

# Fundamentals of dc SQUID magnetometer

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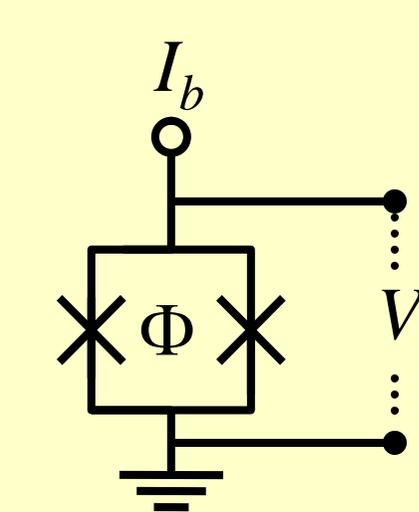
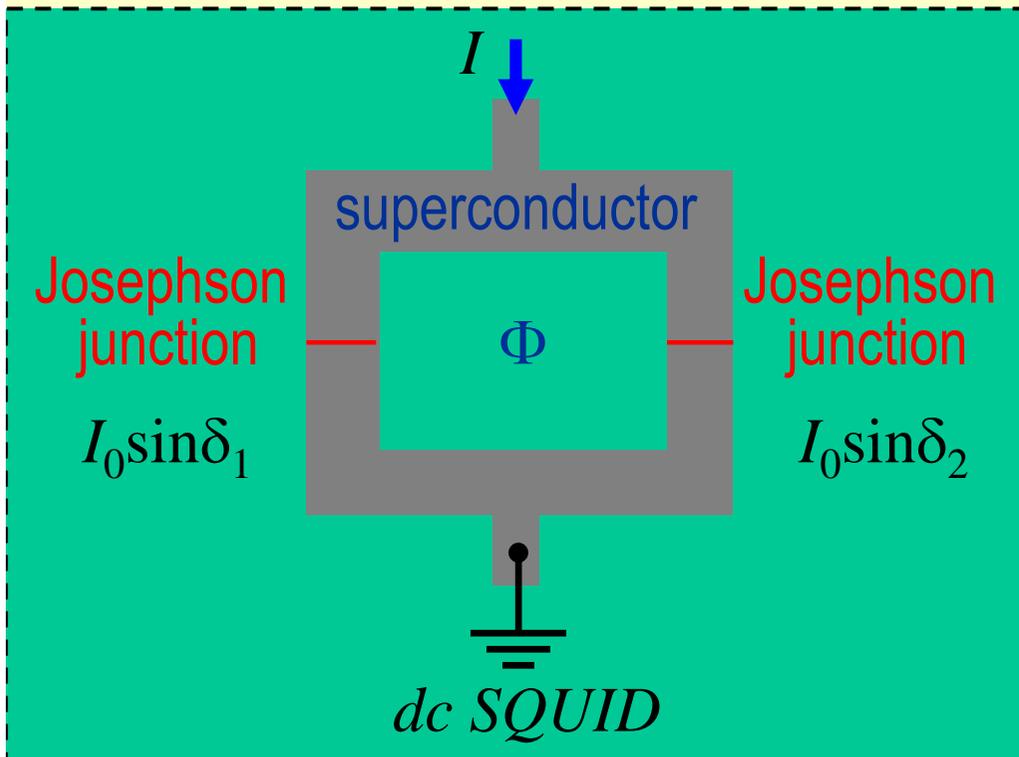
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## References:

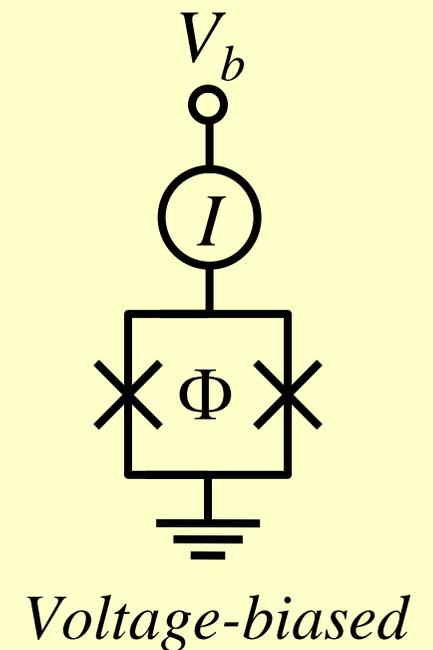
1. *The SQUID Handbook: Vol. I Fundamentals and Technology of SQUIDs and SQUID Systems*, ed. by J. Clarke & A. I. Braginski, Wiley VCH, 2004.
2. *The SQUID Handbook: Vol. II Applications of SQUIDs and SQUID Systems*, ed. by J. Clarke & A. I. Braginski, Wiley VCH, 2004.
3. D. Koelle, R. Kleiner, F. Ludwig, E. Dantsker, and John Clarke, “High-transition-temperature superconducting quantum interference devices”, *Review of Modern Physics*, 71, 631 (1999)

# Introduction

- ◆ The superconducting quantum interference device (SQUID) is the most sensitive detector of magnetic flux with the frequency bandwidth from **dc to over 1 MHz**.
- ◆ The SQUID magnetometers are **linear** flux-to-voltage or flux-to-current transducers.



