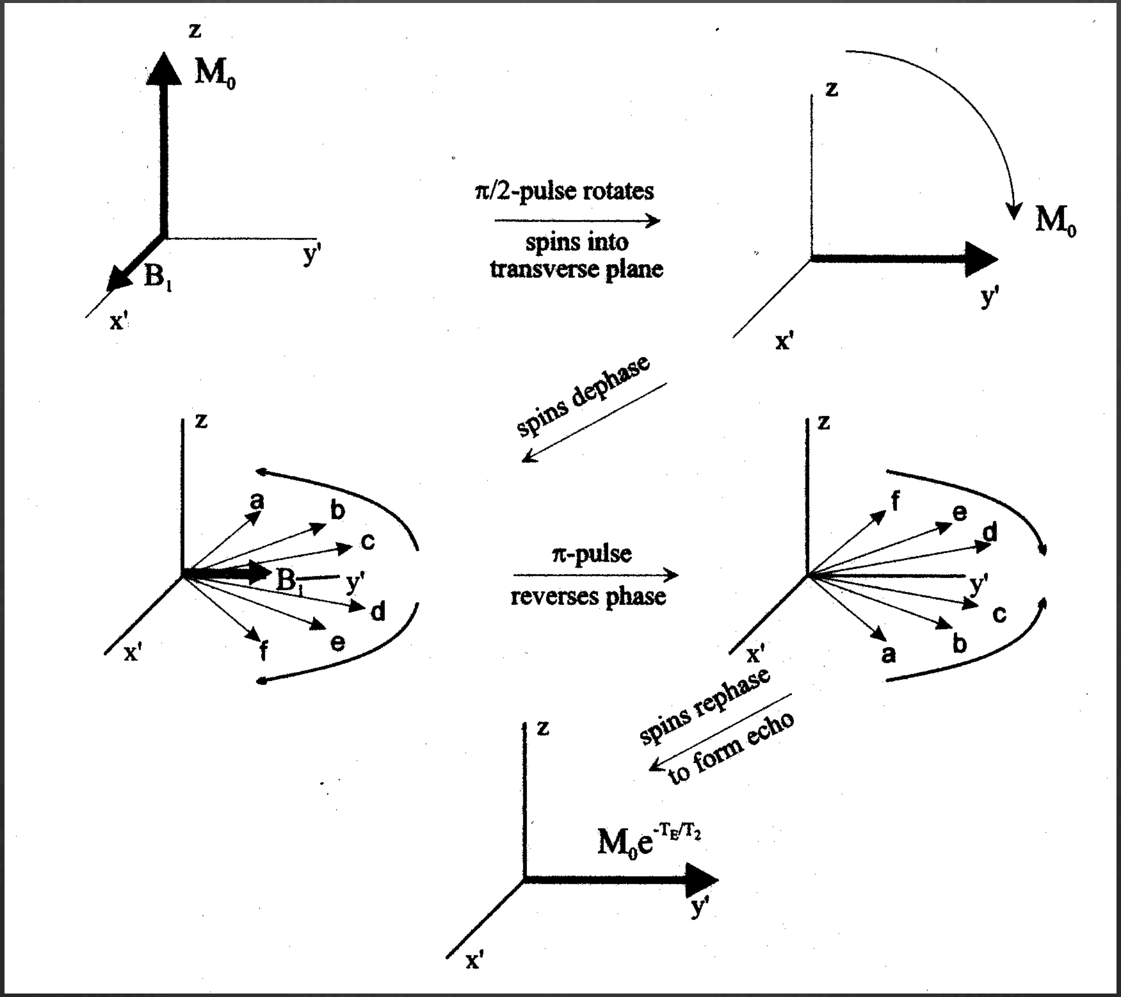
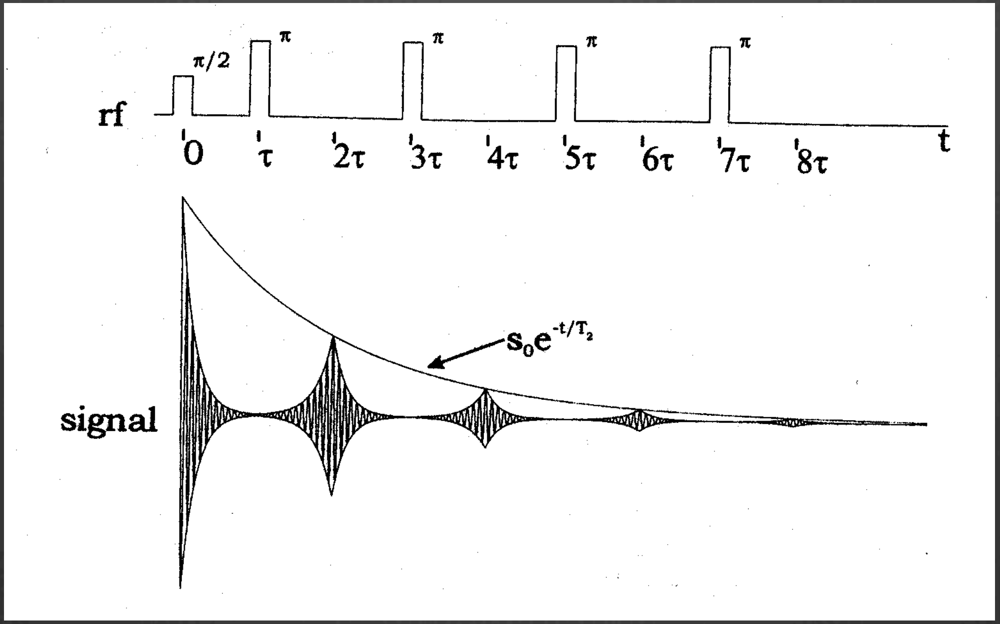


