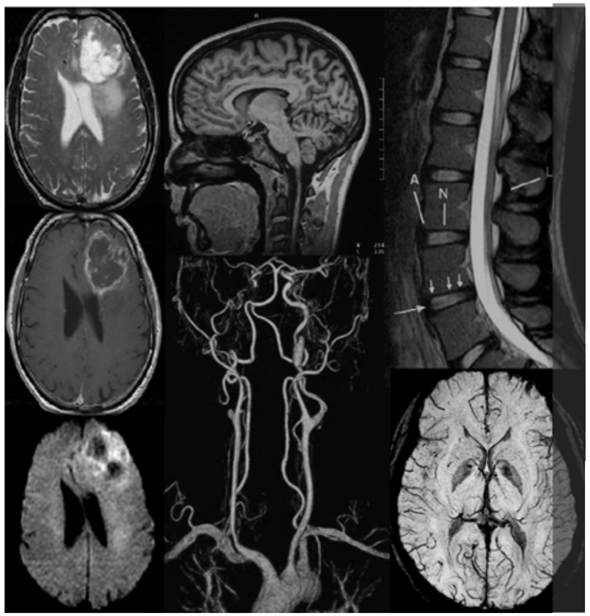

磁振影像學MRI
空間編碼

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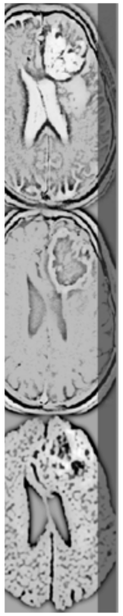
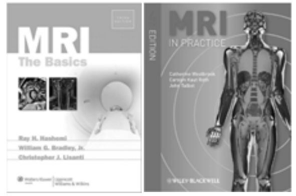


本週課程內容 http://www.ym.edu.tw/~cflu

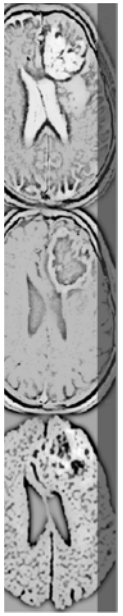
- 磁振造影流程
- 空間編碼
- 訊號取樣

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

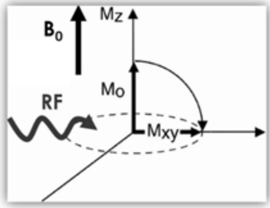


磁振造影流程

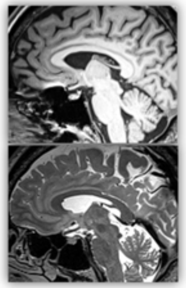
MRI Procedure



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

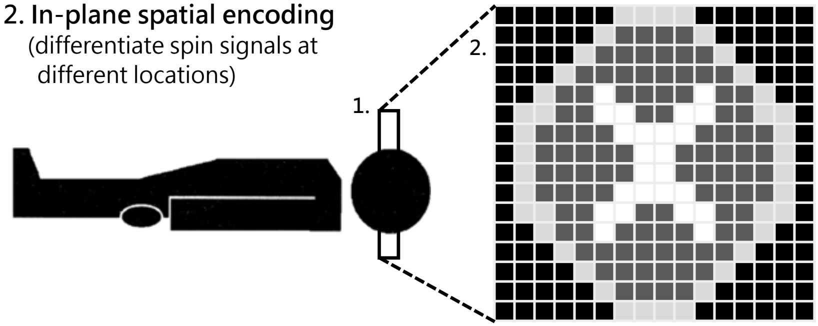


空間編碼

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

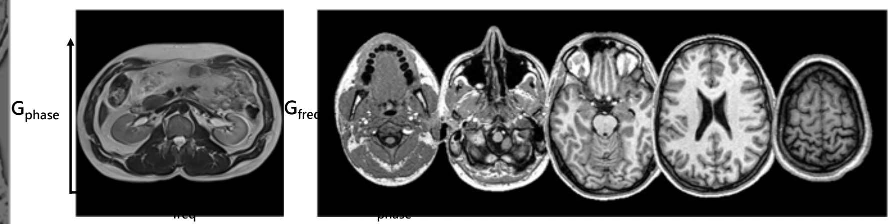
- The received signal is the mixture of the oscillating signals (FID) from all excited spins in the selected image plane.
- Without spatial encoding, we can not reveal the spatial information.