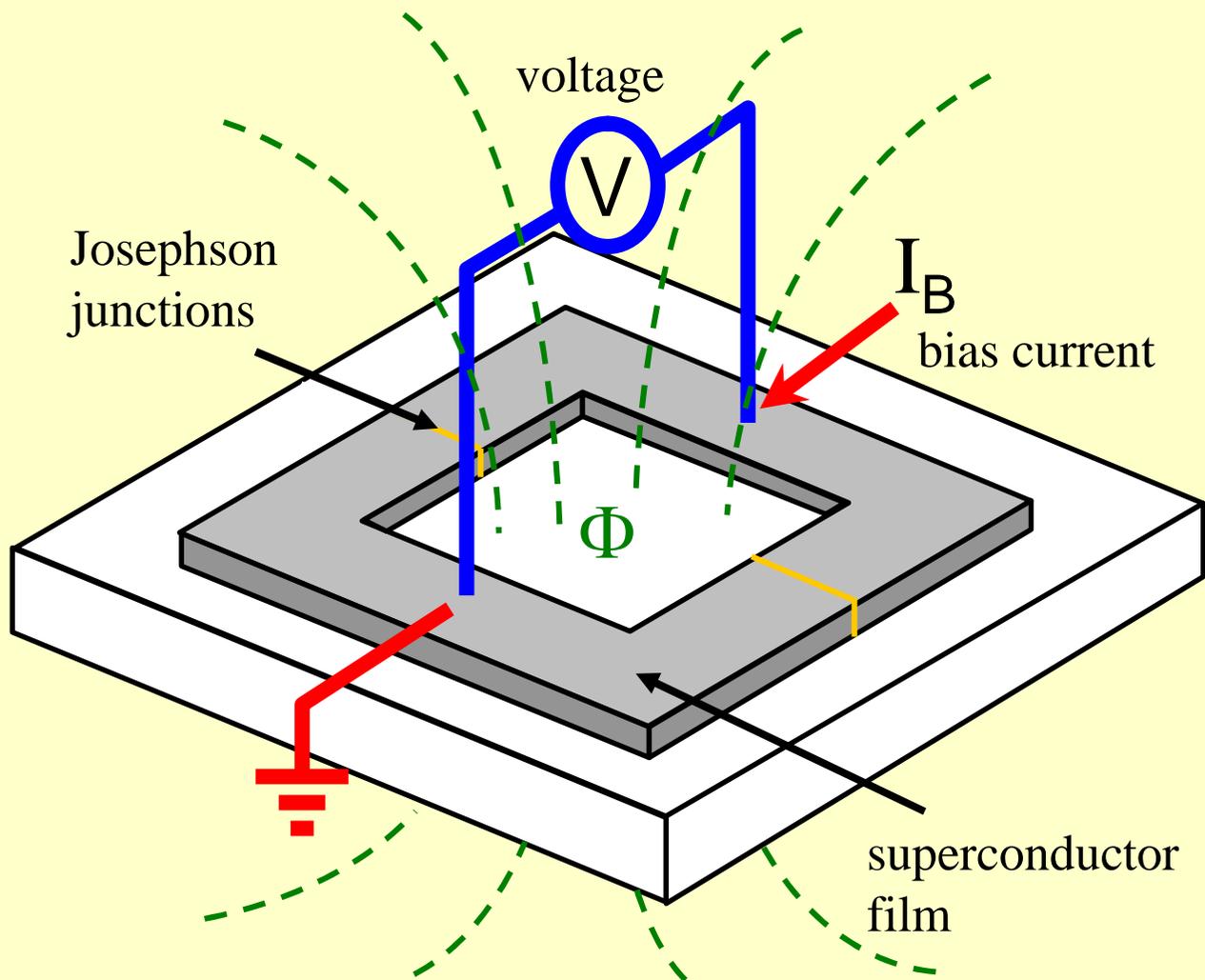
*Current-biased*



*Voltage-biased*



# SQUID = Superconducting QUantum Interference Device



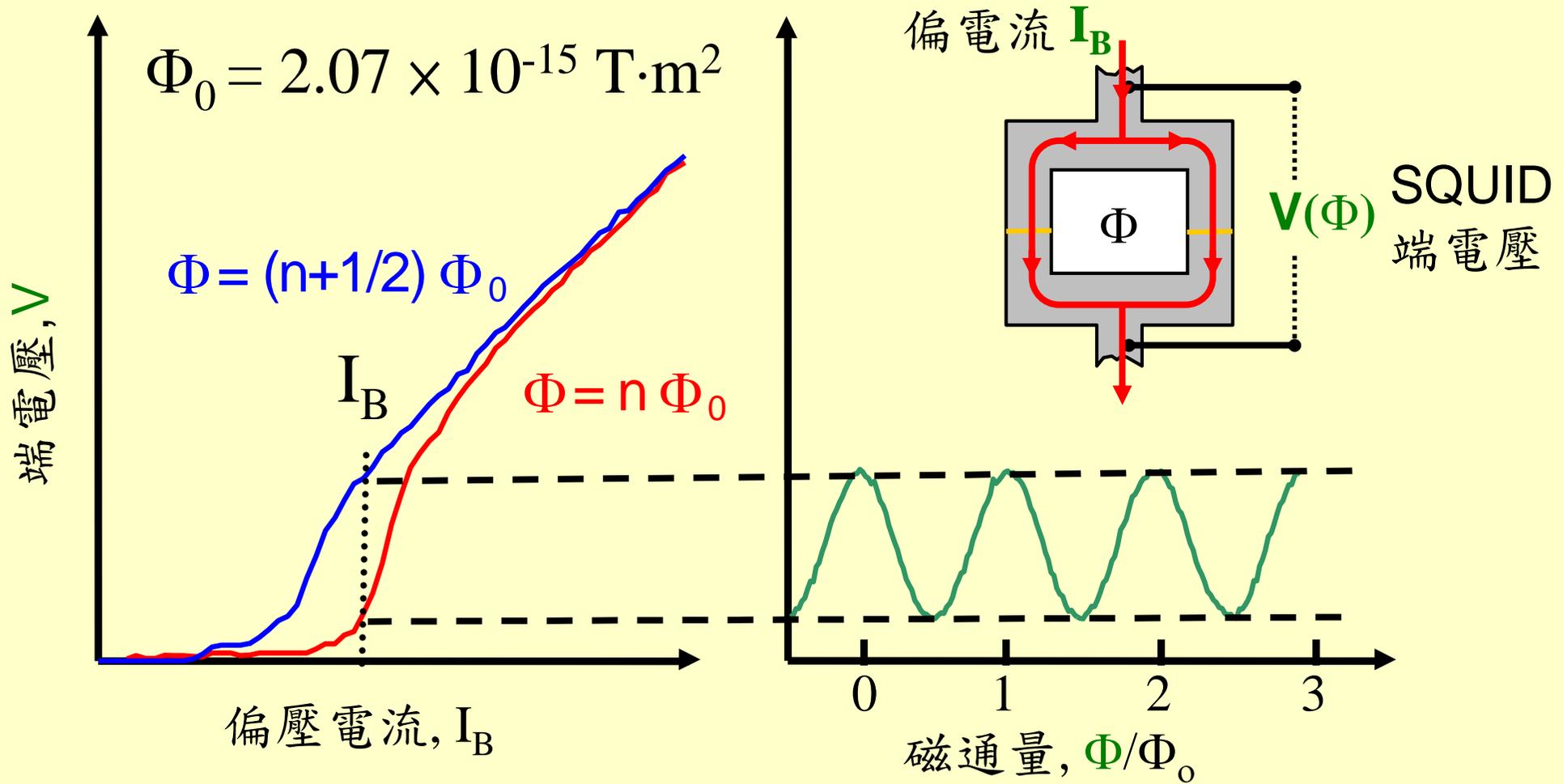
Definition:

$$\text{磁通 } \Phi = BA_{eff}$$

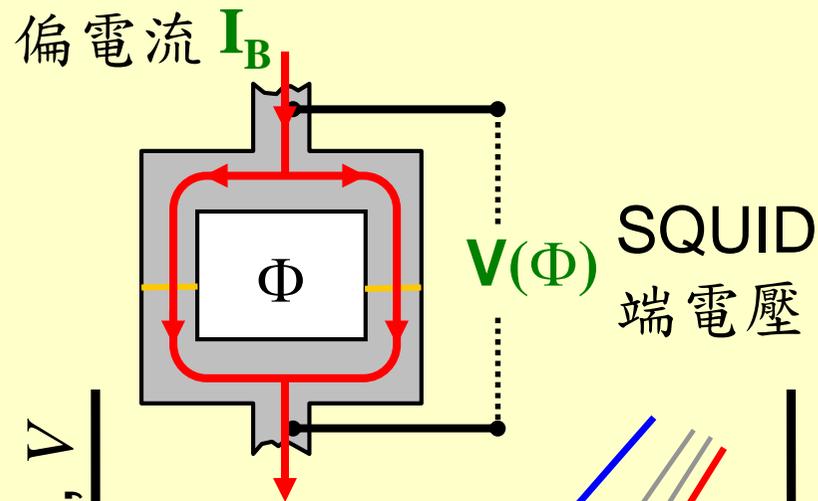
$B$ : magnetic flux density  
(磁通密度, 單位 T)

