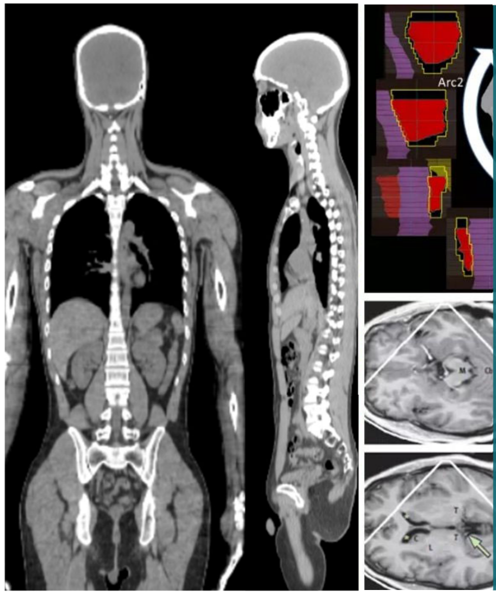
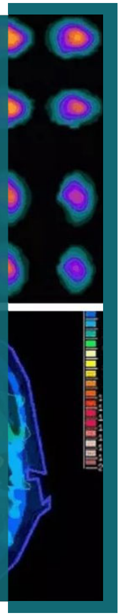

醫學影像原理與實務

磁振影像設備與造影原理I

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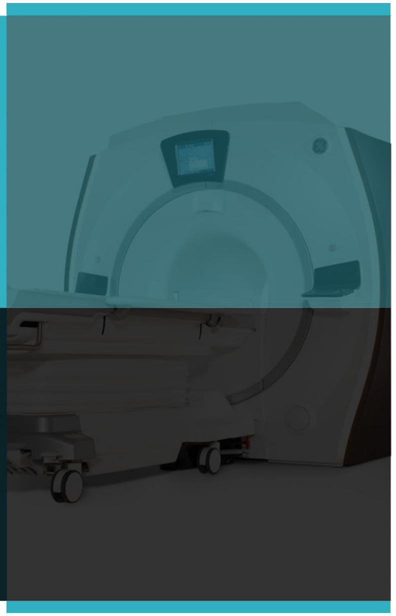
本週學習目標

1. **認識磁振造影原理與設備**
   - 基本磁振原理
   - 磁振造影主要設備元件
2. **了解磁振影像重建概念**
   - 組織磁振特性 → 影像對比
   - 空間編碼 → 位置資訊
   - 磁振造影波序簡介

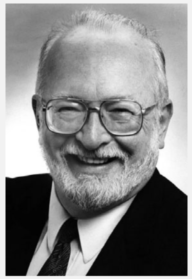
References:
- Fundamentals of Medical Imaging (2nd Ed.) Chapter 4
- MRI The Basics (4th Ed.)
- MRI in Practice, (5th Ed.)



磁振造影原理與設備

Nobel Prize in Physiology or Medicine 2003

- The Nobel Prize in Physiology or Medicine 2003 was awarded jointly to Paul C. Lauterbur and Sir Peter Mansfield for their discoveries concerning **magnetic resonance imaging (MRI)**.

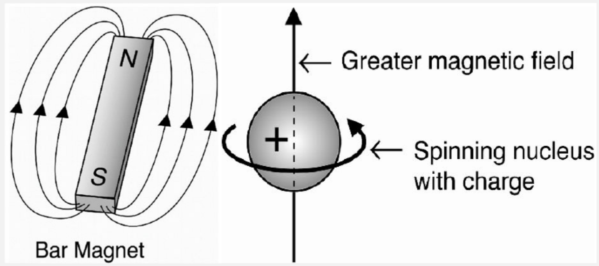
Paul C. Lauterbur


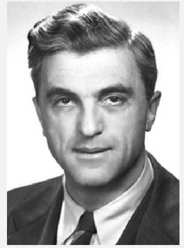
Sir Peter Mansfield

https://www.nobelprize.org/prizes/medicine/2003/summary/

Spins and electromagnetic field

- **Felix Bloch** (Standard University, Nobel prize in physics, 1952)
  - Any spinning charged particle (such as the **hydrogen nucleus**) creates an electromagnetic field.





