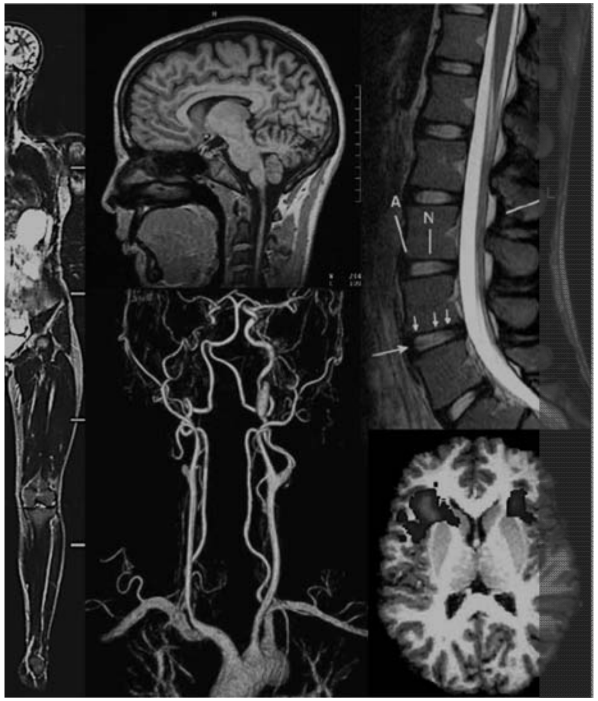

影像重建
A Course of MRI

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本週課程內容

- 脈衝程序圖(Pulse sequences diagram)
- 訊號處理與資料空間 (Signal processing, Data space/K space)

脈衝程序圖

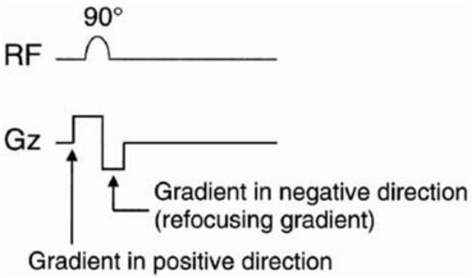
Pulse Sequences Diagram

Pulse Sequences Diagram

- RF pulses
  - 90º pulse
  - 180º pulse
- Gradients
  - G_z: slice-selective gradient
  - G_y: phase-encoding gradient
  - G_x: frequency-encoding/readout gradient
- Signals
  - Echo

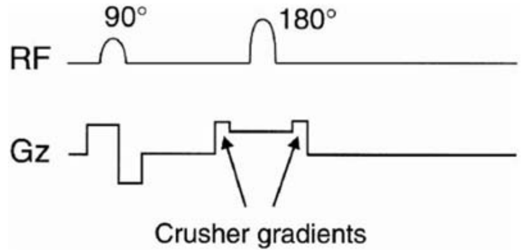
Slice-selective gradient G_z

- Every time we apply a gradient, we dephase the spins.
- We apply a G_z gradient to select a slice. But after the slice is selected, we need to reverse the effect of dephasing (refocusing).



Slice-selective gradient G_z

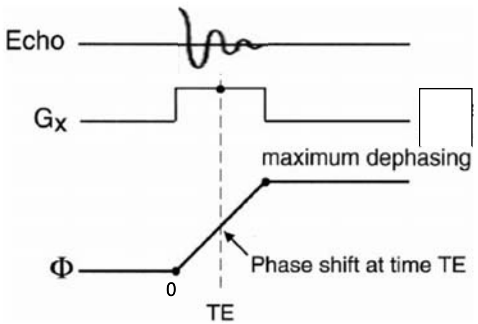
- Before and after the 180^o pulse, we apply a so-called crusher gradient.
- These crusher gradients are applied to offset the unwanted additional transverse magnetization.