Fig. 4.3: The trajectory of the tip of the magnetization vector showing the combined regrowth of the longitudinal magnetization and decay of the transverse components. The initial value was along the y axis and the reference frame is the laboratory.

Spin-Echo Pulse Sequence

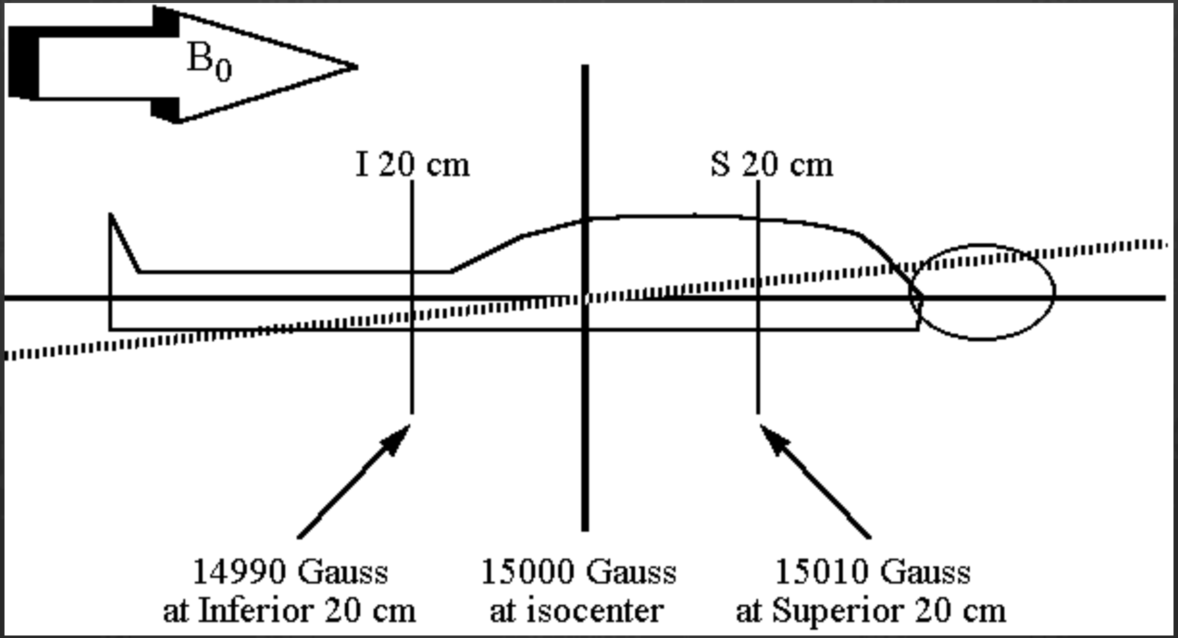


Multiple Spin-Echo



Spatial Localization

Here's a picture of the total magnetic field as a function of position:



Spatial Localization

- Recall the Larmor equation:

$$\omega = \gamma B_o$$

For hydrogen:

γ = 42.58 MHz/Tesla = 42.58 x 10^6 Hz/Tesla

Calculating the center frequency at 1.5 Tesla:

$\omega = \gamma B_o$

ω = (42.58 MHz / Tesla)(1.5 Tesla)

ω = 63.87 MHz

Spatial Localization

What are the frequencies at Inferior 20cm and Superior 20cm?

