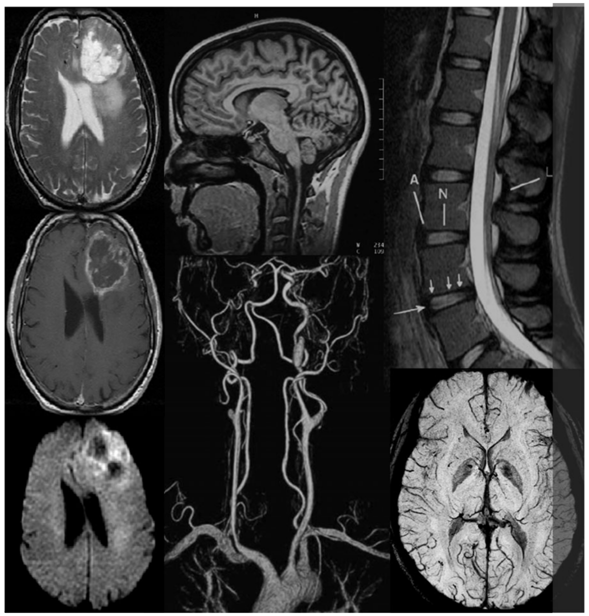

磁振影像學MRI
空間編碼

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生物醫學影像暨放射科學系
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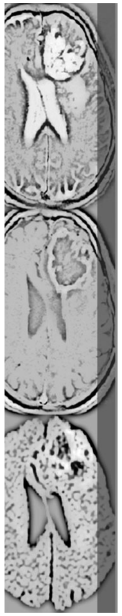
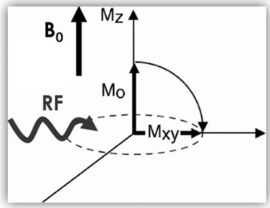
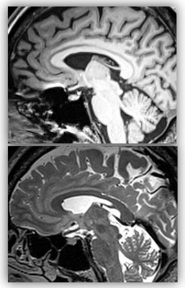
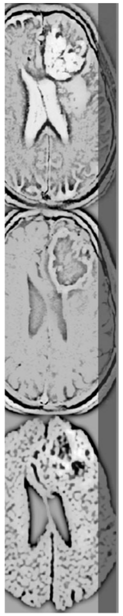


Procedure of MRI



- ☑ 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

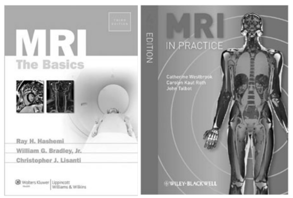




本週課程內容 http://cflu.lab.nycu.edu.tw

- 空間編碼
- 訊號取樣

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

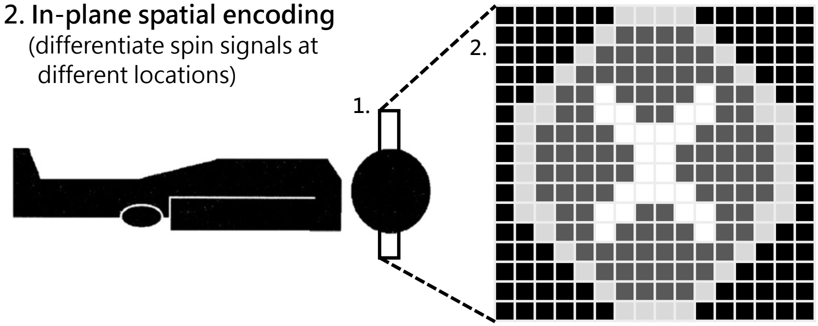


空間編碼

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)

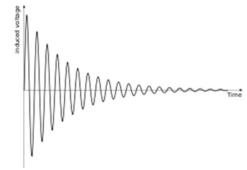


Received Signals

- 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.