To achieve more accurate refocusing at time TE

Frequency-encoding gradient G_x

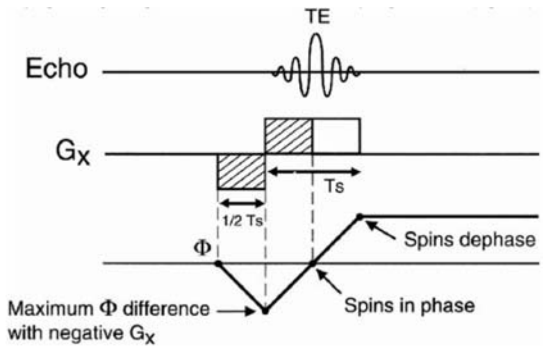
- Without a proper compensation, the signal intensity will be…
  - decrease at the time in the middle of echo;
  - Maximum dephasing at the time in the end of echo.



Phase difference ➔ weak signal

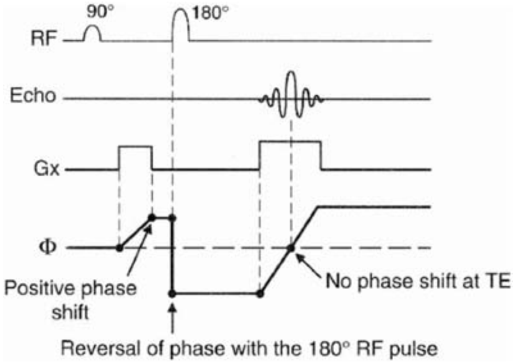
Frequency-encoding gradient G_x

- We apply a gradient in the negative direction that has an area equal to **1/2** of that of the readout gradient.



Frequency-encoding gradient G_x

- Another illustration for the extra G_x gradient: a positive G_x gradient before the 180° pulse.
- After the 180° RF pulse, the phase difference will be reversed.

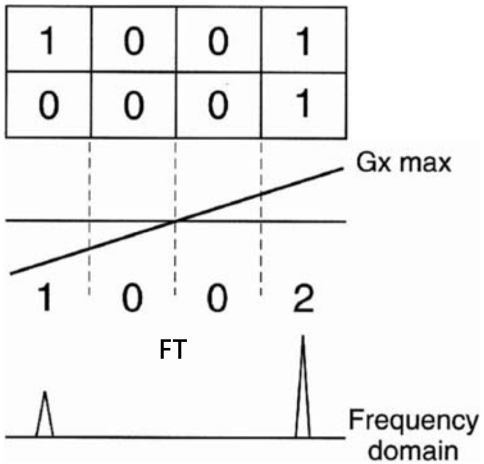


Phase-encoding gradient G_y

- We need to do a separate phase encode for each row of pixels, that is, 256 rows of pixels costs 256 steps of phase encode.
- We can only perform one phase-encoding step in one TR for a selected slice.
- With each new phase-encoding step, we change the magnetic gradient G_y.
- **Δθ=360°/# of rows**

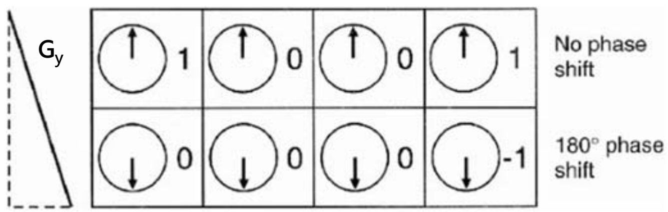
An Example: a 2 x 4 image

- A frequency encode along x axis can help us to discriminate the difference between columns.



An Example: a 2 x 4 image

- To discriminate the signals from different rows, we apply a phase encode along y axis.
- Δθ=360°/2 rows=180°
- We need to apply two different G_y
  - Zero phase difference between rows
  - 180° phase difference