At I 20cm, $B_{tot} = 1.499$ T:

$\omega_I = \gamma B_{tot}$

$\omega_I = (42.58 \text{ MHz / Tesla})(1.499 \text{ Tesla})$

$\omega_I = 63.827$ MHz

At S 20cm, $B_{tot} = 1.501$ T:

$\omega_S = \gamma B_{tot}$

$\omega_S = (42.58 \text{ MHz / Tesla})(1.501 \text{ Tesla})$

$\omega_S = 63.913$ MHz

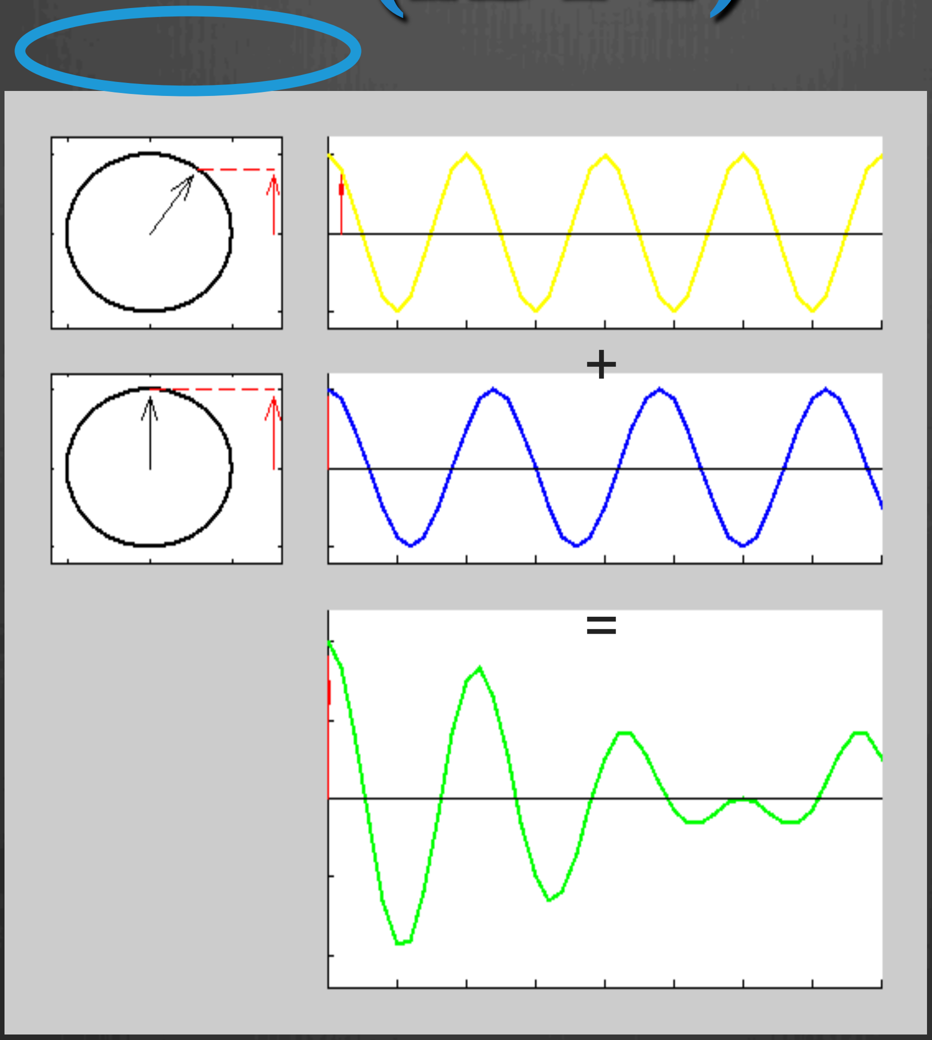
Difference in frequencies: .086 MHz

Two-Dimensional Fourier Transform MRI (2DFT)

Receiver Coil

Spin #1

Spin #2



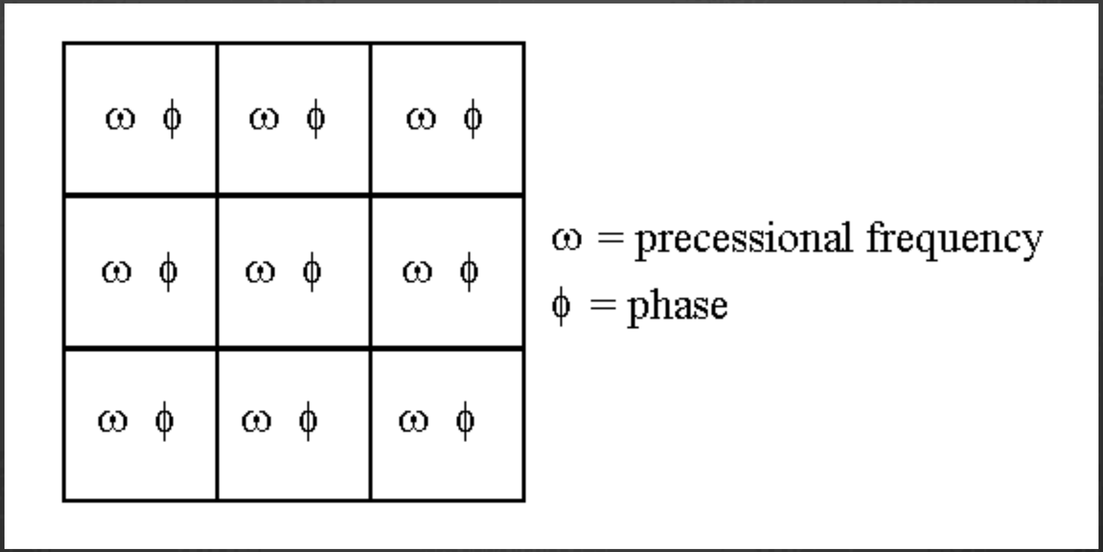
Example #2: two spin case, with different frequencies

Summed signal can be complicated…but, this is useful.