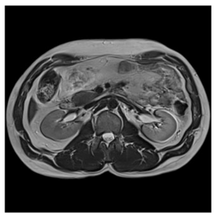
0	$\cos\omega_0 t$	$\cos\omega_0 t$
$\cos\omega_0 t$	$2\cos\omega_0 t$	0
$2\cos\omega_0 t$	0	$\cos\omega_0 t$

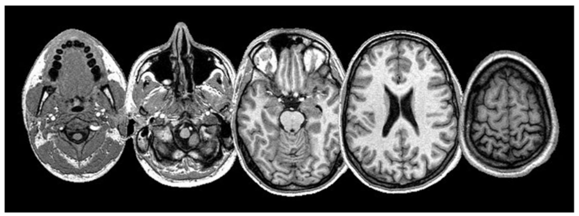
→ $8\cos\omega_0 t$



In-plane Spatial Encoding

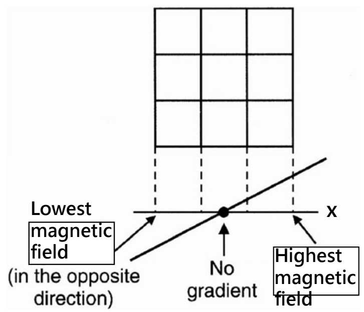
- Extract the spatial information regarding each slice
  - Frequency encoding or readout gradient
    - Usually apply to the long axis of image
  - Phase encoding gradient
    - Usually apply to the short axis of image or less motion direction





Frequency Encoding

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



Frequency Encoding

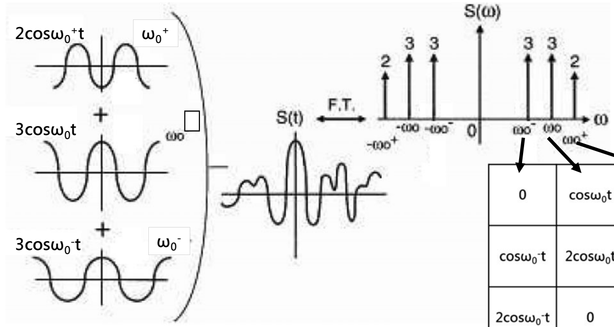
- The center frequency comes from each column differs from each other.

