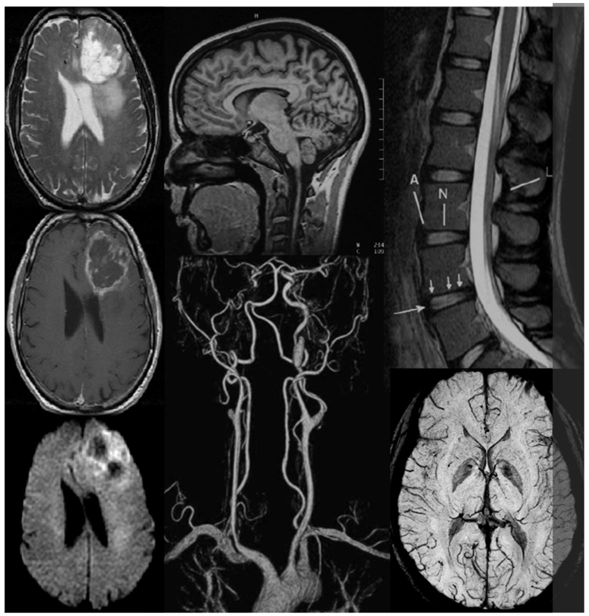

磁振影像學MRI
切面選擇與空間編碼

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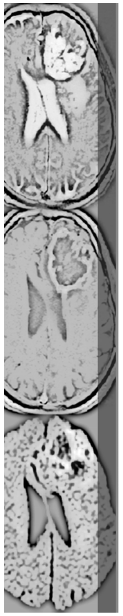
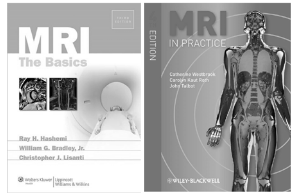
alvin4016@nycu.edu.tw



本週課程內容 http://www.ym.edu.tw/~cflu

- 切面選擇 Slice Selection
- 空間編碼 Spatial Encoding
- 梯度線圈 Gradient Coils
- 訊號取樣 Sampling

- MRI The Basics (3rd edition)
  - Chapter 10: Slice Selection
  - Chapter 11: Spatial Encoding
  - Chapter 12: Signal Processing
- MRI in Practice, (4th edition)
  - Chapter 3: Encoding and image formation
  - Chapter 9: Instrumentation and equipment



切面選擇

Slice Selection

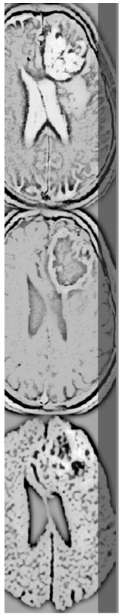
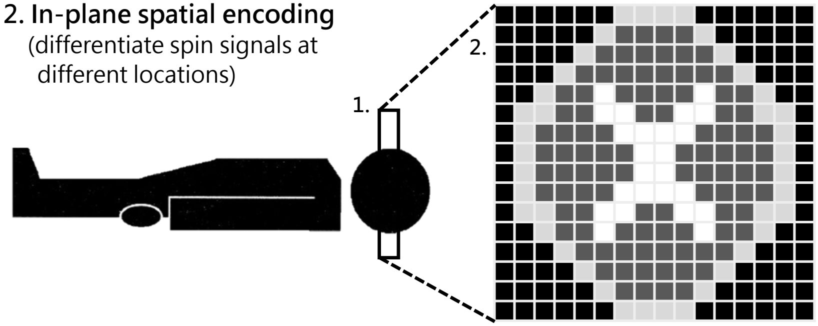


Image Construction

1. **Slice selection**
   (only excite spins on a specific slice location)
2. **In-plane spatial encoding**
   (differentiate spin signals at different locations)

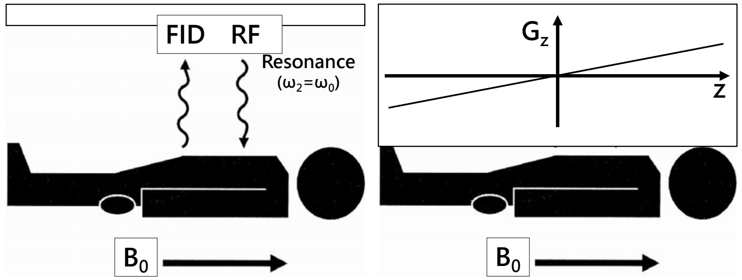


Gradients

- An MR image = slice selection + in-plane spatial encoding
- A gradient is simply a magnetic field that changes from point to point – usually in a *linear* fashion.
  - The slice-select gradient
  - The readout or frequency-encoding gradient
  - The phase-encoding gradient