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	$\cos\omega_0 t$

$\longrightarrow 8\cos\omega_0 t$

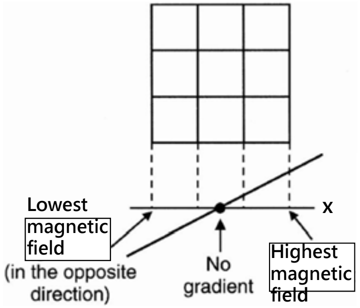
In-plane Spatial Encoding

- 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



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

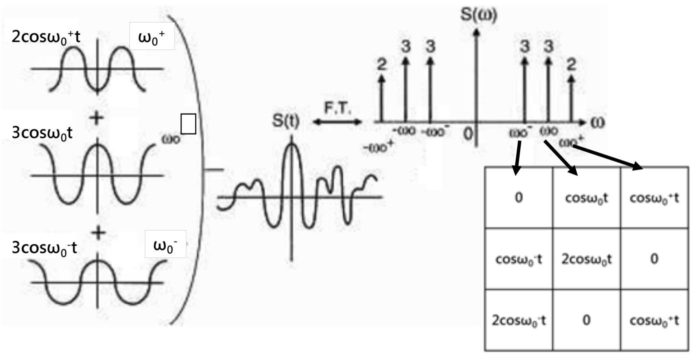
- The center frequency comes from each column differs from each other.

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	$\cos\omega_0^+ t$

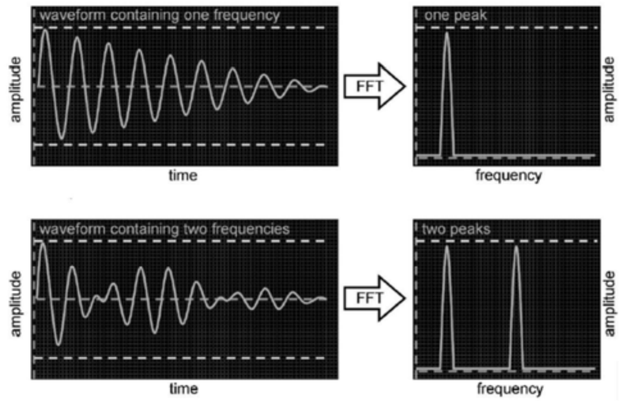
→ $3\cos\omega_0^- t+3\cos\omega_0 t+2\cos\omega_0^+ t$

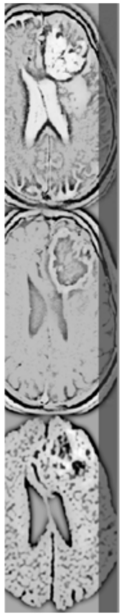
Frequency Encoding & FT

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



Free Induction Decay & FT





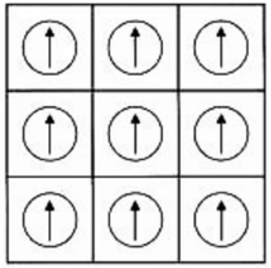
Phase Encoding

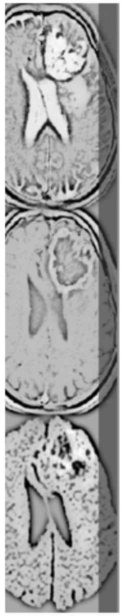
- The phase encoding gradient is aimed to create a phase difference between image lines.

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	$\cos\omega_0 t$

=

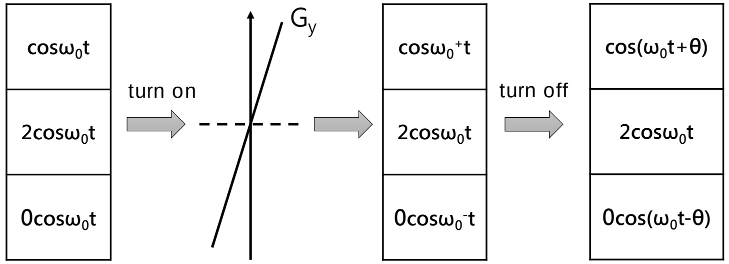
In phase

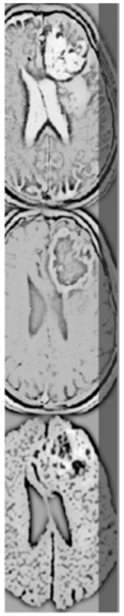




Phase Encoding Gradient

- 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.