$A_{eff}$ : 有效面積, 單位  $\text{mm}^2$

# SQUID的端電壓 $V$ 與磁通量 $\Phi$ 之關係



# Transfer coefficient: $V_\Phi$ and $I_\Phi$



$$V_\Phi = \frac{\partial V}{\partial \Phi}$$

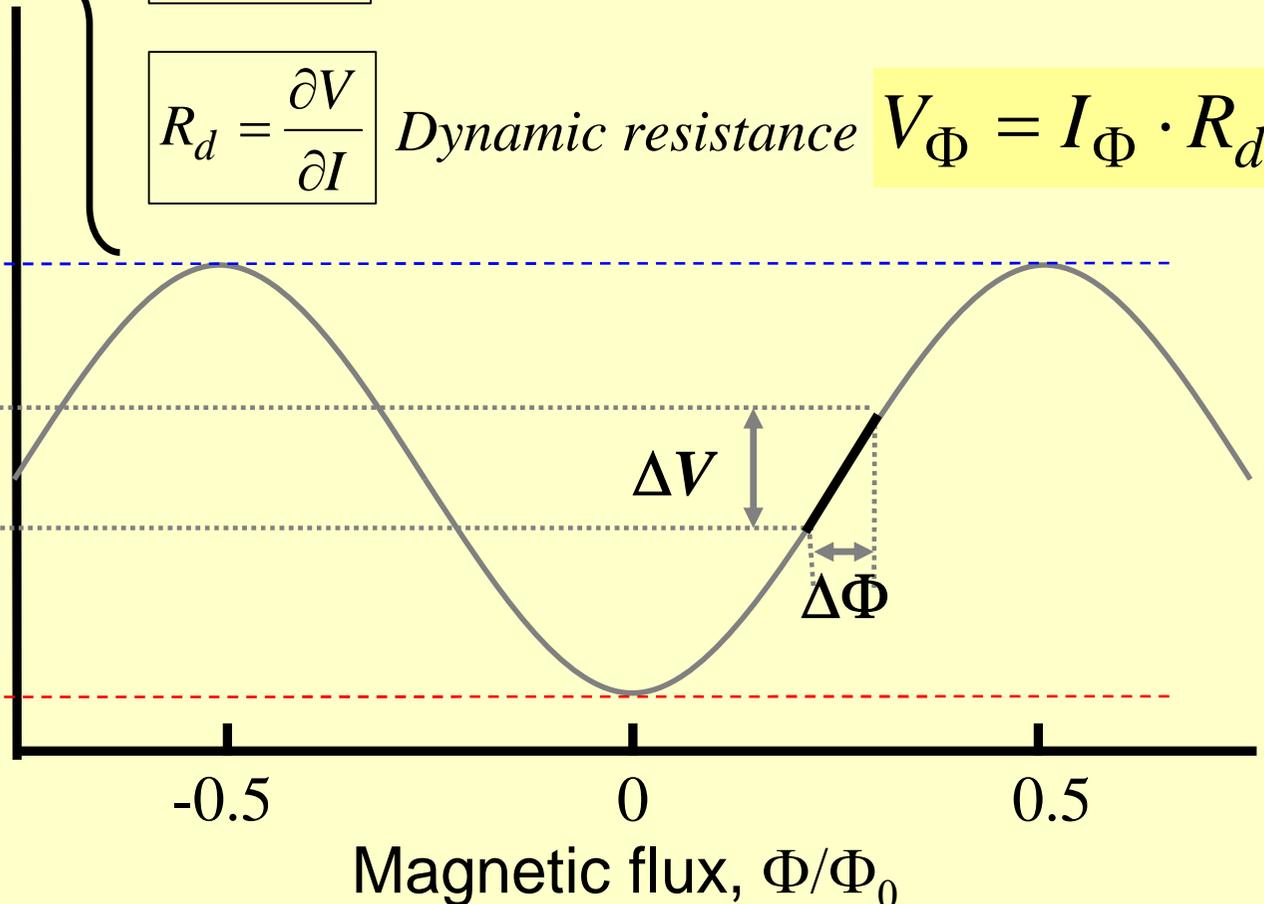
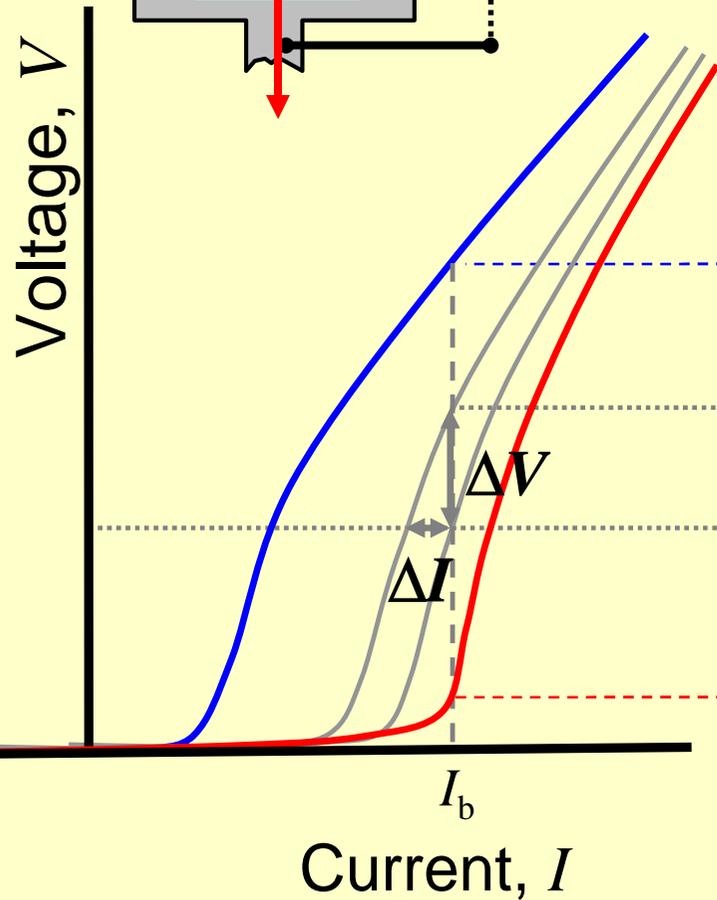
*Flux-to-voltage transfer coefficient*