Multiplied by cos(θ)
- cos(0)=1
- cos(180)=-1

An Example: a 2 x 4 image

1	0	0	1
0	0	0	1

- Zero phase difference

1	0	0	1
0	0	0	1

a	0	0	c
b	0	0	d

- a+b=1
- c+d=2

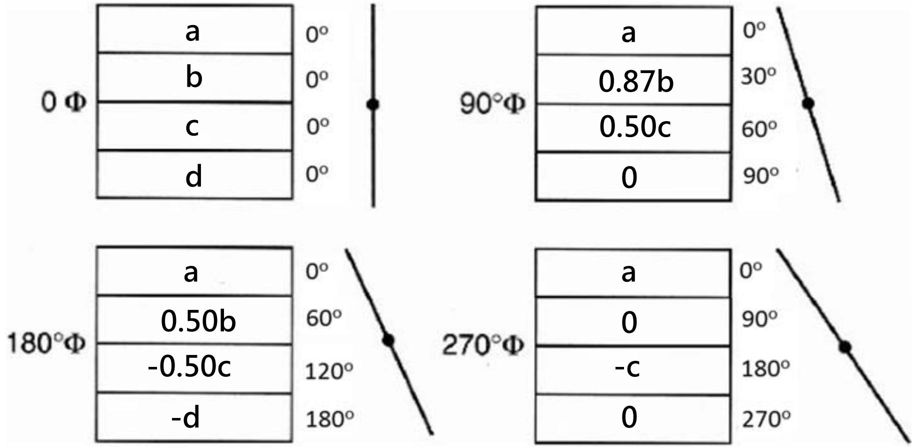
- 180º phase difference

1	0	0	1
0	0	0	-1

a	0	0	c
-b	0	0	-d

- a-b=1 ➔a = 1, b = 0
- c-d=0 ➔c = 1, d = 1

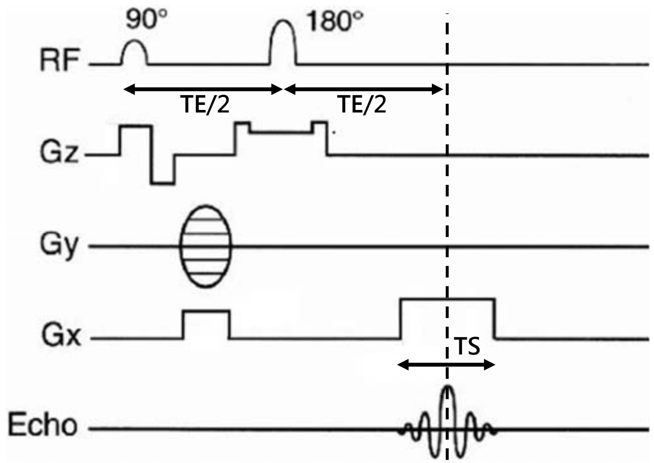
An Example: a 4 x 1 image



Time Requirements

- Each RF pulse (with a G_z gradient) takes 2~10 msec.
- The phase-encoding step takes 1~5 msec.
- The frequency-encoding step takes about 10msec (4~8 msec at high fields; 16~30 msec at lower fields).