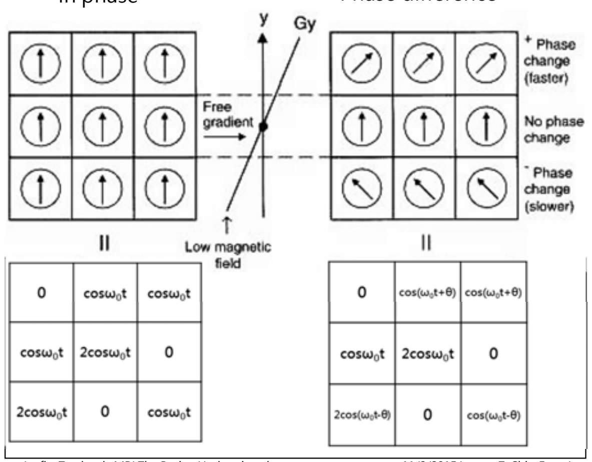


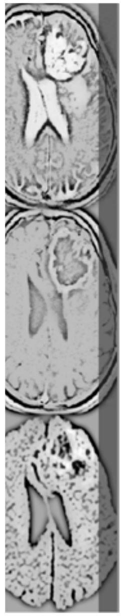


Phase Encoding

In phase

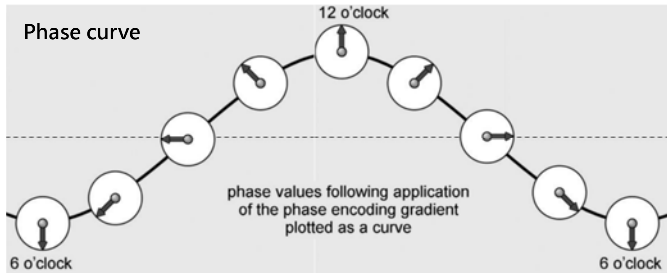
Phase difference





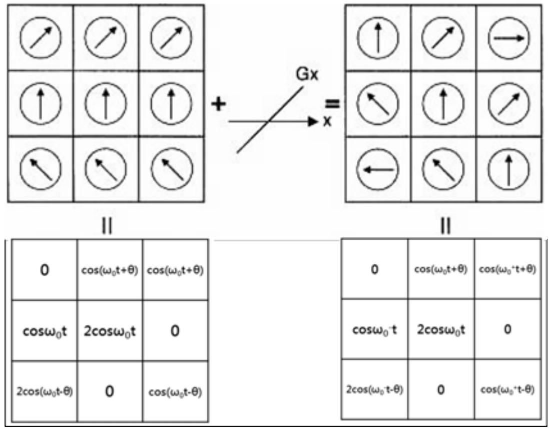
Phase shift & pseudo-frequency

- A cosine wave formed from connecting all the phase values associated with a certain phase shift.
- This cosine wave has a frequency or pseudo-frequency that depends on the degree of phase shift produced by the gradient.



Spatial Encoding

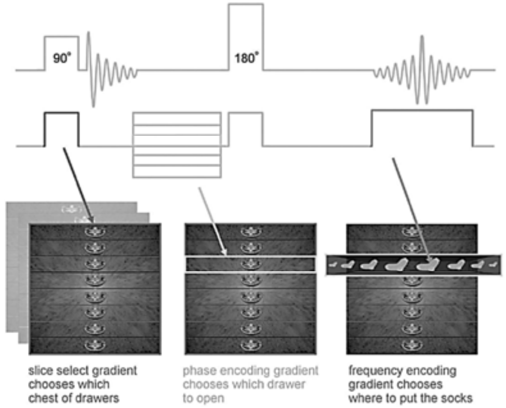
- The protons in each pixel have a distinct frequency and a distinct phase, which are unique and encode for the x and y coordinates for that pixel.