$$I_\Phi = \frac{\partial I}{\partial \Phi}$$

*Flux-to-current transfer coefficient*

$$R_d = \frac{\partial V}{\partial I}$$

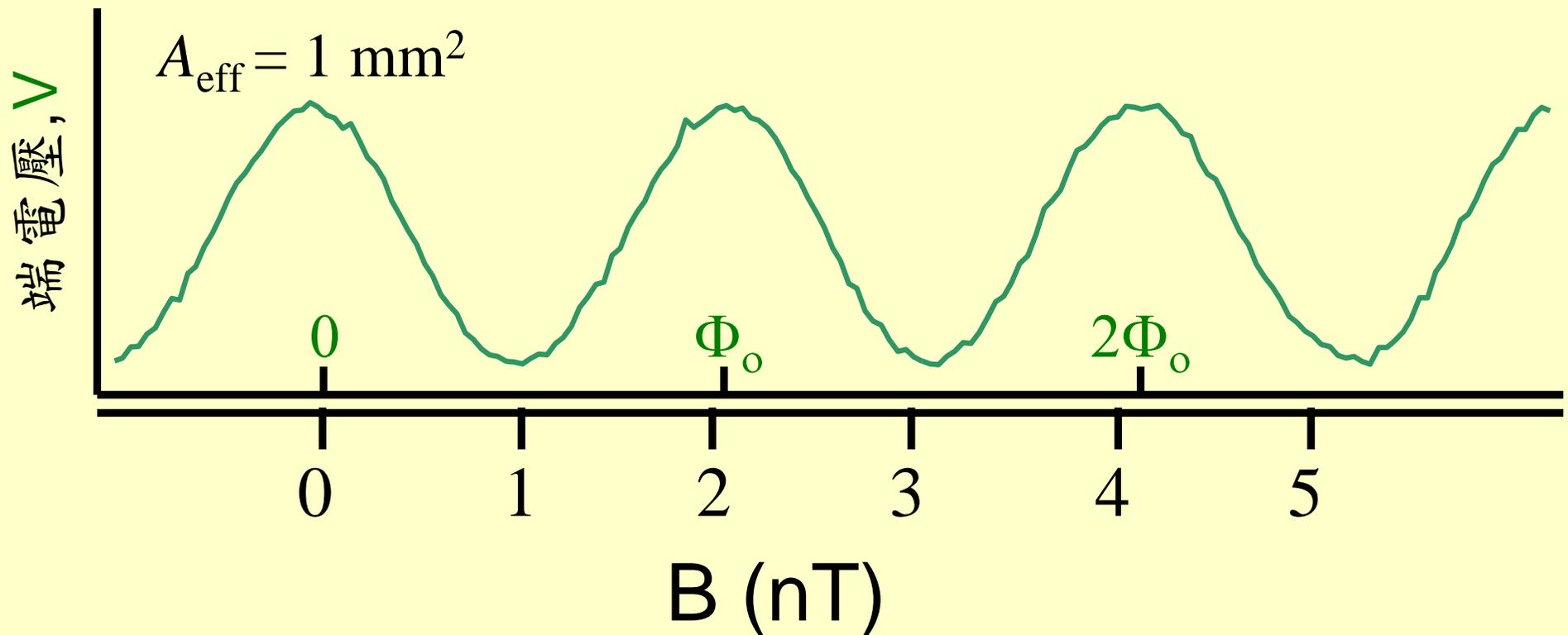
*Dynamic resistance*  $V_\Phi = I_\Phi \cdot R_d$



*Question 1:* The typical effective area of a high- $T_c$  SQUID magnetometer is  $A_{\text{eff}} = 0.2 \text{ mm}^2$ . What's the magnetic flux density required for the device to capture one magnetic flux quantum,  $\Phi_0$ ?

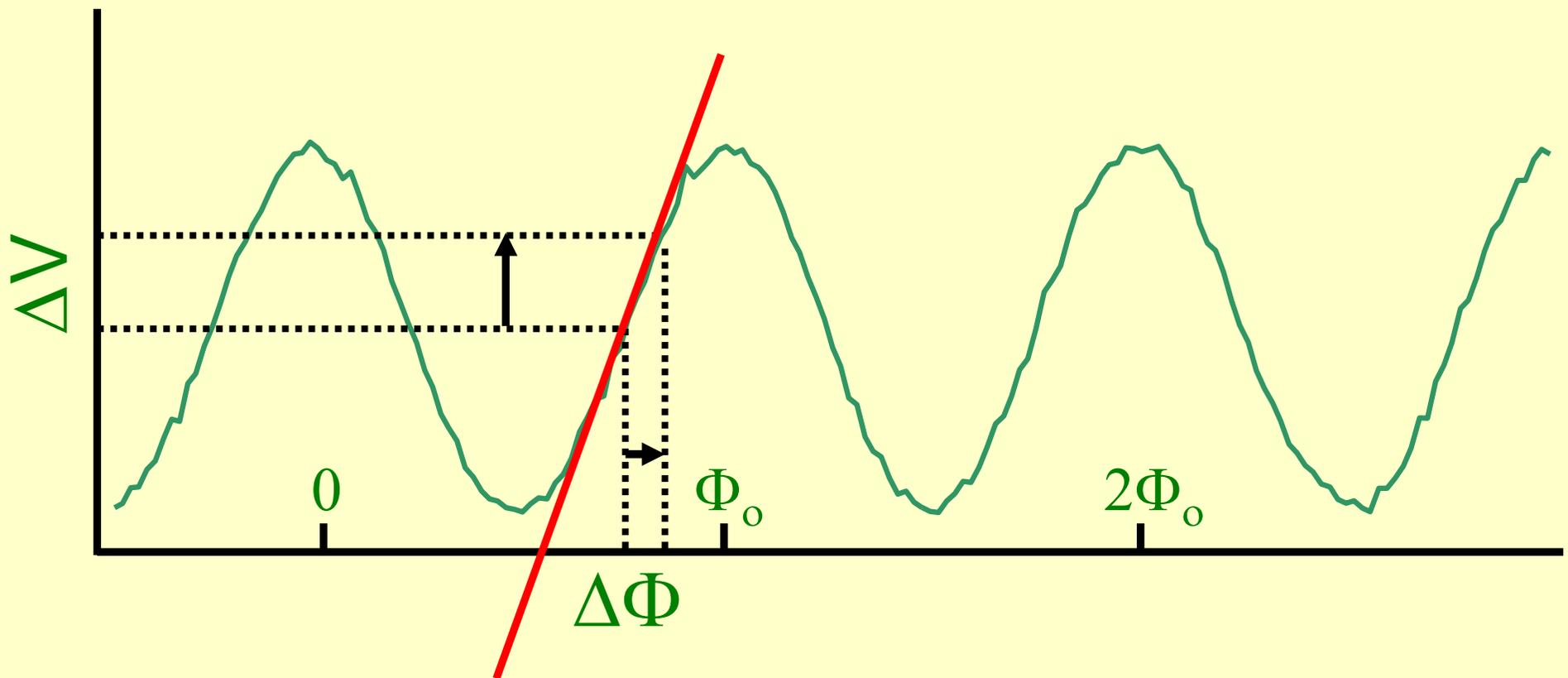
Ans:  $B = \Phi_0 / A_{\text{eff}} = 2.07 \times 10^{-15} / 0.2 \times 10^{-6} = 10 \text{ (nT)}$