Phase and Frequency Encoding

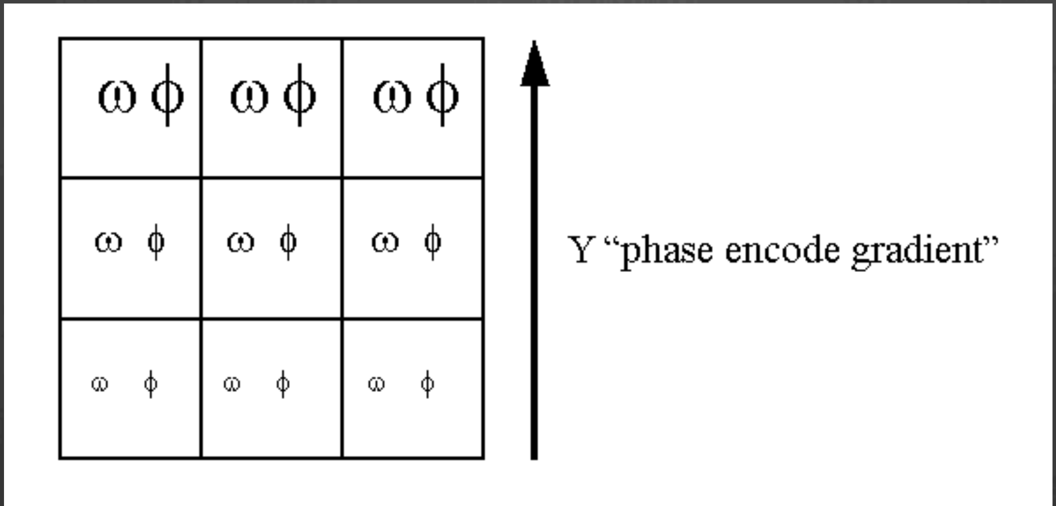
Consider an MRI image composed of 9 voxels

(3 x 3 matrix)



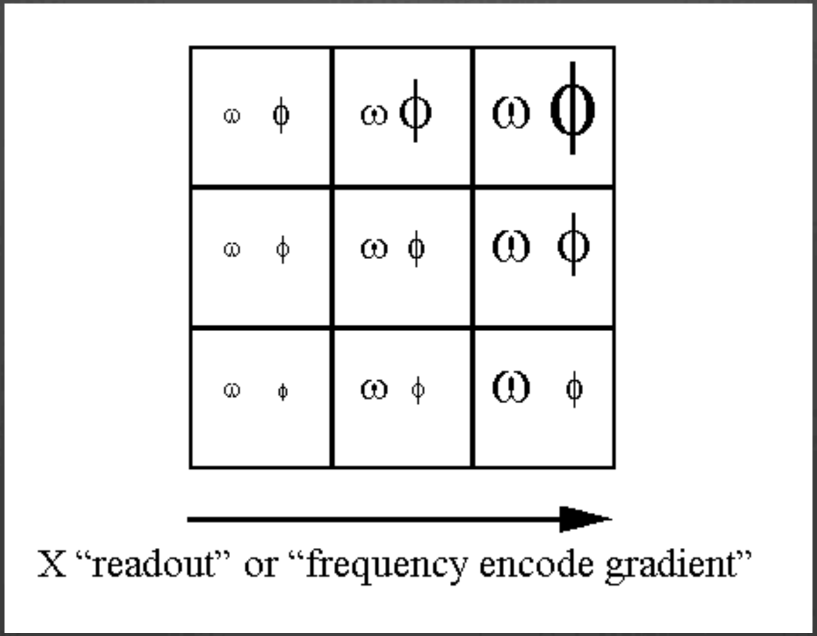
All voxels have the same precessional frequency and are all "in phase" after the slice select gradient and RF pulse.