Q1: When?

How do we arrange RF and gradients?

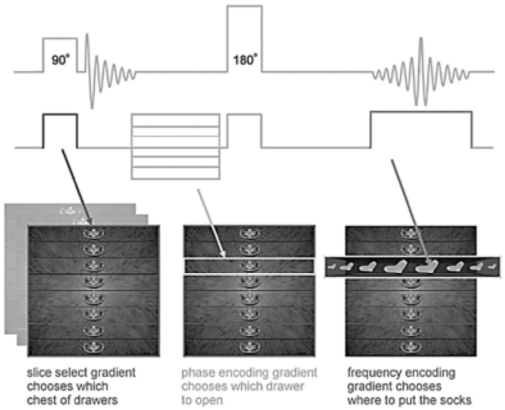
- Pulse sequence diagram
- A slice select gradient is applied with RF pulses.
- The phase-encoding gradient is turned on between the RF pulse and the echo.
- The frequency-encoding gradient turns on during signal readout.



Q2: Duration?

How do we arrange RF and gradients?

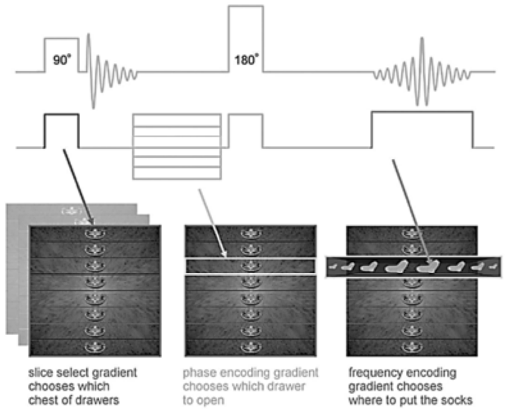
- Pulse sequence diagram
- Each RF pulse (with a slice select gradient) takes 2-10 msec.
- The phase-encoding step takes 1-5 msec.
- The frequency-encoding step takes about 10 msec.



Q3: Strength?

How do we arrange RF and gradients?

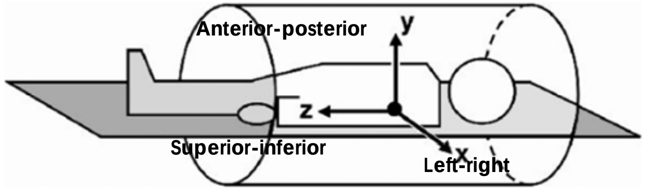
- Pulse sequence diagram
- Fixed strength (slope) for both slice select and frequency-encoding gradients.
  - Consistent slice thickness and frequency FOV
- The strength of phase-encoding changes between TR cycles.
  - Create different pseudo-frequency components



Plane of Imaging

In-plane spatial encoding (Phase-Encoding Gradient ⟺ Frequency-Encoding Gradient)

	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

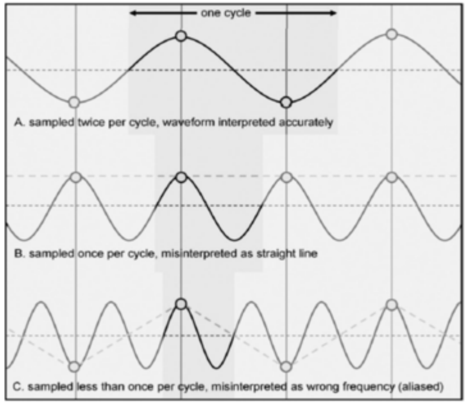
Nyquist Theorem

- 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)

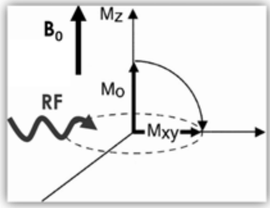
Wider bandwidth → lower SNR

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!

Procedure of MRI



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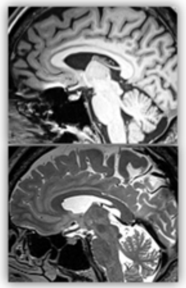

THE END

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