$= 0.1 \text{ mG}$

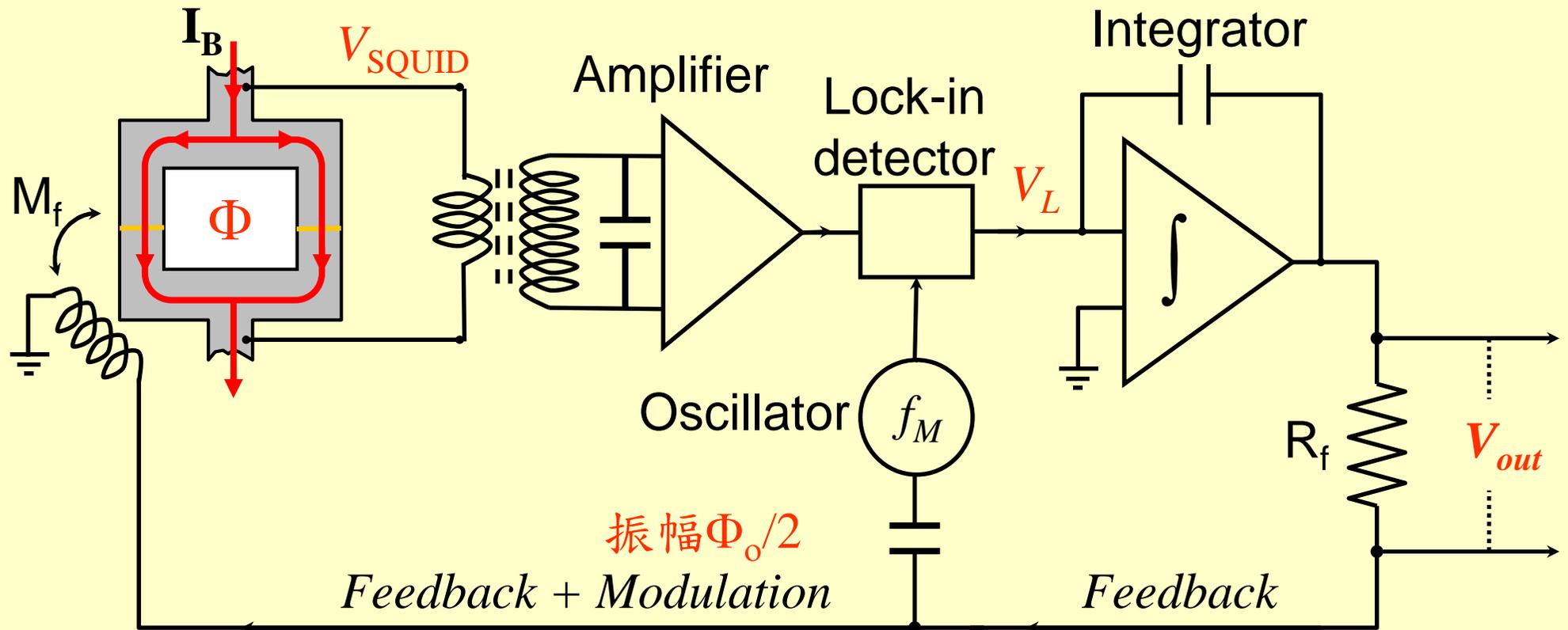


*Question 2:* As voltage across a SQUID is a periodic function of the applied magnetic flux, is it possible to measure more than one magnetic flux quantum,  $\Phi_0$ , by using this device?

Ans: 利用“負回饋”電路，使SQUID內的磁通量維持不變，則回饋的磁通量即為測得之磁通量



# SQUID之磁通鎖定電路(flux-locked loop)



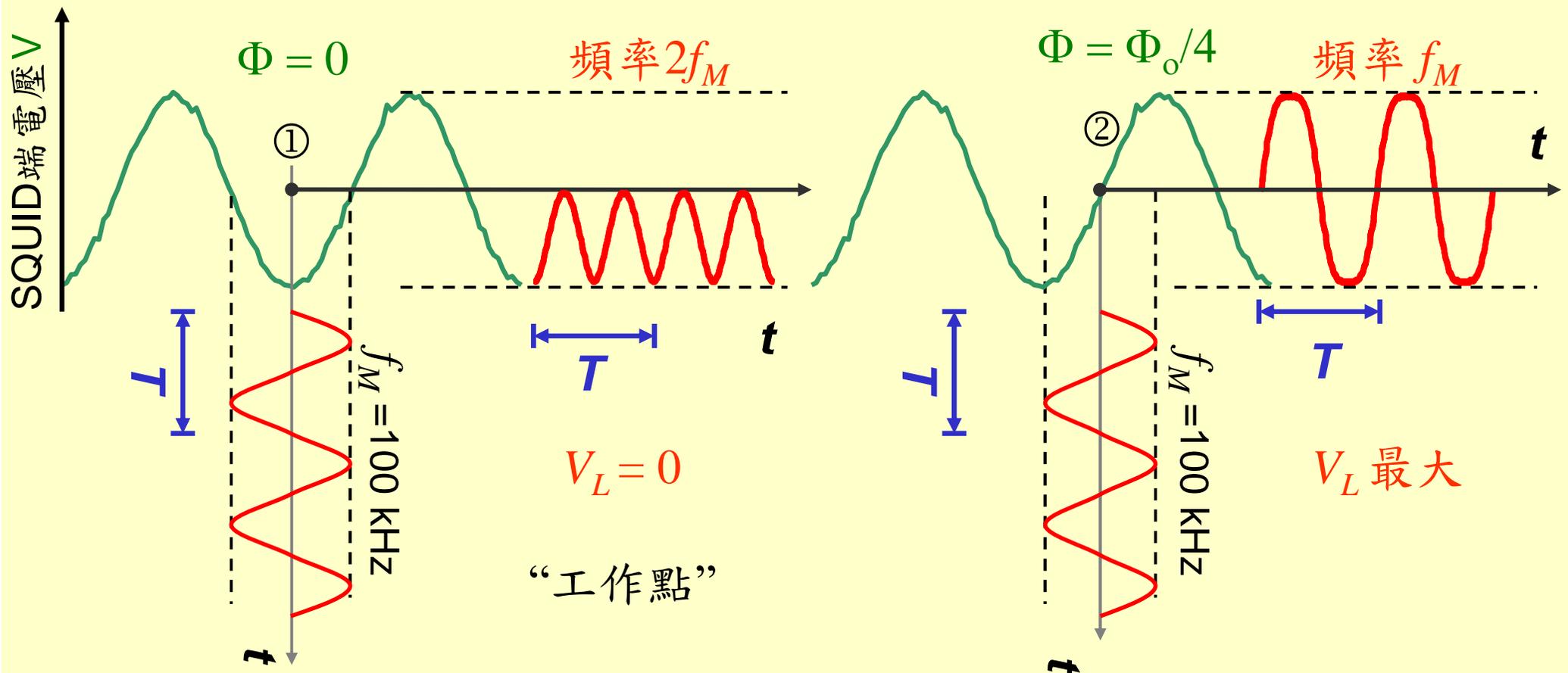
➔ 輸出電壓  $V_{out}$  與磁通量  $\Phi$  的函數關係： $V_{out} = (R_f/M_f) \Phi$

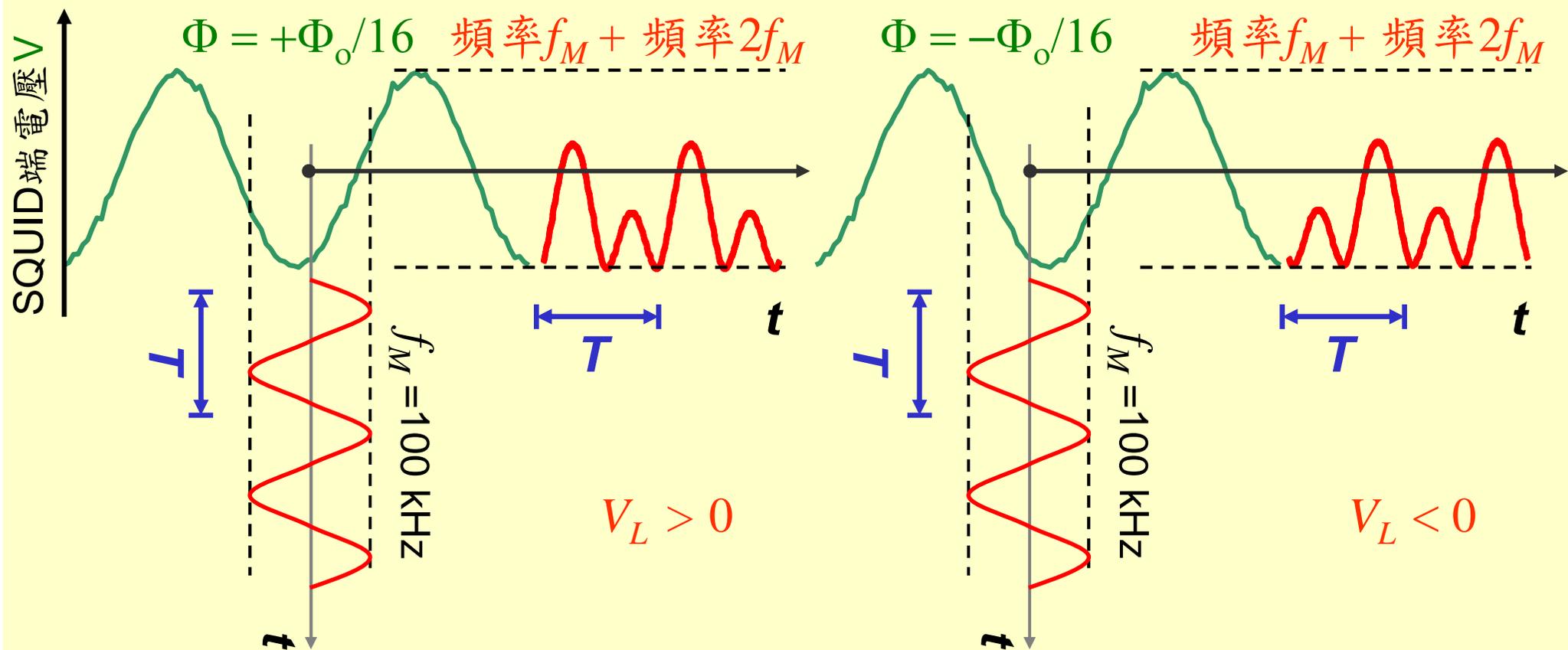
### Question 3: What's the flux modulation technique?