A Spin-echo PSD

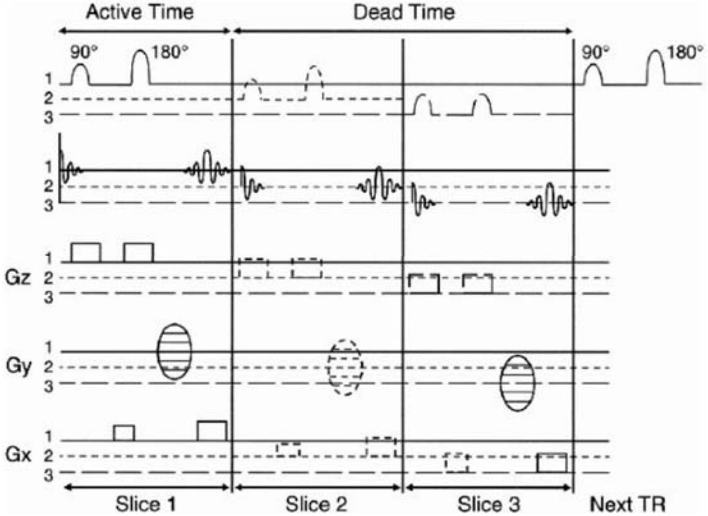


TS: sampling time

Active time = TE+TS/2

TR > active time

Multislice Acquisition in a TR



Rough approximation

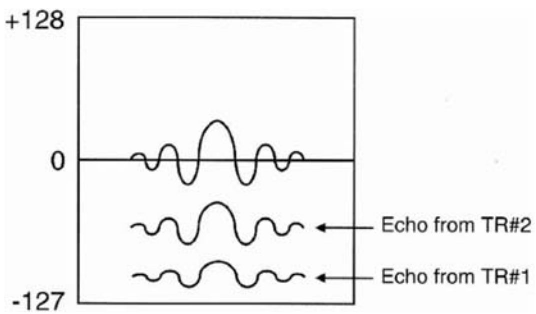
Max # slice < TR/TE

訊號處理與資料空間

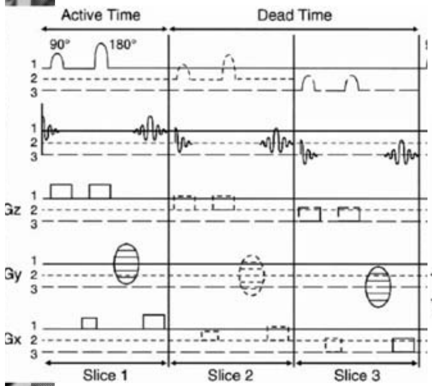
Signal Processing, Data Space/K Space

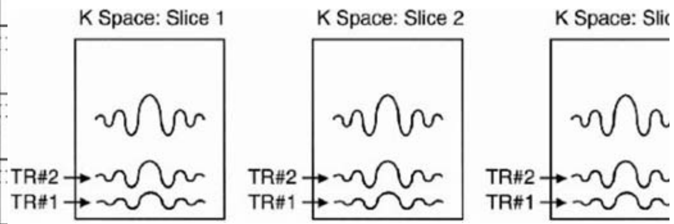
Data Space

- Each slice has its own data space.
- Each of received signals (echos) with different phase-encoding gradient fills one line in a set of rows referred to as the data space.
- Each signal in each row of the data space is the sum of all the signals from individual pixels in the slice.
- The center of the data space does not represent the center of image.



Multislice Acquisition in a TR

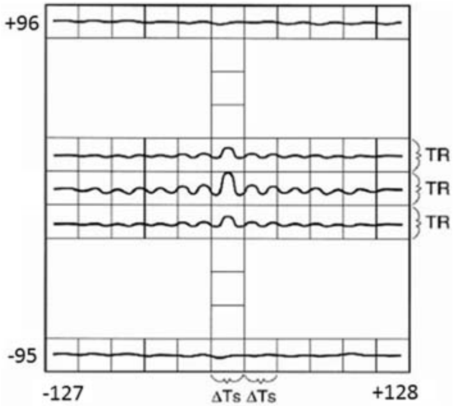




We use the same magnitude of G_y in each TR

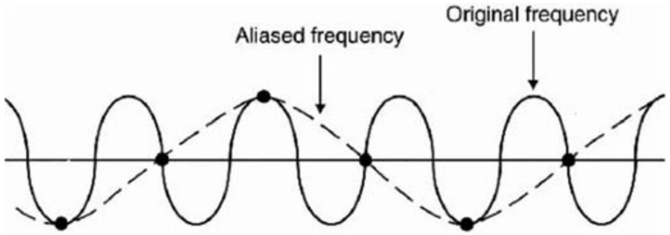
K Space

- K space is a digitized (sampled) version of the data space.
- A 256 x 192 k-space matrix
  - The first number represents the different number of frequencies we used.
  - The second number refers to the number of phase encoding steps.



Nyquist Sampling theorem

- Analog-to-digital conversion (ADC) is a process by which a time-varying (analog) signal is converted to a digitized form.
- The sampling rate must be at least twice *the maximum signal frequency* to avoid aliasing, i.e., $\omega_{sampling}=1/\Delta Ts \geqq 2\omega_{signal}$



ΔTs: sampling interval

However, reduce ΔTs can also decrease SNR.

Oversampling (take more than two samples per cycle) along the frequency-encoding direction can avoid aliasing (wraparound) artifacts.