Phase and Frequency Encoding
(continued)

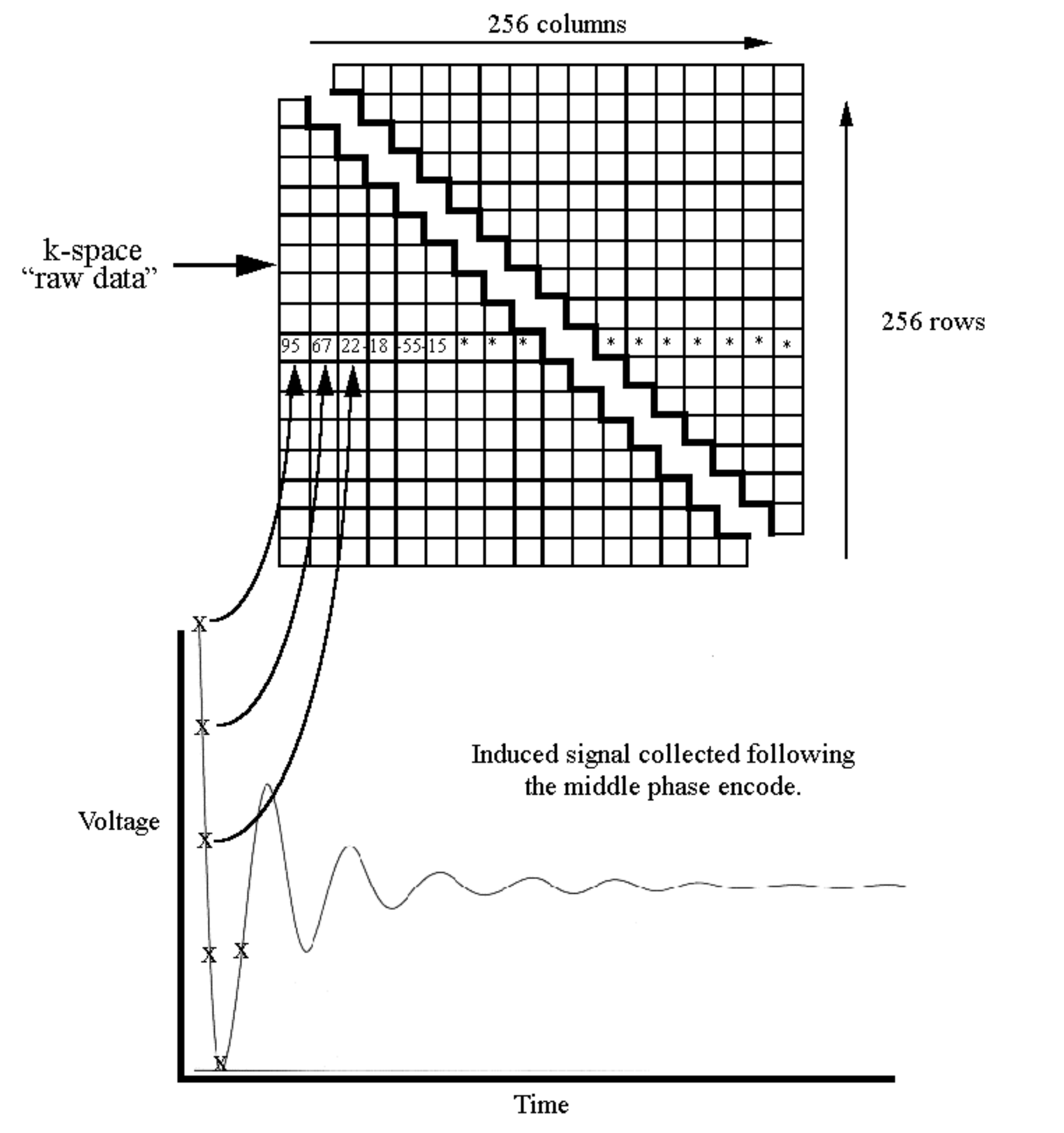


When the Y "phase encode gradient" is on, spins on the top row have relatively higher precessional frequency and advanced phase. Spins on the bottom row have reduced precessional frequency and retarded phase.