1905.10.23~1983.09.10

Magnetic dipole moment (MDM)

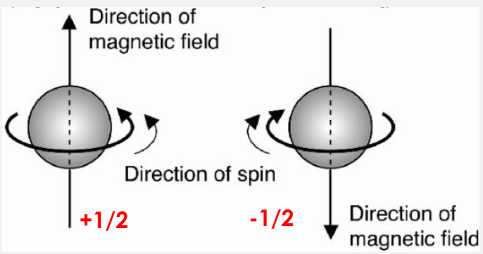
Quantum theory: Energy levels

- The hydrogen nucleus (a proton) has a **spin quantum number (S)**

  S (^{1}H)=1/2

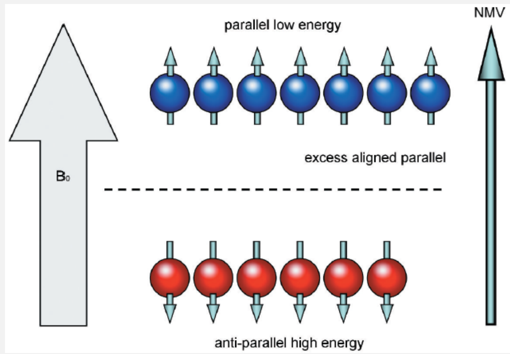
- The number of energy states of a nucleus

  \# of energy states = 2S+1 (for ^{1}H = 2)



Net Magnetic Vector (NMV)

- With B_0, protons line up and approximately half spin-up (parallel, low energy) and half spin-down (anti-parallel, high energy).
- About one in a million more protons point in the direction of B_0.
- ppm (parts per million)



Precession 旋進

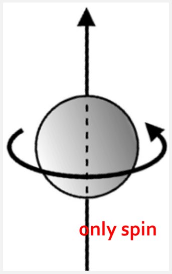
- With B_0, the proton not only spins about its own axis, but also precesses about the axis of the B_0.
- **Larmor equation (frequency)**

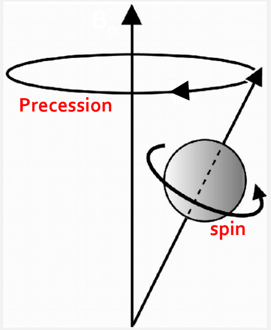
  $\omega_0 = \gamma B_0$

  γ is gyromagnetic ratio (MHz/T)

For B_0 from 1.5T → 3T
ω = 42.6 x 1.5T = 63.9 MHz
= 42.6 x 3.0T = 127.8 MHz

For positive γ , the precession is clockwise.





Spin and Precession

- Wheel rolling: spin
- Gravity: B_0

↓

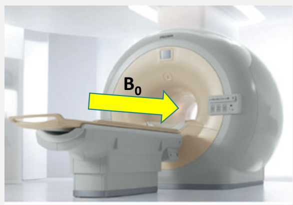
- Spiral precession

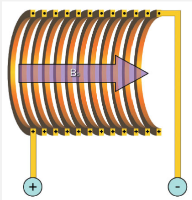
Magritek videos on youtube (6:33)!!

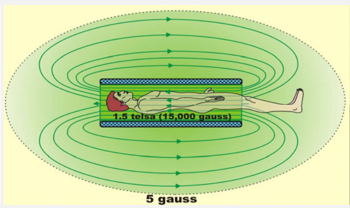
Main Magnet and Magnetic Field B_0

- **Superconducting magnets** (the most common today)
  - operate near absolute zero temperature
  - generate a high B_0 without generating significant heat
  - require cryogens (interior 4°K liquid helium; outer 77°K liquid nitrogen), very expensive !!

1.5T/3.0T/7.0T



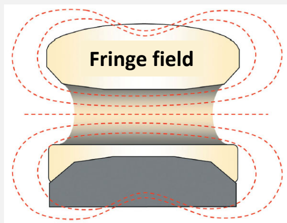


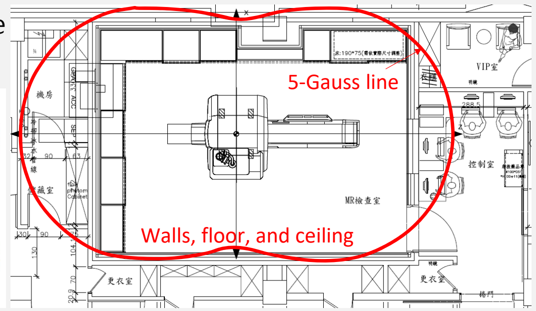


1 Tesla (1T) = 10000 Gauss (0.5 Gauss for earth's magnetic field in average)

Shielding 屏蔽

- **Passive shielding**: scanner room with galvanized steel plates.
- **Active shielding**: additional solenoid electromagnets located around the outside of the main magnet coil.
- **5 Gauss line** – safety zone