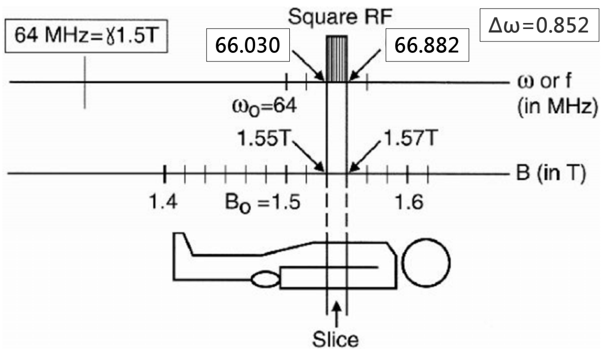
How to Select a Slice

- Create a variation in the field along the z-axis in linearly increasing or decreasing by G_z.



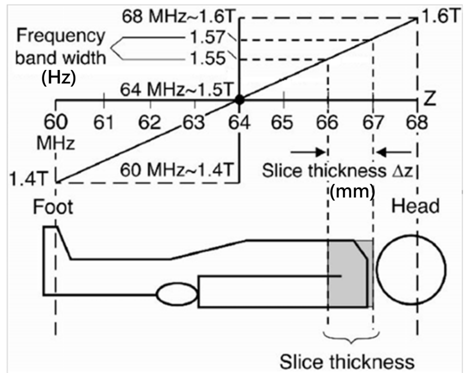
Field Strength and Larmor Frequency

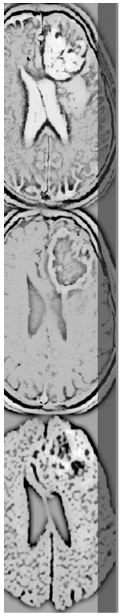
- Larmor frequency: $\omega(z)=\gamma(B_0+G_z \cdot z)$



Bandwidth of RF Pulse

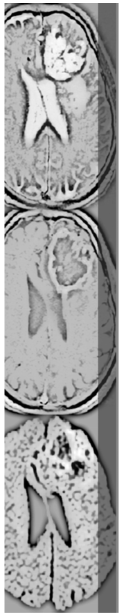
- We can excite one slice by an RF pulse with a specific frequency range.
- This range of frequencies determines the slice thickness and is referred to as the bandwidth.





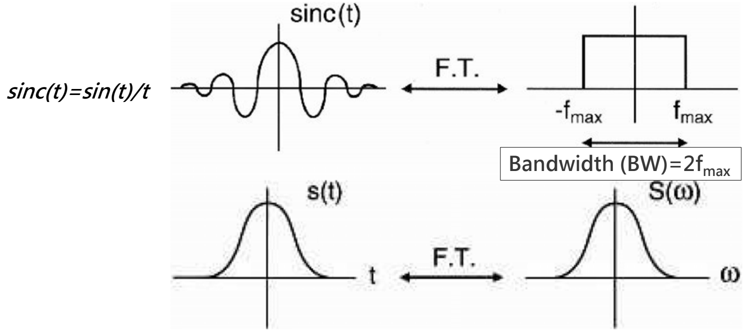
Slice-Select Gradient

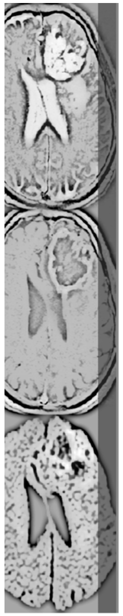
- We transmit an RF pulse with a bandwidth that has the appropriate **center frequency**.
- This gradient is turned on only when we transmit the RF pulses.
- When we transmit the 180º pulse (*rephasing pulse*) for the same slice, we activate the same gradient.



Fourier Transform (FT)