Ans: 在頻率  $f_M = 100 \text{ kHz}$  的 modulation 磁場下, 當 SQUID 的 dc 磁通值為:

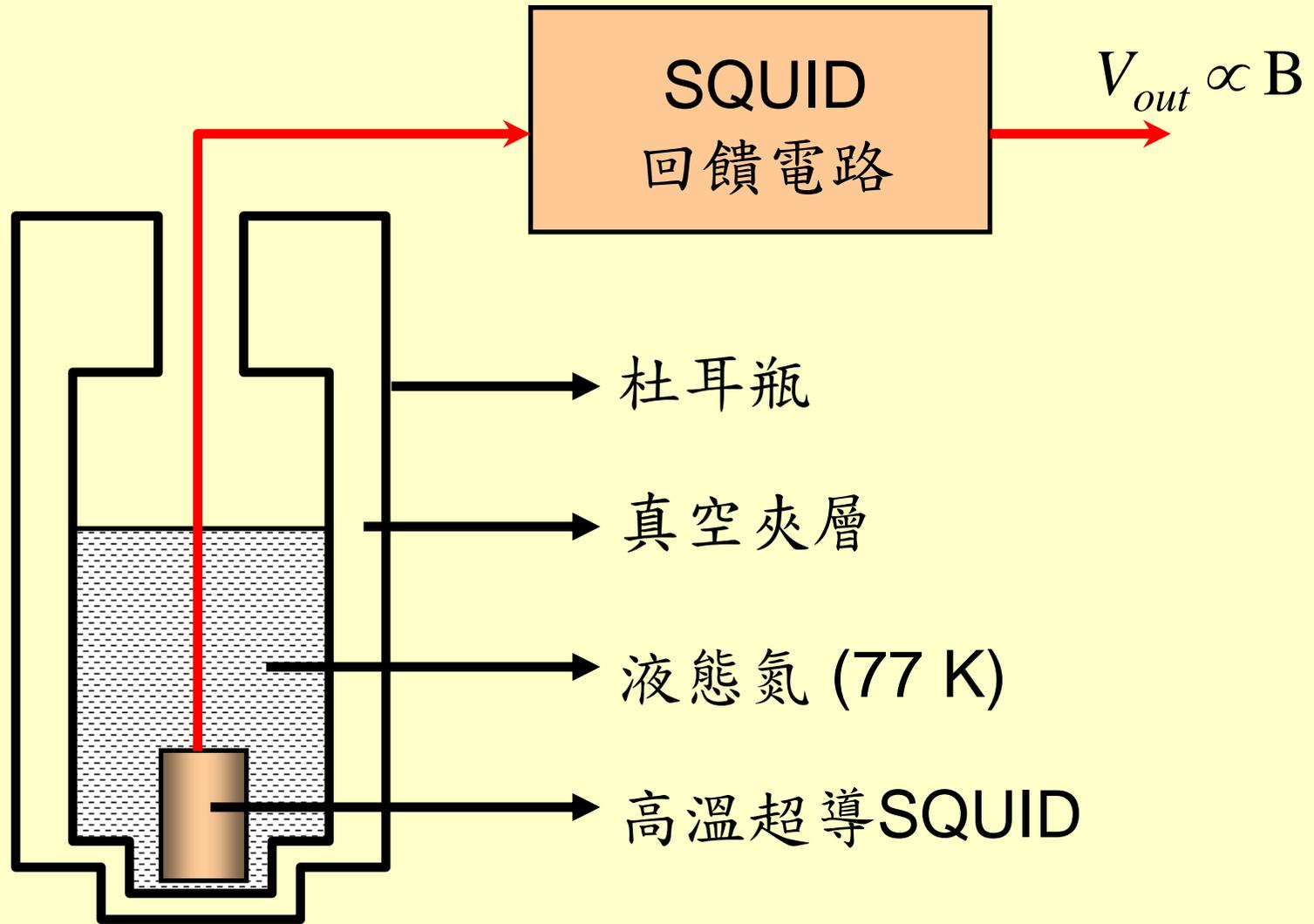
$\Phi = 0$ , 即 ①  $\rightarrow V_{\text{SQUID}}$  波形的頻率為  $2f_M$ , 在頻率  $f_M$  的分量  $V_L = 0$

$\Phi = \Phi_0/4$ , 即 ②  $\rightarrow V_{\text{SQUID}}$  波形在頻率  $f_M$  的分量  $V_L$  為最大