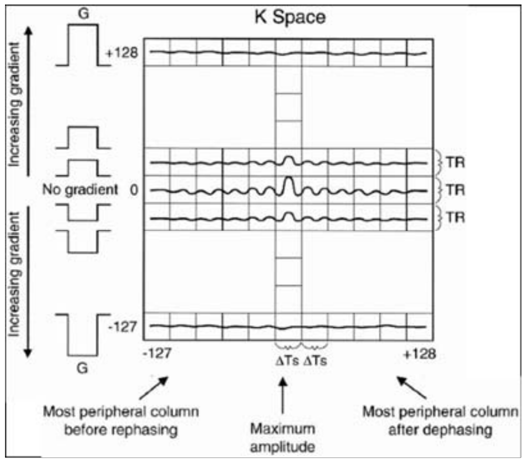
Signal-to-Noise Ratio (SNR)

- $\mathbf{SNR} \propto (\mathbf{pixel\ volume})\sqrt{\frac{\mathbf{Ny \times NEX}}{\mathbf{BW}}}$
  - BW (receiver bandwidth) = 1/ΔTs
  - Ny is the number of phase-encoding steps
  - NEX is the number of times we repeat the whole sequence (number of excitations)

  - Pixel volume ↑, spatial resolution ↓
  - Ny ↑, spatial resolution ↑, scanning time ↑
  - NEX ↑, scanning time ↑
  - BW ↓, ΔTs ↑, Ts ↑, TE ↑, T2W ↑, # of slice ↓

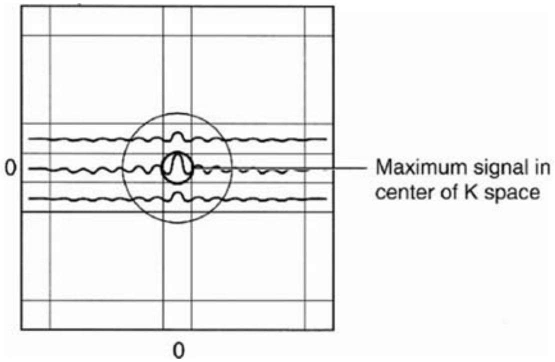
Properties of K-Space

- Each of the signals has its maximum signal amplitude in the center column.
- The maximum amplitude occurs in the center row because this line is obtained without additional dephasing.



Properties of K-Space

- The center point of the data space contains maximum amplitude, i.e., maximum SNR.



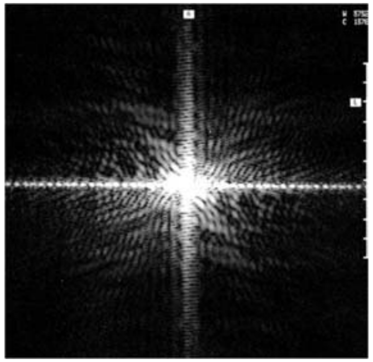
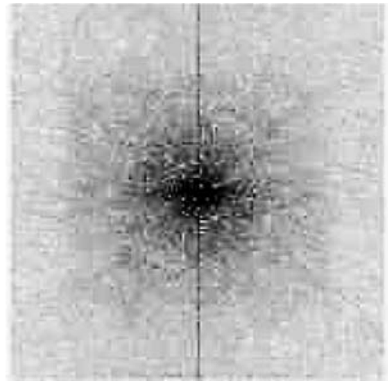


Image of K-Space

K Space



2D FFT ➔

Reconstructed Image

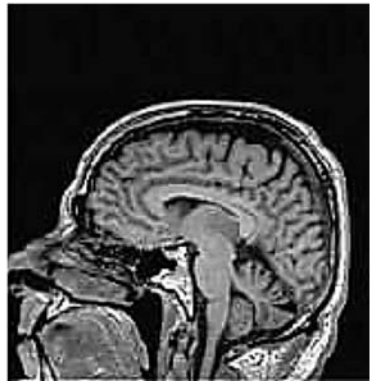
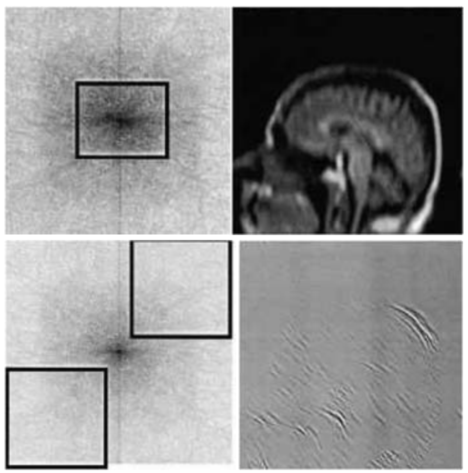