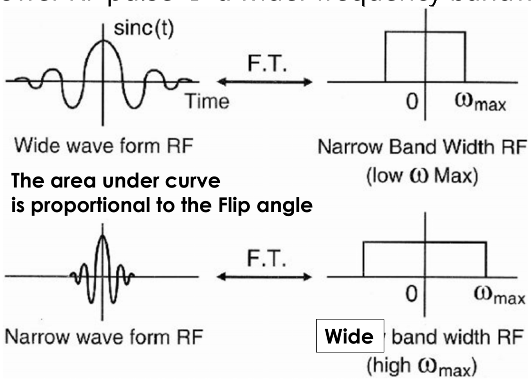
Time domain ⬄ Frequency domain

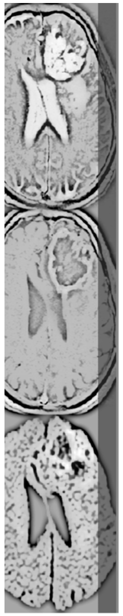




Waveform and Bandwidth

- A narrower RF pulse ➔ a wider frequency bandwidth

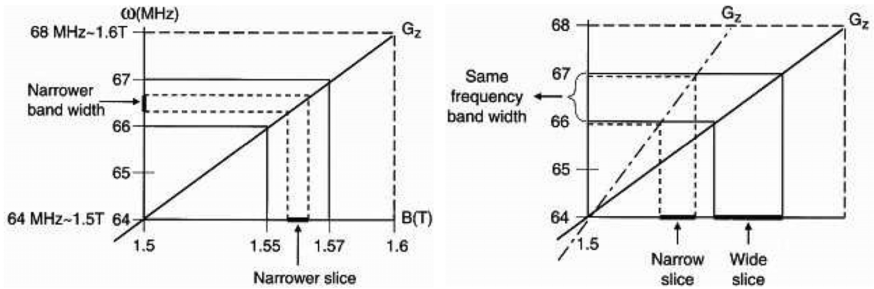




Slice Thickness

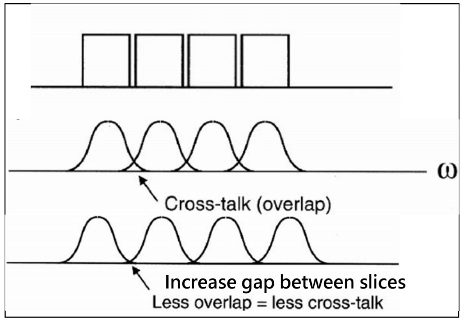
Slice thickness ↓ → Excited spins ↓ → SNR ↓

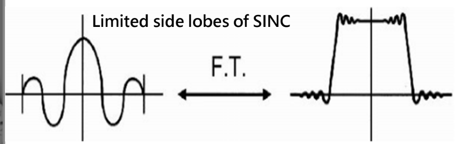
- Two ways to reduce the slice thickness
  - Use a narrow bandwidth
  - Increase the slope of the magnetic field gradient (G_z)



Contiguous Slices Cross Talk

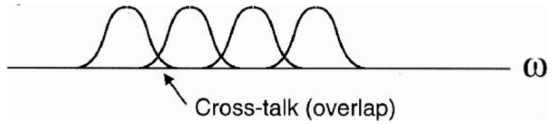
- Ideally, the contiguous slices are right next to each other and the Fourier transform has a rectangular shape.
- In reality, the frequency spectrum of the RF pulse does not have a rectangular shape.





Cross-Talk effects

- Decrease effective TR per slice
  - Due to saturation of protons by the RF signals for adjacent slices
- Cross-talk effects
  - Increase T1 weighting
  - Decrease SNR

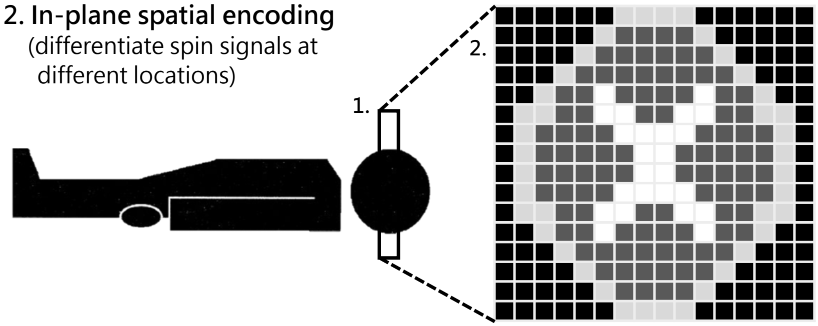


空間編碼

Spatial Encoding

Image Construction

1. **Slice selection**
   (only excite spins on a specific slice location)
2. **In-plane spatial encoding**
   (differentiate spin signals at different locations)

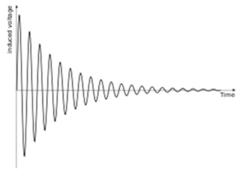


Received Signals

- The received signal is the mixture of the oscillating signals (FID) from all excited spins in the selected image plane.
- Without spatial encoding, we can not reveal the spatial information.