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	$\cos\omega_0^+ t$

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

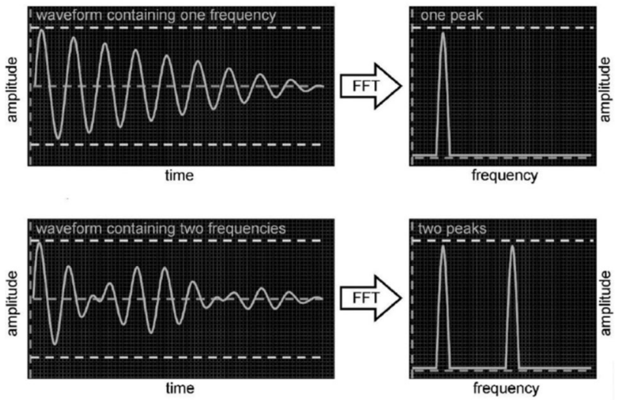
Frequency Encoding & FT

- 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



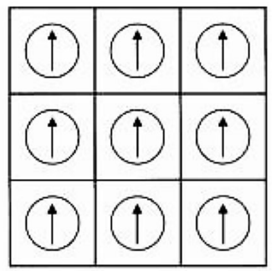
Phase Encoding

- 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	$\cos\omega_0 t$

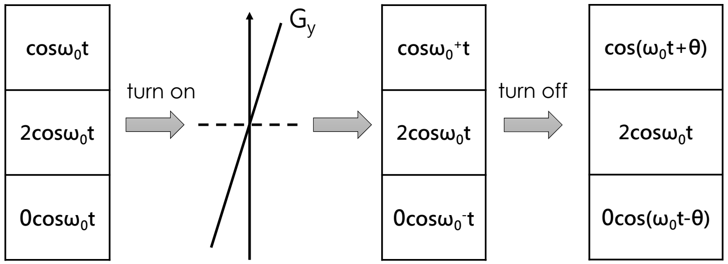
=

In phase

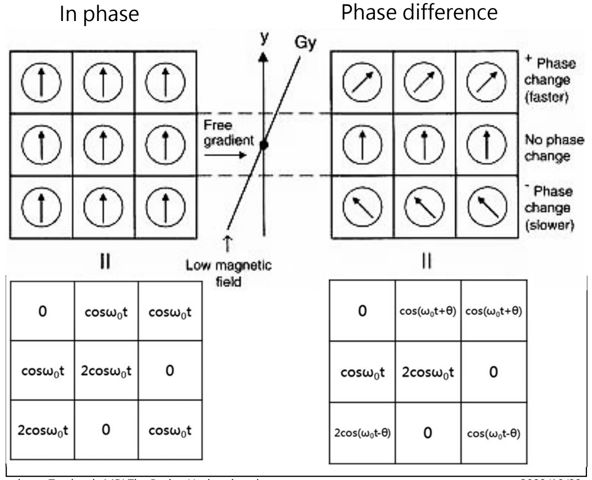


Phase Encoding Gradient

- The phase-encoding gradient (G_y) is turned on between the 90° 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.

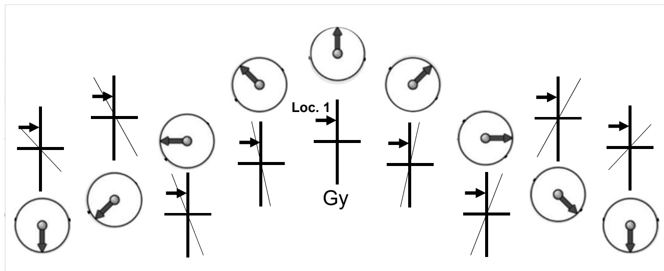


Phase Encoding



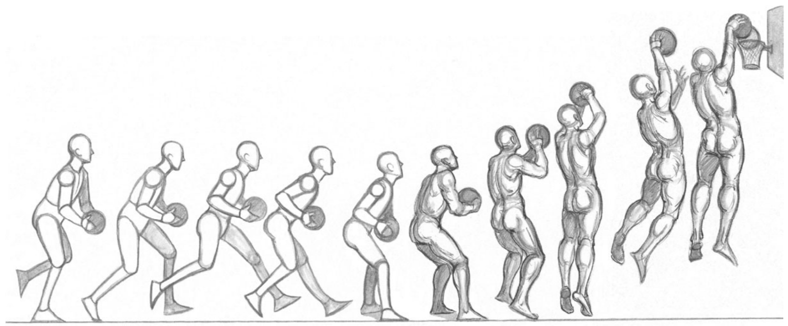
Phase shift & pseudo-frequency

- 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.

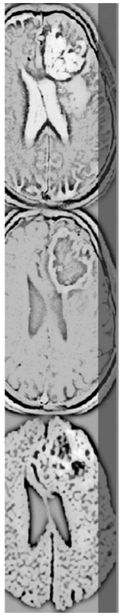


Sequential Movement

- Capture a movement by combining sequential images.