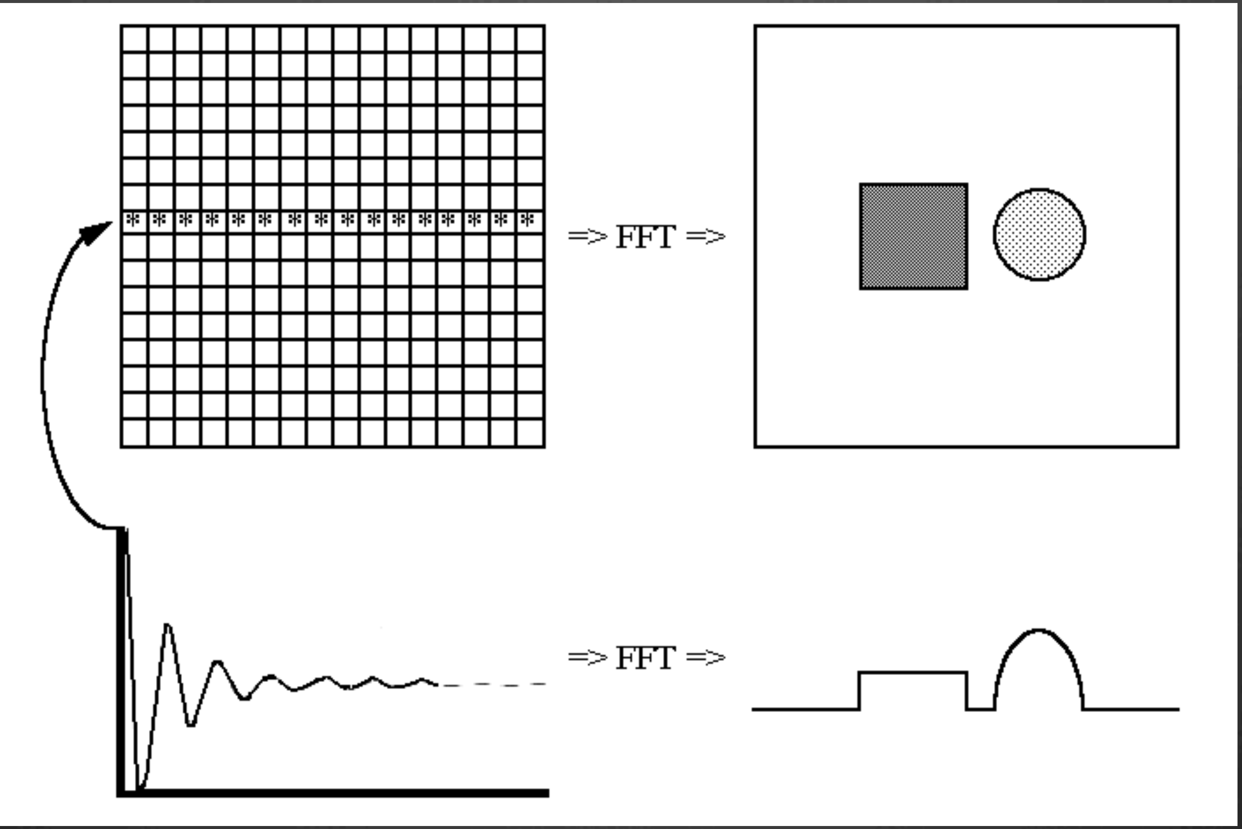
Phase and Frequency Encoding
(continued)



While the frequency encoding gradient is on, each voxel contributes a unique combination of phase and frequency. The signal induced in the RF coil is measured while the frequency encoding gradient is on.

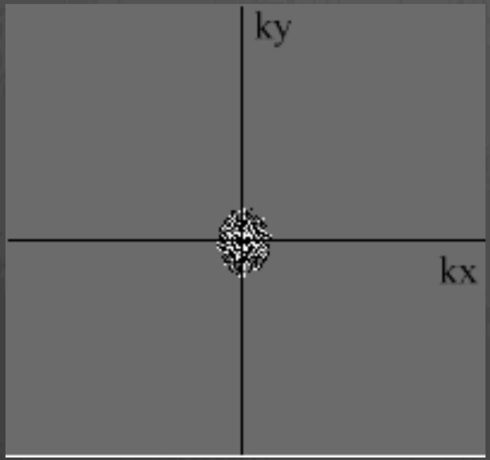

256 columns
256 rows
k-space
"raw data"
95 67 22 -18 -55 -15 * * * * * * * * * *
Voltage
Time
Induced signal collected following
the middle phase encode.

k - space
(continued)

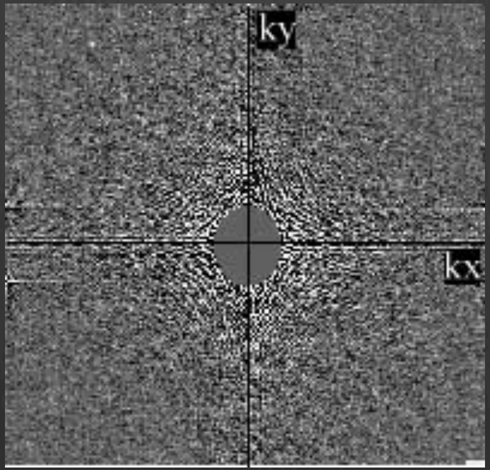


The central row of k-space is measured with the phase encode gradient turned off. An FFT of the data in the central row produces a projection or profile of the object.

Linee centrali del K spazio- basse frequenze: risoluzione di contrasto.