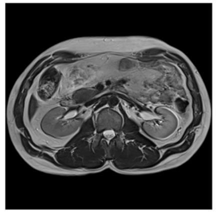
0	$\cos\omega_0 t$	$\cos\omega_0 t$
$\cos\omega_0 t$	$2\cos\omega_0 t$	0
$2\cos\omega_0 t$	0	$\cos\omega_0 t$

→ $8\cos\omega_0 t$



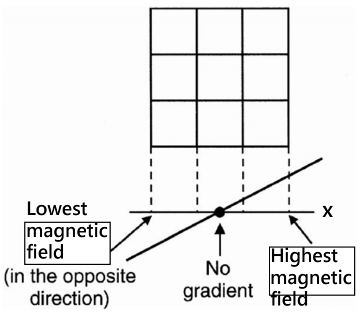
In-plane Spatial Encoding

- Extract the spatial information regarding each slice
  - Frequency encoding or readout gradient
  - Phase encoding gradient



Frequency Encoding

- The frequency-encoding gradient (G_x) is applied during the time of echo is received, i.e., during readout.
- Larmor frequency: $\boldsymbol{\omega(x)=\gamma(B_0+G_x \cdot x)}$

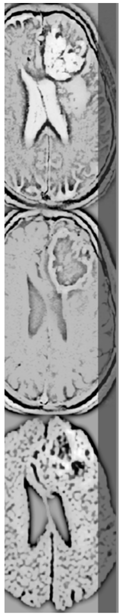


Frequency Encoding

- The center frequency comes from each column differs from each other.

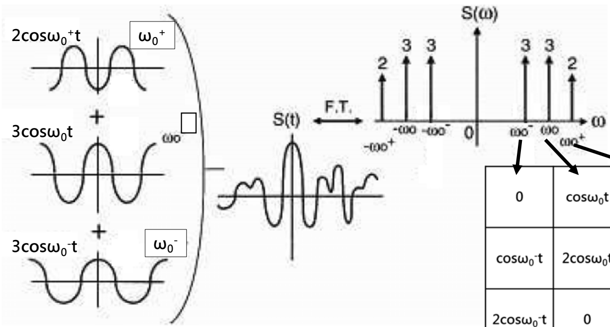
0	$\cos\omega_0 t$	$\cos\omega_0^{+} t$
$\cos\omega_0^{-} t$	$2\cos\omega_0 t$	0
$2\cos\omega_0^{-} t$	0	$\cos\omega_0^{+} t$

→ $3\cos\omega_0^{-} t+3\cos\omega_0 t+2\cos\omega_0^{+} t$

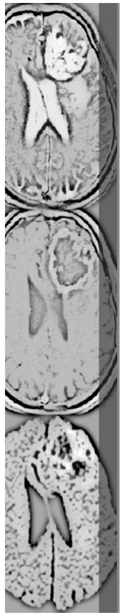


Frequency Encoding & FT

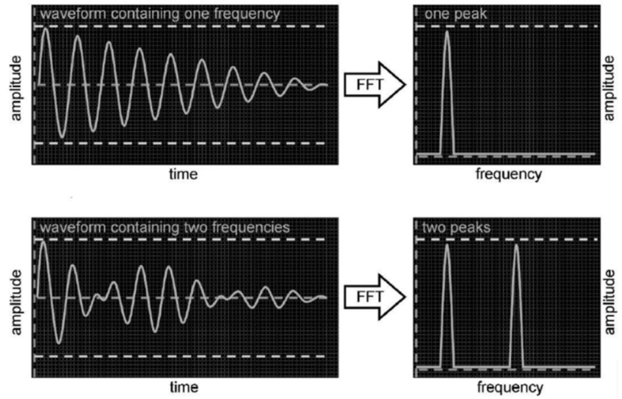
- We can analyze the magnitude of each frequency component using FT (Fourier transform).

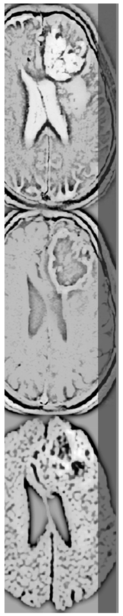


0	$\cos\omega_0 t$	$\cos\omega_0^+ t$
$\cos\omega_0^- t$	$2\cos\omega_0 t$	0
$2\cos\omega_0^- t$	0	$\cos\omega_0^+ t$



Free Induction Decay & FT





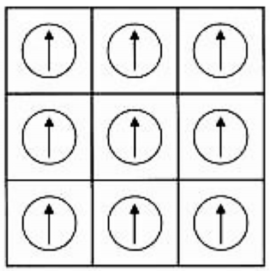
Phase Encoding

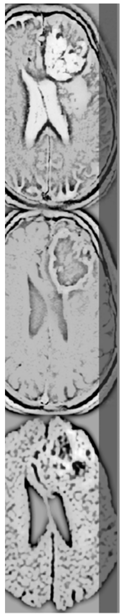
- The phase encoding gradient is aimed to create a phase difference between image lines.