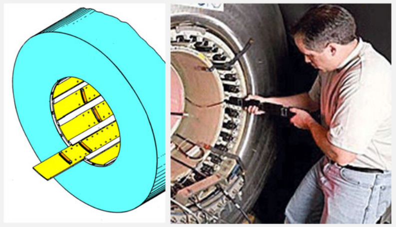


Shimming 補墊

- **Passive shimming**
  - involving the use of ferromagnetic materials, typically iron or steel, placed along the inner bore of the magnet.
- **Active shimming**
  - electromagnetic coils to shim the system for each patient or even each sequence.

Magnetic uniformity should be **<1~5 ppm (parts per million).**

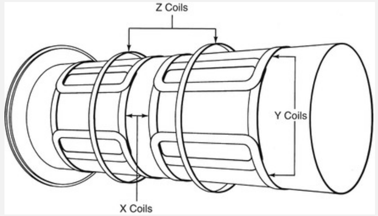
Passive shimming



12-24 sliding trays arranged symmetrically with metallic shims
http://mriquestions.com/passive-shimming.html

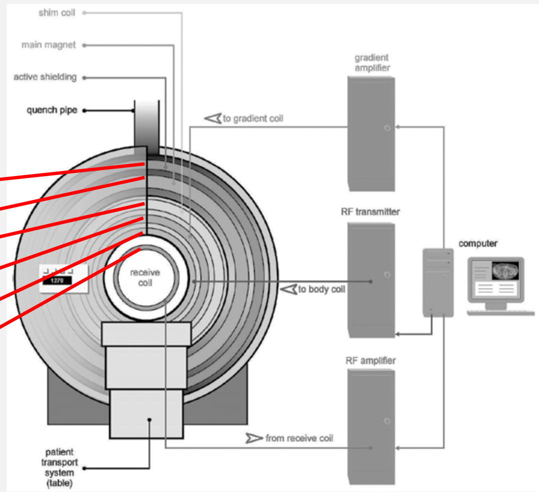
Gradient and Radiofrequency (RF) Coils

- **Transmit/receive RF coils 射頻線圈**
  - A transmitter coil transmits an RF pulse.
  - A receiver coil receives an RF pulse.
- **Gradient coils 梯度線圈**
  - Intentional magnetic perturbation for spatial encoding



MRI Hardware Setup

- Outer → inner
  - Active shielding
  - Main magnet
  - Shim coil
  - Gradient coil
  - Body (transmit) coil
  - Receive coil



磁振影像重建概念

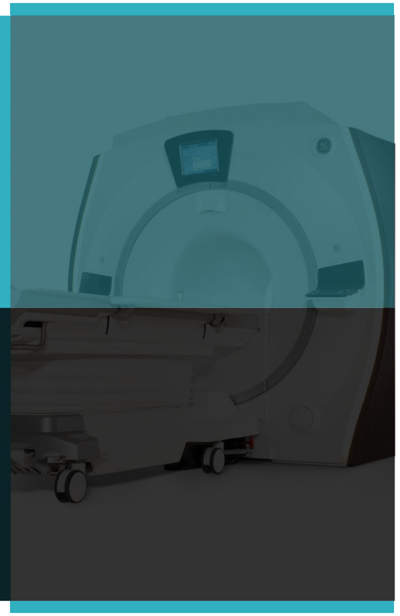
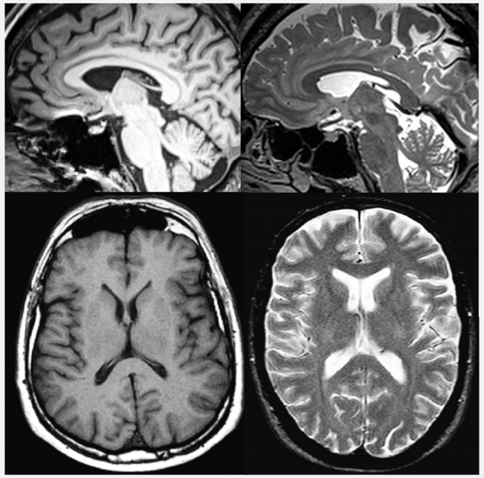