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



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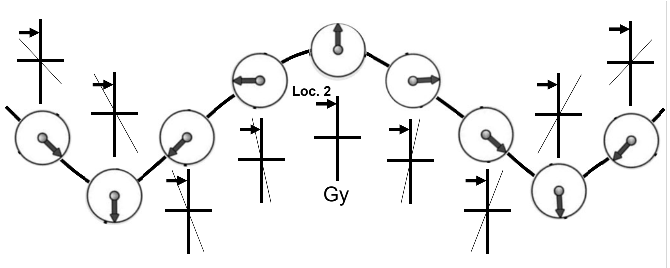
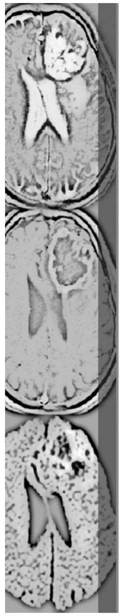
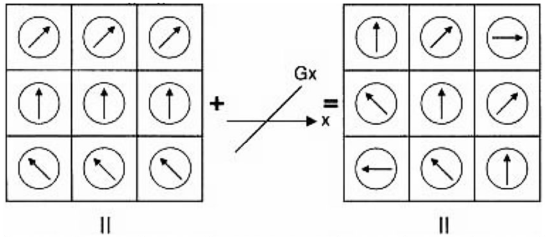




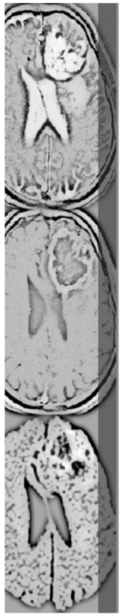
Spatial Encoding

- 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.



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	$\cos(\omega_0 t-\theta)$

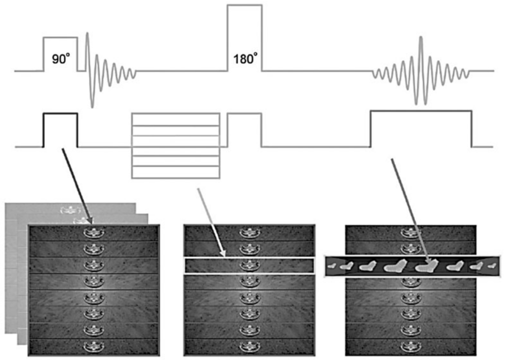
0	$\cos(\omega_0 t+\theta)$	$\cos(\omega_0^+ t+\theta)$
$\cos\omega_0^- t$	$2\cos\omega_0 t$	0
$2\cos(\omega_0^- t-\theta)$	0	$\cos(\omega_0^+ t-\theta)$



Q1: When?

How do we arrange RF and gradients?

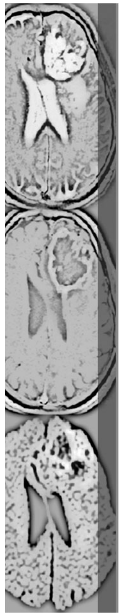
- Pulse sequence diagram
- A slice select gradient is applied with RF pulses.
- The phase-encoding gradient is turned on between the RF pulse and the echo.
- The frequency-encoding gradient turns on during signal readout.



slice select gradient chooses which chest of drawers

phase encoding gradient chooses which drawer to open

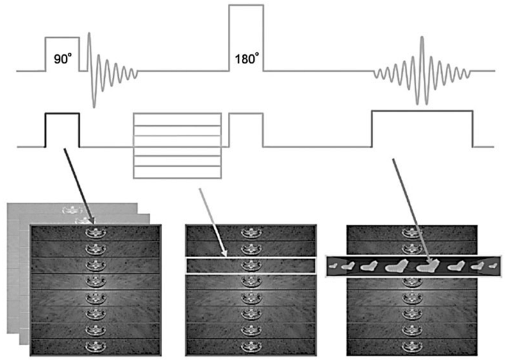
frequency encoding gradient chooses where to put the socks



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.



slice select gradient chooses which chest of drawers

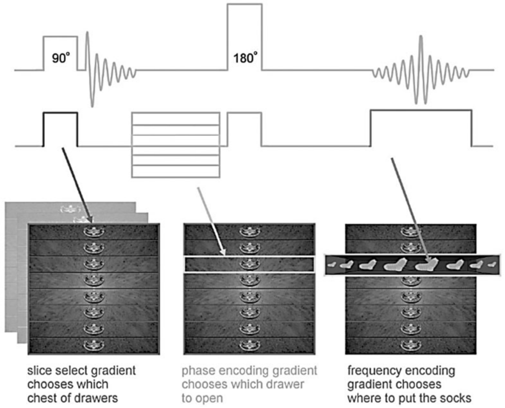
phase encoding gradient chooses which drawer to open

frequency encoding gradient chooses where to put the socks

Q3: Strength?