0	$\cos\omega_0 t$	$\cos\omega_0 t$
$\cos\omega_0 t$	$2\cos\omega_0 t$	0
$2\cos\omega_0 t$	0	$\cos\omega_0 t$

=

In phase



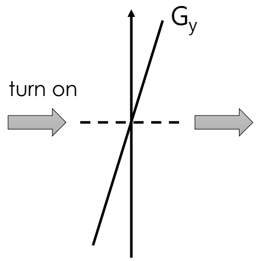


Phase Encoding Gradient

- The phase-encoding gradient (G_y) is turned on between the 90º RF pulse and the echo.
- The phase-encoding gradient is turned on for a short period and then turned off to create a phase difference between lines.

$\cos\omega_0 t$
$2\cos\omega_0 t$
$0\cos\omega_0 t$

turn on

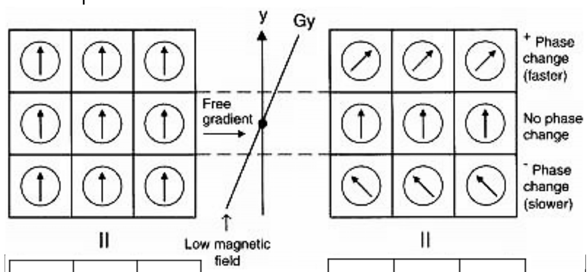


$\cos\omega_0^+ t$
$2\cos\omega_0 t$
$0\cos\omega_0^- t$

turn off

$\cos(\omega_0 t+\theta)$
$2\cos\omega_0 t$
$0\cos(\omega_0 t-\theta)$

Phase Encoding

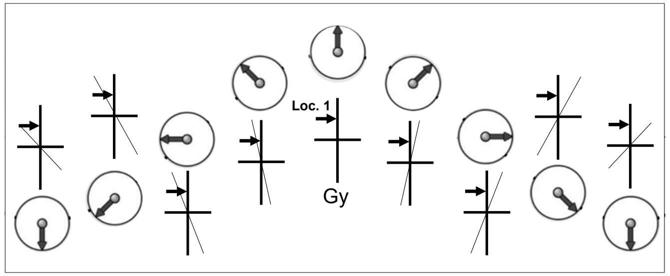


0	$\cos\omega_0 t$	$\cos\omega_0 t$
$\cos\omega_0 t$	$2\cos\omega_0 t$	0
$2\cos\omega_0 t$	0	$\cos\omega_0 t$

0	$\cos(\omega_0 t+\theta)$	$\cos(\omega_0 t+\theta)$
$\cos\omega_0 t$	$2\cos\omega_0 t$	0
$2\cos(\omega_0 t-\theta)$	0	$\cos(\omega_0 t-\theta)$

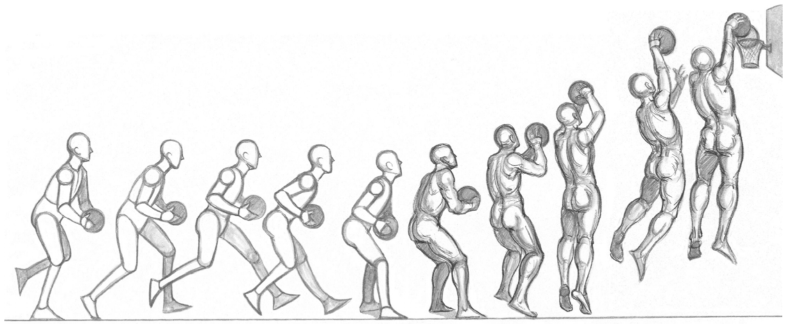
Phase shift & pseudo-frequency

- A cosine wave formed from connecting all the phase values (produced by multiple phase encodings) at a certain location.
- This cosine wave has a frequency or pseudo-frequency that depends on the degree of phase shift produced by the gradient.