Image and Tissue Contrast

sagittal

T1-weighted (T1W) image

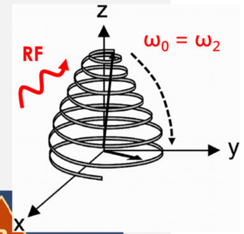


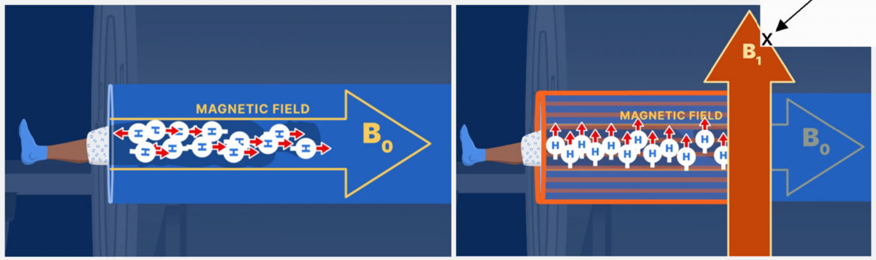
T2-weighted (T2W) image

axial

Excitation by Radiofrequency (RF) Pulse

- The RF pulse (**B_1** field) causes a spiral downward motion of the protons ➔ flipping
- By introducing the B_1, the spinning protons will then be in phase ➔ creates transverse magnetization

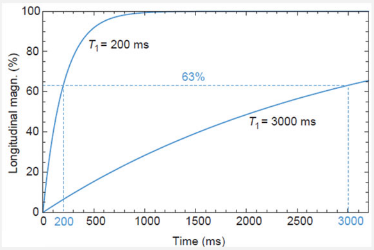




https://www.youtube.com/watch?v=qrR2yoRhAmY

T1 Relaxation

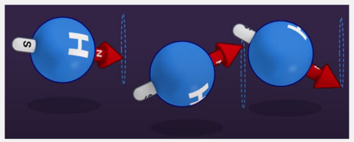
- During relaxation, hydrogen nuclei give up absorbed RF energy and the NMV returns to B_0 direction.
- Recovery of **longitudinal magnetization** (M_z) → T1 recovery
  - **Spin-lattice relaxation**

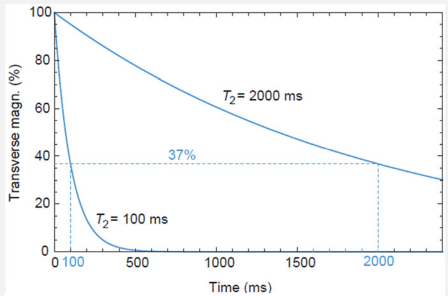


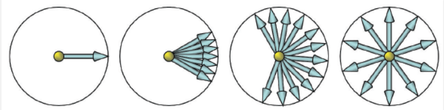
https://www.youtube.com/watch?v=lKp67lqQjH4

T2 Relaxation

- The magnetic moments of hydrogen nuclei lose coherency due to out of phase.
- Decay of **transverse magnetization** (M_{xy}) → T2 decay
  - **Spin-spin relaxation**





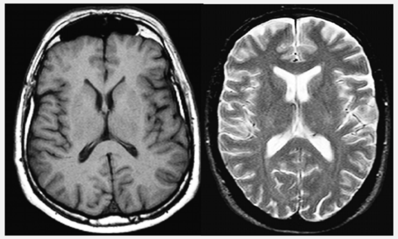


T1 and T2 Characteristics: Brain Tissues

- T1 (longer T1, slower M_z recovery)
  - Cerebrospinal fluid (CSF) > Gray matter (GM) > White matter (WM)
- T2 (longer T2, slower M_{xy} decay)
  - CSF > GM > WM

	T1 (msec)	T2 (msec)	N(H)
White matter	510	67	0.61
Gray matter	760	77	0.69
Edema	900	126	0.86
CSF	2650	180	1.00