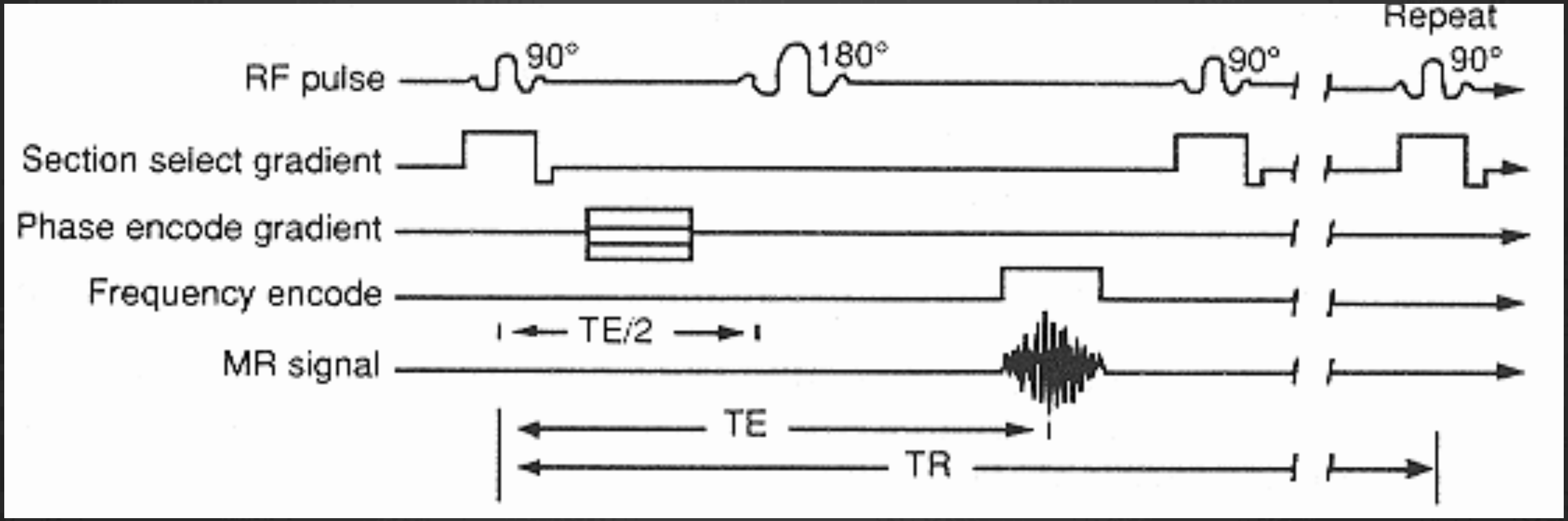


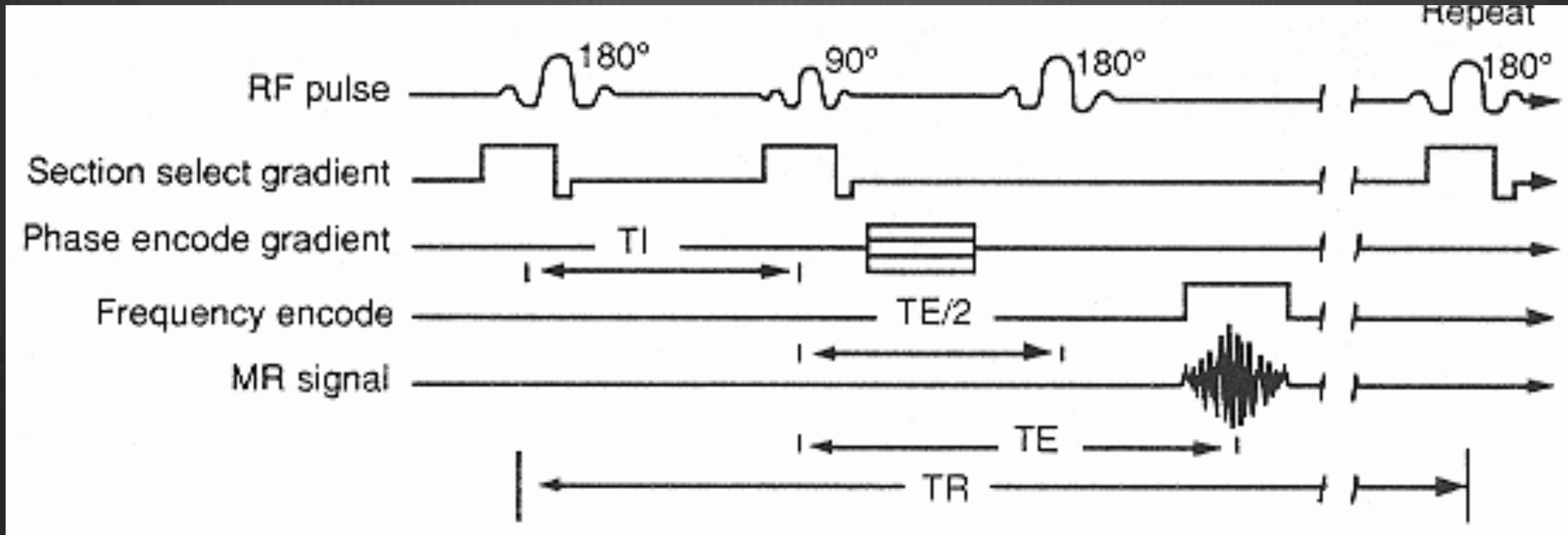
Linee periferiche del K spazio-alte frequenze: risoluzione spaziale



SEQUENZA: insieme di impulsi di RF di eccitazione, dei gradienti di campo e della lettura degli echi.