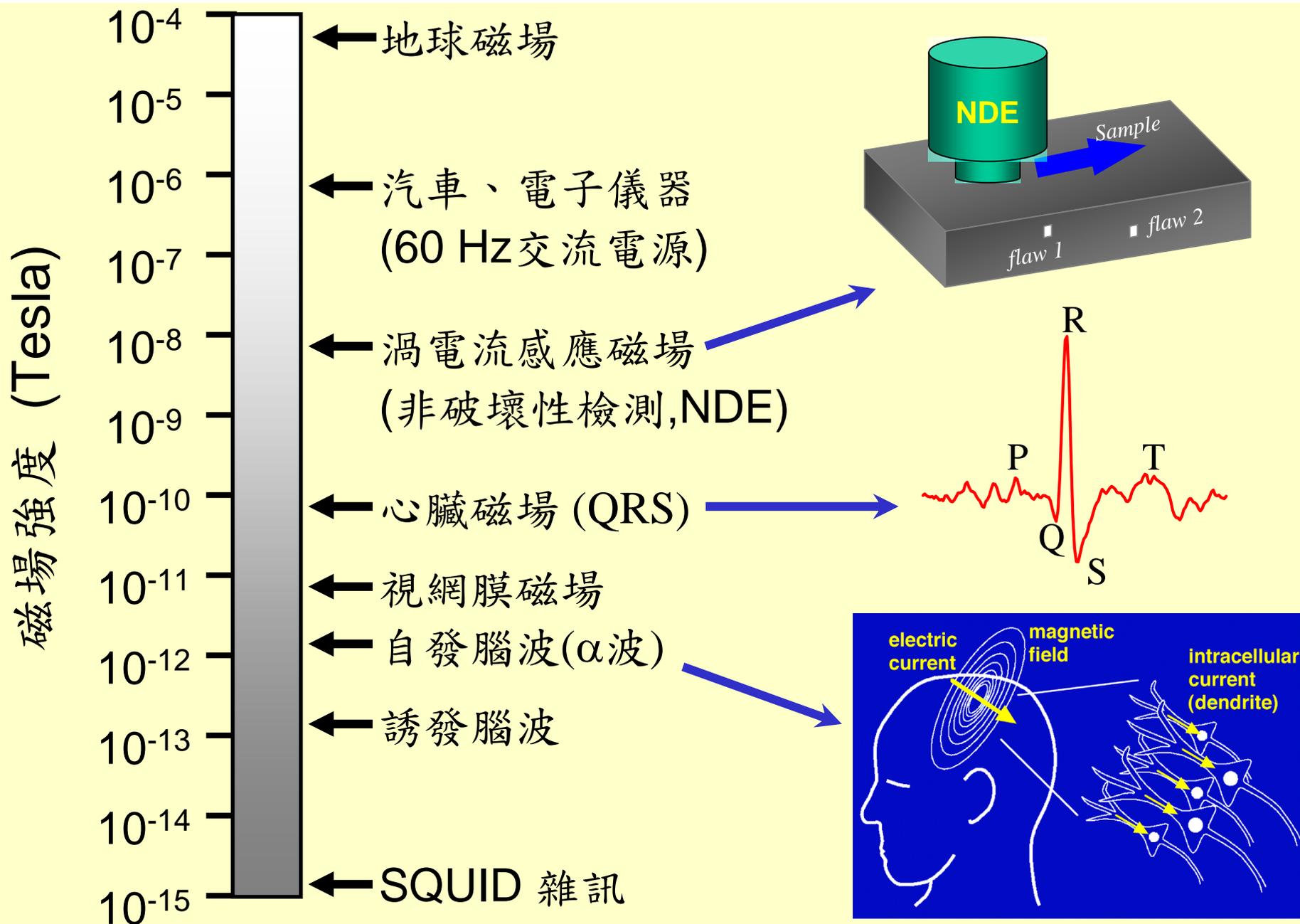




# 高溫超導SQUID磁場測量系統

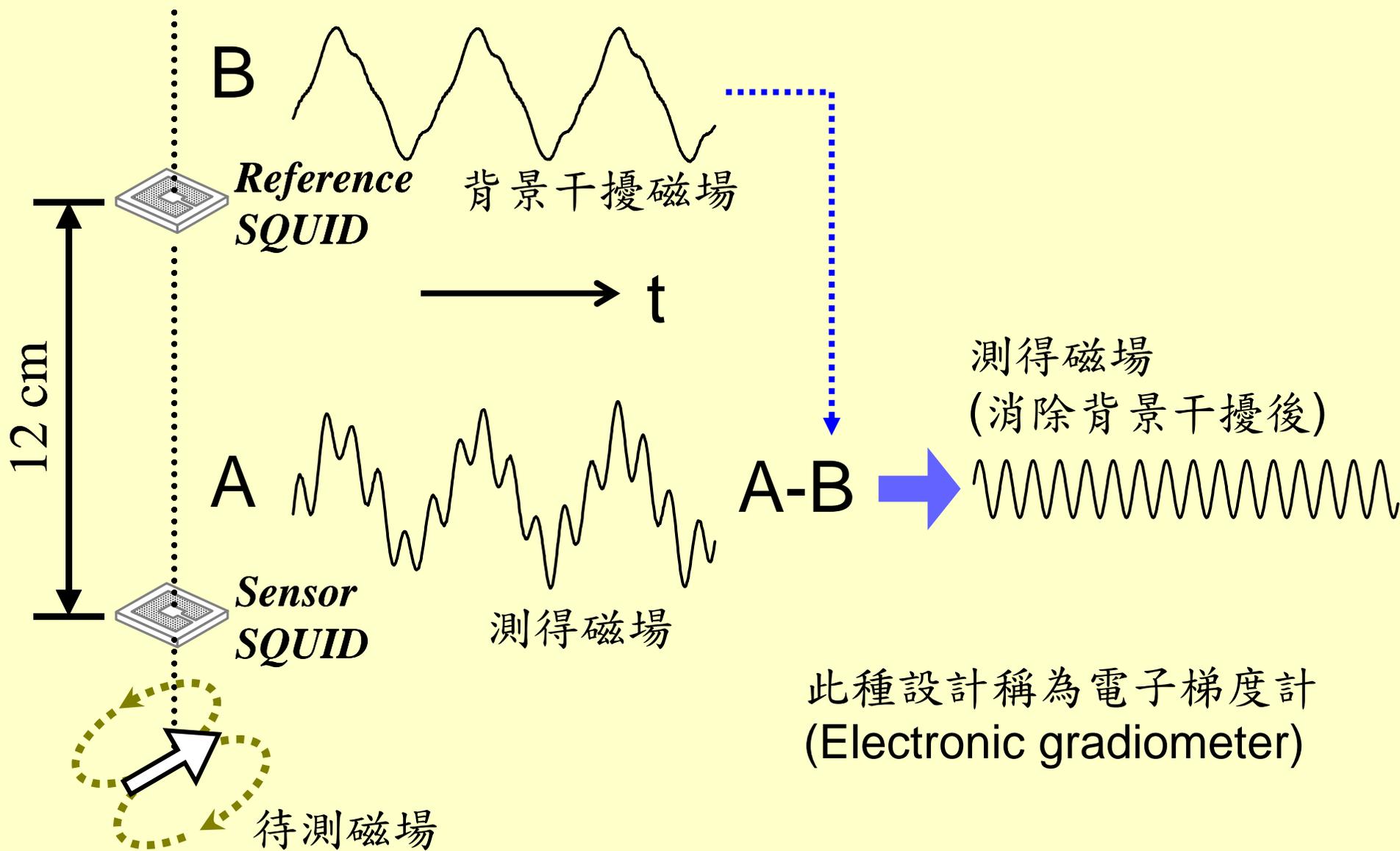


# SQUID之測量能力



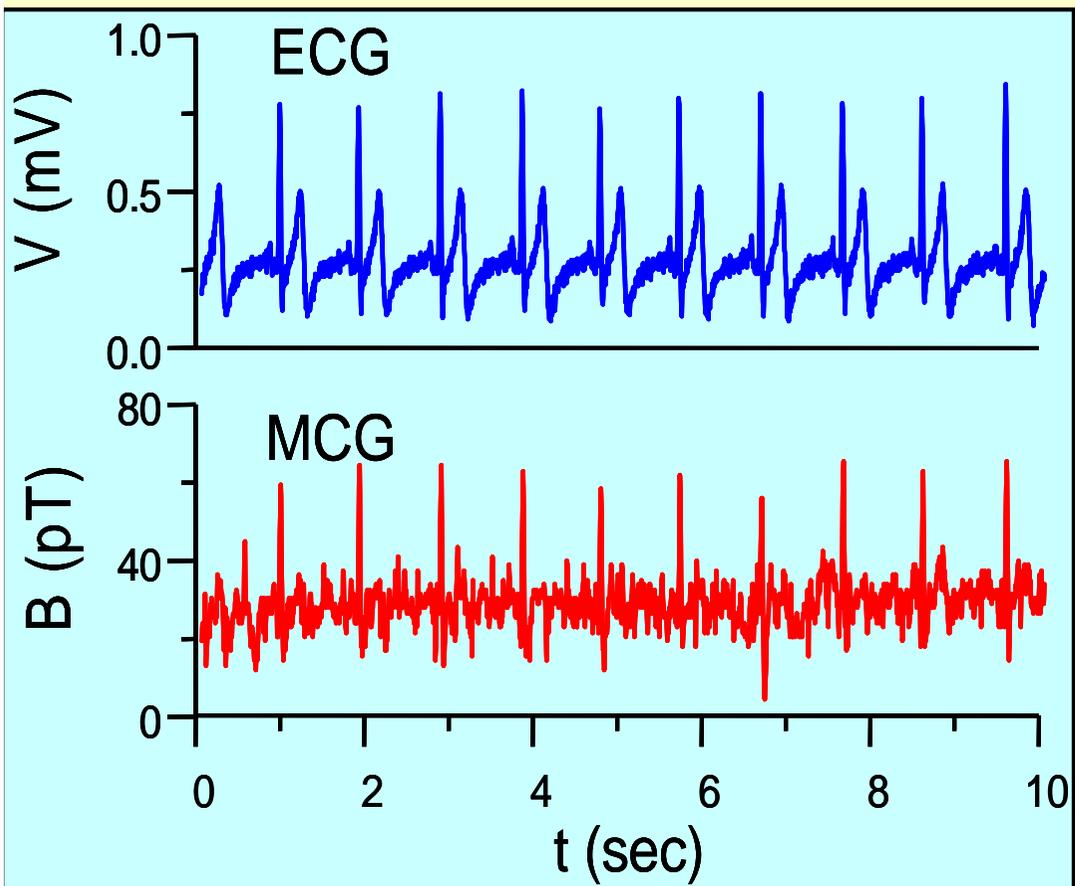
# Question 4: How to eliminate the environmental disturbance?