Sequential Movement

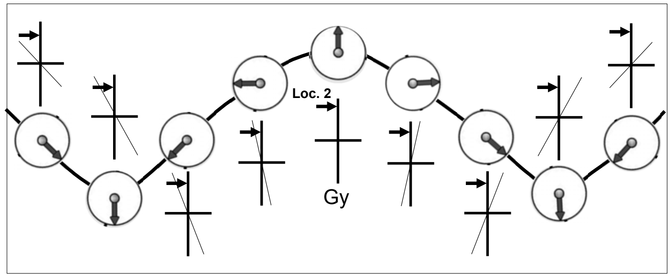
- Capture a movement by combining sequential images.



https://doctorlib.info/anatomy/classic-human-anatomy-motion/14.html

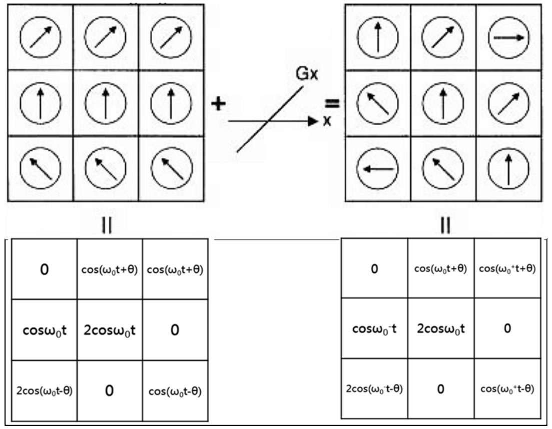
Phase shift & pseudo-frequency

- A cosine wave formed from connecting all the phase values (produced by multiple phase encodings) at a certain location.
- This cosine wave has a frequency or pseudo-frequency that depends on the degree of phase shift produced by the gradient.



Spatial Encoding

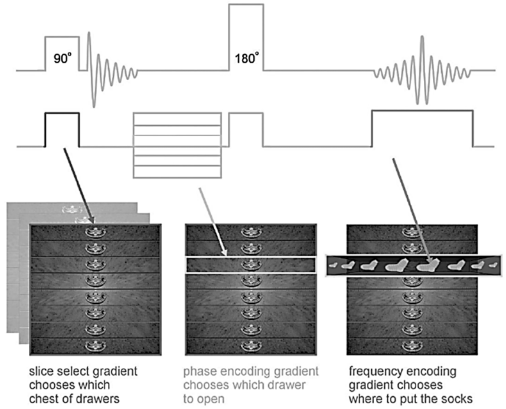
- The protons in each pixel have a distinct frequency and a distinct phase, which are unique and encode for the x and y coordinates for that pixel.



Q1: When?

How do we arrange RF and gradients?

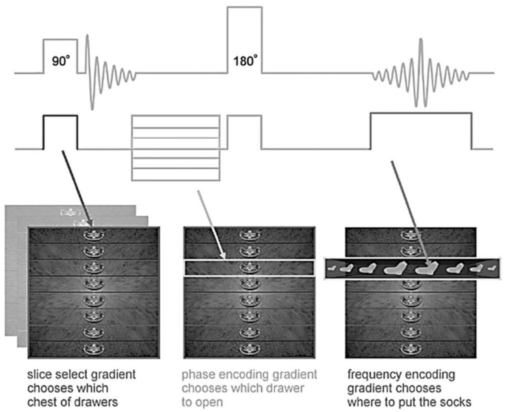
- Pulse sequence diagram
- A slice select gradient is applied with RF pulses.
- The phase-encoding gradient is turned on between the RF pulse and the echo.
- The frequency-encoding gradient turns on during signal readout.



Q2: Duration?

How do we arrange RF and gradients?

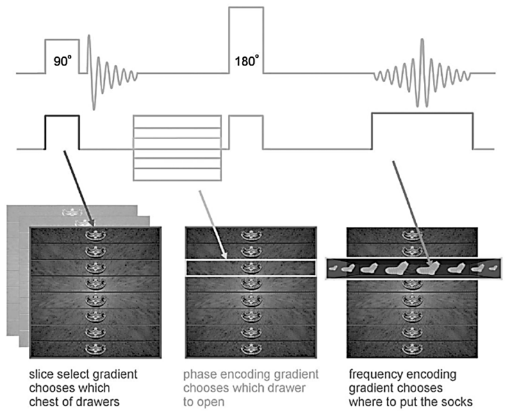
- Pulse sequence diagram
- Each RF pulse (with a slice select gradient) takes 2-10 msec.
- The phase-encoding step takes 1-5 msec.
- The frequency-encoding step takes about 10 msec.

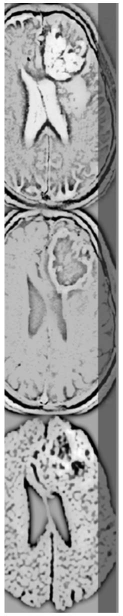


Q3: Strength?

How do we arrange RF and gradients?