Image of K-Space

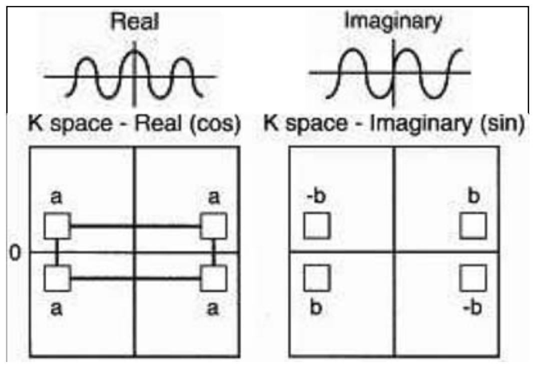
- The center of k-space contributes to the primary information of image.
- The periphery of k-space provides information regarding fitness of the image and clarity at sharp interfaces

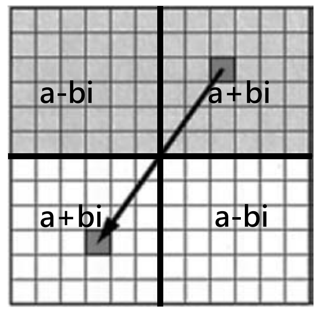
K Space Image



Conjugate (Hermitian) Symmetry

- We preliminarily decompose the signal into its real and imaginary components ➔ a real and an imaginary k space.



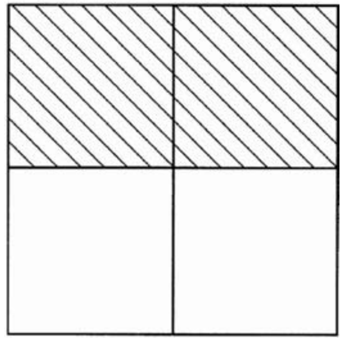


Magnitude and Phase Image

- Magnitude (modulus) image
  - $\boldsymbol{Magnitude} = \sqrt{\boldsymbol{a^2 + b^2}}$
  - It is what we commonly used in MR imaging.
- Phase (angle) image
  - $\boldsymbol{tan\theta = b/a}$
  - It is used in cases in which the direction is important.
  - ex: phase contrast MR angiography

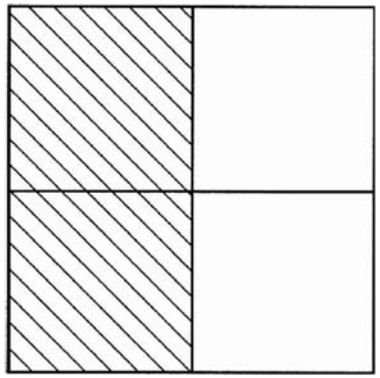
Half-Fourier Technique

- We acquire the data from the upper half of k-space and construct the lower part mathematically, thus reducing the scan time.
- The trade-off is a reduced SNR by a factor of $\sqrt{2}$.
- Overscanning: we sample half of the phase-encoding steps plus a few lines below the 0 line to compensate the phase errors.



Fractional (Partial) Echo

- Only a half of the echo is sampled, and another half is constructed based on the acquired half.
- It allows TE to be shorter.
- The dephasing in the frequency direction is reduced.
- Give better SNR at a given TE when a smaller FOV or thinner slices are selected.
- Gradient echo sequences (FLASH, Fast SPGR)



Acquisition Time

- The acquisition time depends on
  - TR (the time to do one line of the data space)
  - Ny (the number of phase-encoding steps)
  - NEX (the number of times we repeat the whole sequence to increase SNR)
- $acquisition\ time \propto TR \cdot Ny \cdot NEX$

THE END

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