1.5T



T1 and T2 Characteristics: Body Tissues

- T1 (longer T1, slower M_z recovery)
  - H_2O > Solid tissue > Fat
- T2 (longer T2, slower M_{xy} decay)
  - H_2O > Fat > Solid tissue

	T1 (msec)	T2 (msec)
Water	4000	2000
Muscle	900	50
Liver	500	40
Fat	250	700

1.5T

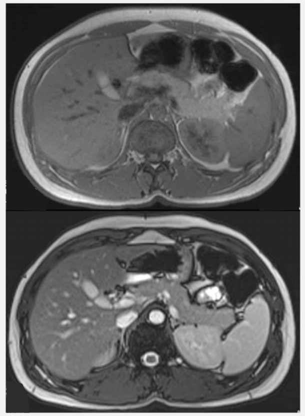
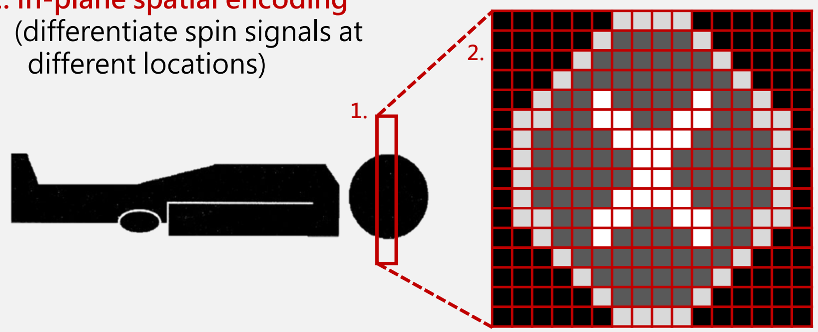


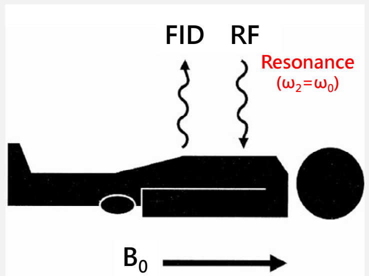
Image Construction

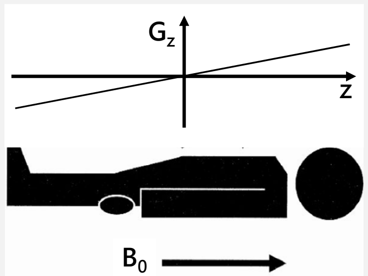
1. Slice selection
   (only excite spins on a specific slice location)
2. In-plane spatial encoding
   (differentiate spin signals at different locations)



How to Selectively Excite a Slice?

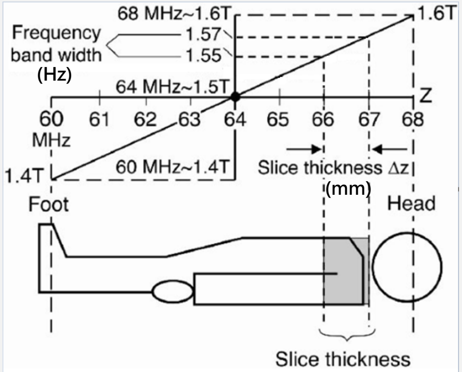
- Create a variation in the field along a specific axis in linearly increasing or decreasing by the gradient coil.





Slice Selection

- We can excite one slice by an RF pulse with a specific frequency range.
- This range of frequencies (bandwidth) determines the **slice thickness**.
- The center frequency determines **the slice location**.

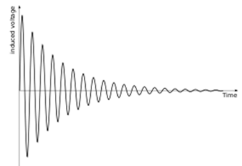


Received Signals

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

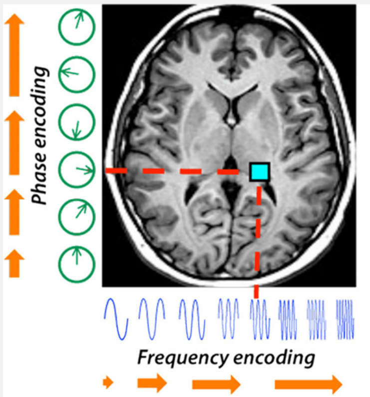
0	**$\cos\omega_0 t$**	**$\cos\omega_0 t$**
$\cos\omega_0 t$	**$2\cos\omega_0 t$**	**0**
$2\cos\omega_0 t$	**0**	**$\cos\omega_0 t$**