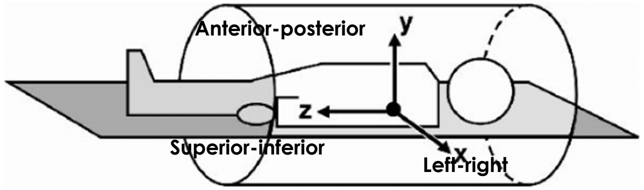
- Pulse sequence diagram
- Fixed strength (slope) for both slice select and frequency-encoding gradients.
  - Consistent slice thickness and frequency FOV
- The strength of phase-encoding changes between TR cycles.
  - Create different pseudo-frequency components





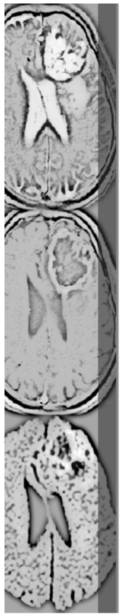
Plane of Imaging

	Slice-Select Gradient	Phase-Encoding Gradient (In-plane spatial encoding)		Frequency-Encoding Gradient (In-plane spatial encoding)
Axial	z	y	⟺	x
Sagittal	x	y	⟺	z
Coronal	y	x	⟺	z



梯度線圈

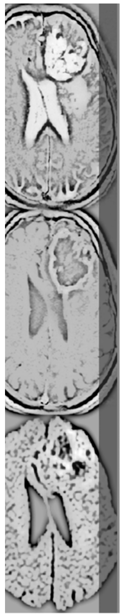
Gradient Coils



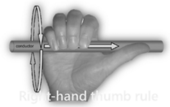
Imaging Gradient Coils

- The three components of the gradient set can be activated to create a slope in the static field along x, y, and z axes, respectively.
- Factors that change the strength of an electromagnet
  - The current passing through the windings
  - The number of windings in the coil
  - The diameter of the wire used in the windings
  - The distance or spacing between the windings

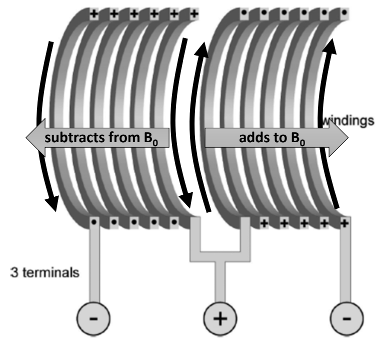
Not superconductive!



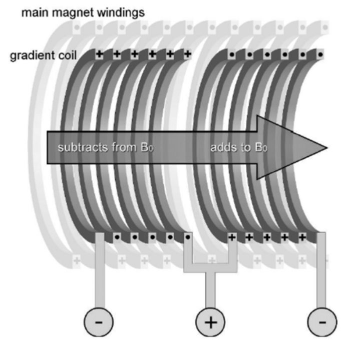
Gradient Coils – Z axis



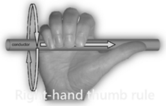
- A three-terminal electromagnet



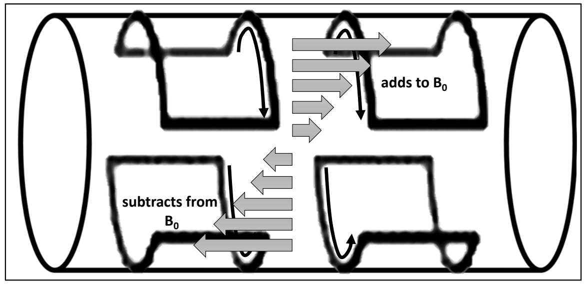
Maxwell Coils



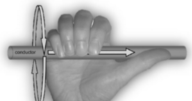
Gradient Coils – Y axis



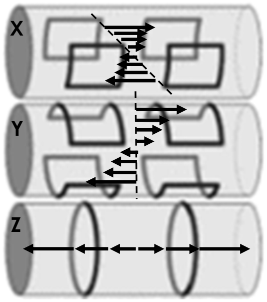
“Double-saddle" coils or Golay coils



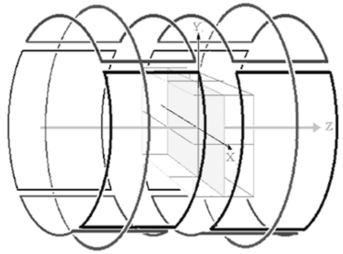
Gradient Coils



- Intentionally create linear perturbation to magnetic field.