How do we arrange RF and gradients?

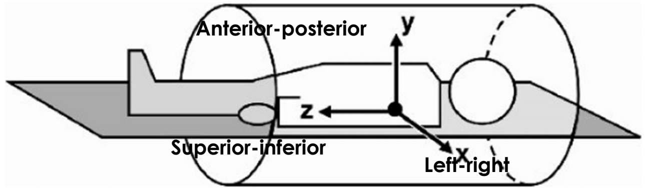
- Pulse sequence diagram
- Fixed strength (slope) for both slice select and frequency-encoding gradients.
  - Consistent slice thickness and frequency FOV
- The strength of phase-encoding changes between TR cycles.
  - Create different pseudo-frequency components



Plane of Imaging

In-plane spatial encoding

	Slice-Select Gradient	Phase-Encoding Gradient	Frequency-Encoding Gradient
Axial	z	y ⟺	x
Sagittal	x	y ⟺	z
Coronal	y	x ⟺	z



訊號取樣

Signal Sampling

Readout Parameters

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

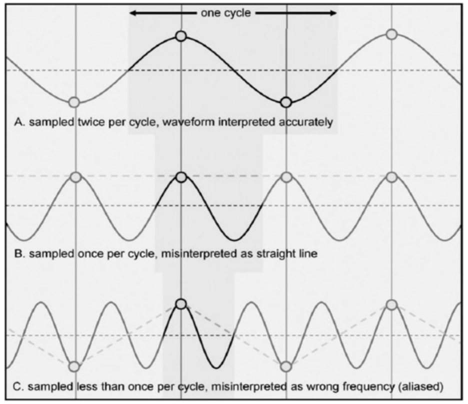
Nyquist Theorem

- 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

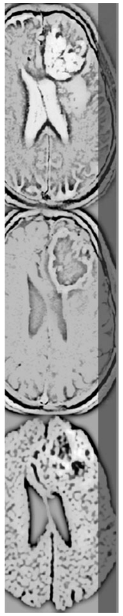
- Transmission/RF bandwidth
  - Determine the slice thickness
- Receiver bandwidth
  - The range of frequencies we wish to sample or digitize during readout.
  - Sampling frequency = 2 x Nyquist frequency
  - Receiver bandwidth = 2 x highest frequency (Nyquist frequency)

Wider bandwidth → lower SNR

Other readout parameters

- Frequency matrix or frequency FOV
  - The matrix size (data points) we demanded for imaging
- Acquisition window
  - The duration demanded for acquire sufficient data points

Higher bandwidth → higher sampling rate → shorter acquisition window to acquire sufficient data points!



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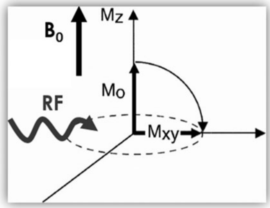

- [x] Alignment (magnetization) B_0
- [x] Precession $\omega_0 = \gamma B_0$
- [x] Resonance (given B_1 by RF with ω_2) $\omega_1 = \gamma B_1$, $B_1 \perp B_0$
  - The most effective resonance is produced when $\omega_0 = \omega_2$
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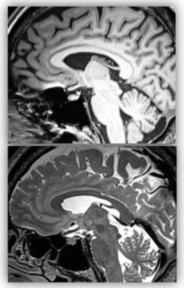
- [ ] Imaging (Pulse sequencing)
  - [x] Tissue Contrast: Image weighting
  - [ ] Spatial localization: Slice selection & Spatial Encoding



THE END

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