→ $8\cos\omega_0 t$



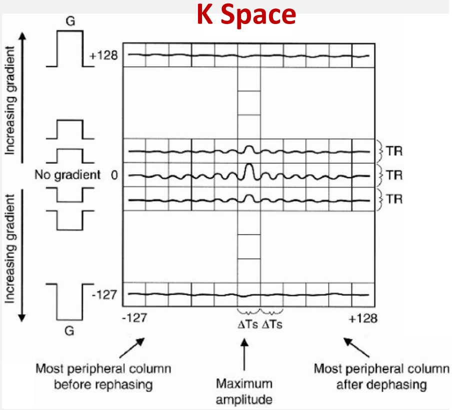
Free Induction Decay (FID)

In-Plane Spatial Encoding



Encoding

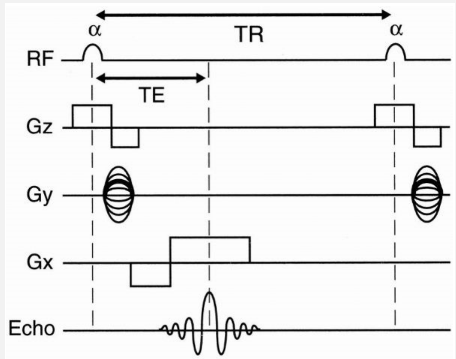
K Space



https://mriquestions.com/how-to-locate-signals.html

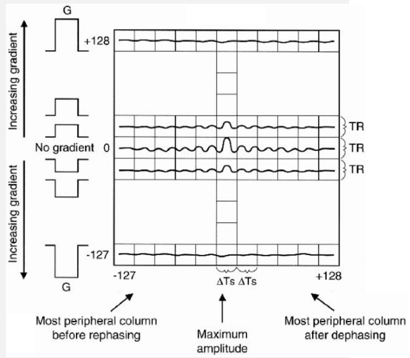
Pulse Sequence Diagram (PSD)

Gradient Echo PSD

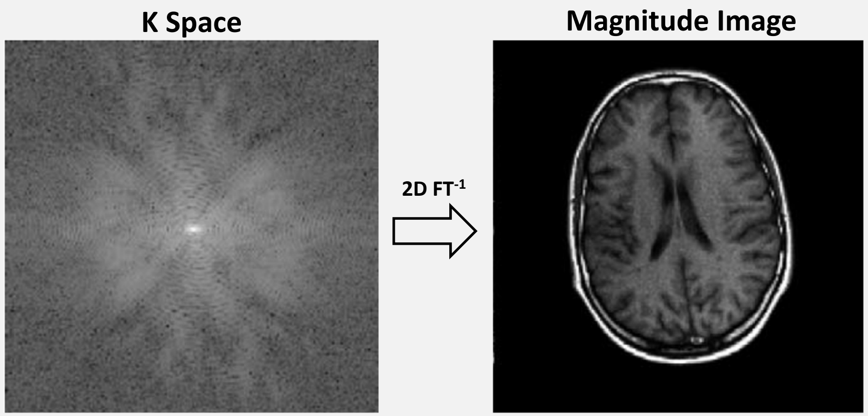


Encoding

K Space



K Space & Inverse Fourier Transform



重點回顧

- 自旋的帶電粒子(例如：氫核)會產生微小的磁場。
- 外加高磁場B_0(1.5~7T)，可產生旋進的靜磁矩(NMV)。
- 給予相同共振頻率的RF脈衝，將能激發靜磁矩至高能狀態。
- 關閉RF脈衝後，物質將會進行T1與T2 relaxation，並據此產生出不同訊號表現。
- 為有效辨識訊號來源位置，需要進行選擇性切面激發、相位編碼與頻率編碼的步驟，取得K space資訊。
- 最終，透過二維反向傳立葉轉換來取得磁振影像。
- 磁振造影設備包含五大重要線圈：屏蔽線圈、主磁體線圈、補墊線圈、梯度線圈、射頻線圈。

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