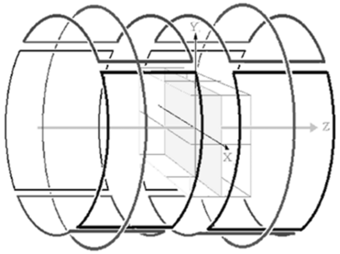
All gradient coils



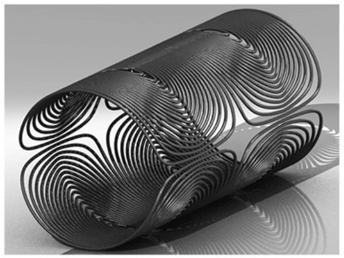
http://www.iomonitoring.org/mri.htm

Gradient Coils

The design for transverse gradients used in cylindrical MR magnets is based on a "double-saddle" coil configuration originally described in 1958 by Marcel Golay.



Advanced Golay design in fingerprint pattern, very typical for modern MR scanners in 2014.



http://mri-q.com/x--and-y--gradients.html

Coil Applications

97. 電阻線圈空氣心式（Resistive Coil Air Core）磁鐵之磁振造影機，該磁鐵之基本設計組態（configuration）為以下何者？

A.Maxwell Pair

B.Helmholtz Pair

C.Goley Pair

D.Gauss Pair

(B, 95 年第二次放射線器材學第 79 題)

Helmholtz coil: create an uniform magnetic field, resistive B0
Maxwell coil: create Gz
Goley coil: (double-saddle coil: create Gx or Gy)
Gauss coil: Gauss rifle, accelerated magnetic gun

Gradient Characteristics

- Gradient strength or gradient amplitude **(mT/m or G/cm)**
  - How steep a particular gradient is.
- Gradient speed or gradient rise time **(μs)**
  - The time it takes for a gradient to reach maximum amplitude.
- Slew rate **(mT/m/s)**
  - The speed and strength of the gradient.
- Duty cycle **(%)**
  - The percentage of time that the gradient is permitted to work.

Acoustic noise

- Caused by the vibration of the gradient set.
- Increased acoustic noise due to
  - Higher amplitude gradient values
  - Rapid gradient activation
- Quiet System

ear plugs

MR-compatible ear phones

訊號取樣

Signal Sampling

Readout Parameters

- Sampling frequency or **bandwidth**
- Frequency matrix or frequency FOV
- Acquisition window

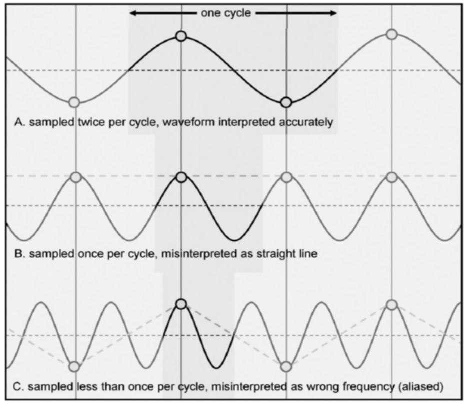
Nyquist Theorem

- The maximum frequency (Nyquist frequency) we can recover is one-half of the sampling frequency (rate).
- The sampling frequency must be at least twice the maximum signal frequency to avoid aliasing.

$$f_{sampling} = 1/\Delta Ts \geqq 2f_{max}$$

Nyquist Theorem

- Aliasing due to insufficient sampling frequency

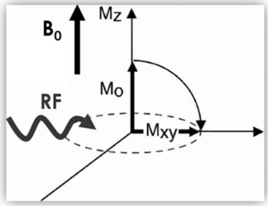


Sampling frequency/bandwidth

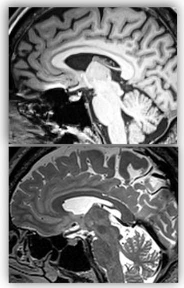
- Transmission/RF bandwidth
  - Determine the slice thickness
- Receiver bandwidth
  - The range of frequencies we wish to sample or digitize during readout.
  - Sampling frequency = 2 x Nyquist frequency
  - Receiver bandwidth = 2 x highest frequency (Nyquist frequency)

Wider bandwidth → lower SNR

Procedure of MRI



- ☑ Alignment (magnetization) B_0
- ☑ Precession $\omega_0 = \gamma B_0$
- ☑ Resonance (given B_1 by RF with ω_2) $\omega_1 = \gamma B_1$, $B_1 \perp B_0$
  - The most effective resonance is produced when $\omega_0 = \omega_2$
- ☑ MR signal (EMF, relaxation time)
- ☐ Imaging (Pulse sequencing)
  - ☑ Tissue Contrast: Image weighting
  - ☐ Spatial localization: Slice selection & Spatial Encoding



THE END

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