SPIN ECHO: impulso a 90° seguito dopo un tempo T da uno a 180°. Viene ripetuta tante volte quante sono i passi della codifica di fase.





L'ampiezza del segnale dipende dalla MT che a sua volta dipende dalla ML

Scegliendo un TI pari al null point di un determinato tessuto annullo il segnale di quel tessuto

STIR
FLAIR
STAIR

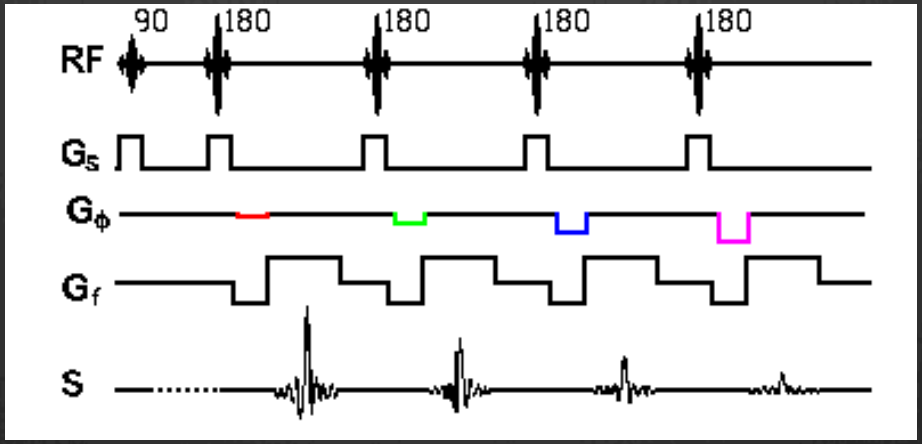
FAST o TURBO SPIN-ECHO FSE-TSE

ETL echo train lenght ; treno di echi a 180° dopo quello a 90°. Sono codificati da un diverso g di codifica di fase: contemporanea trascrizione di più linee dello spazio K.

ES echo spacing; intervallo tra gli echi

ETL

ES

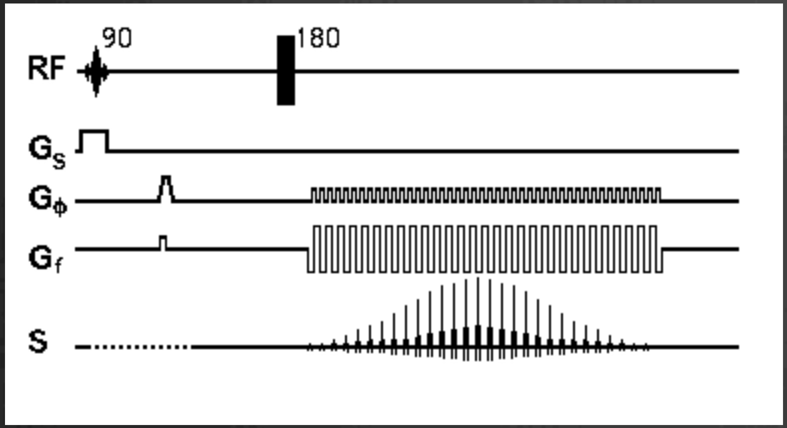


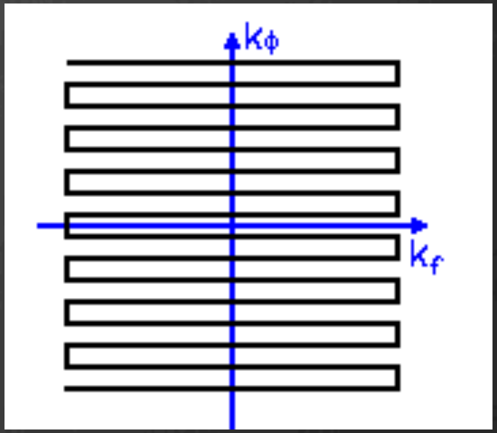
Sequenze ultrarapide: EPI, HASTE

EPI Echo Planar Imaging: tecnica veloce TA 20 msec. Codifica dell'informazione spaziale dopo un impulso RF seguito da multiple e rapide inversioni del gradiente di lettura .

Tecnica single shot (unico impulso) o multi shot.

Combinabili con vari tipi di sequenze convenzionali





Vantaggi: indagini veloci. Indagini funzionali diffusione perfusione.

Svantaggi: elevata suscettibilità magnetica