Ans: (1) 電子式梯度計 (electronic gradiometer)

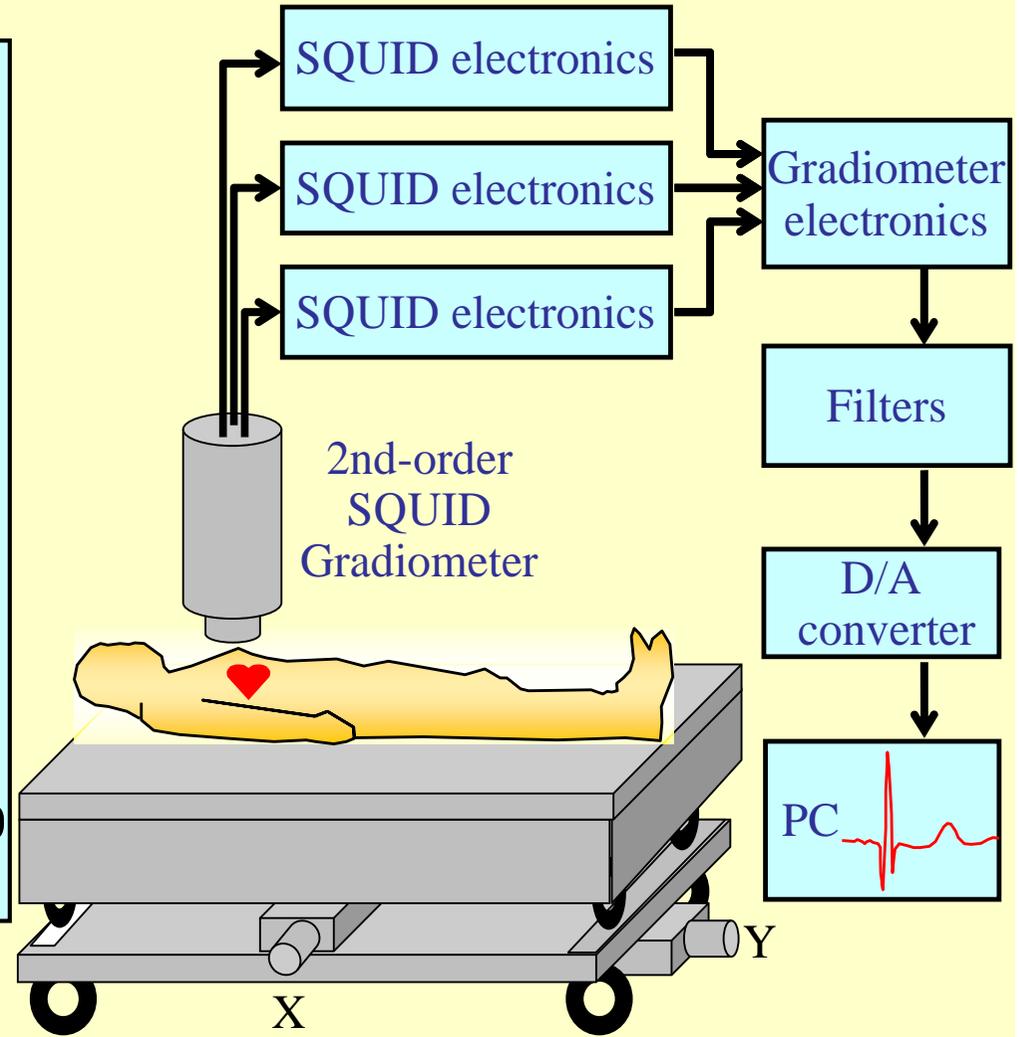


此種設計稱為電子梯度計 (Electronic gradiometer)

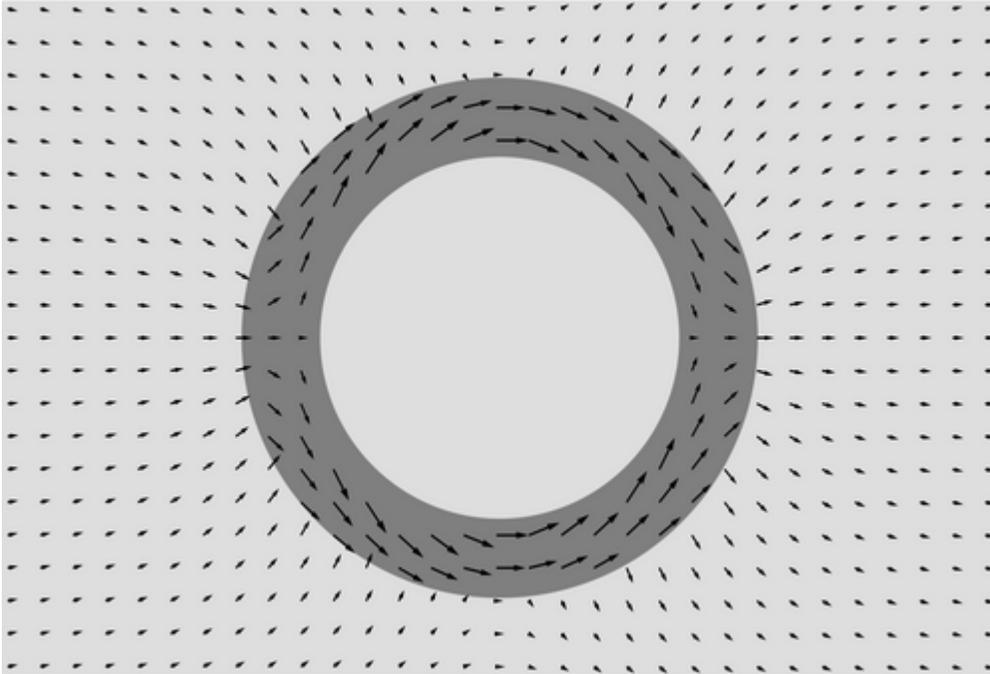
# Magnetocardiogram (MCG, 心磁圖) in an unshielded environment



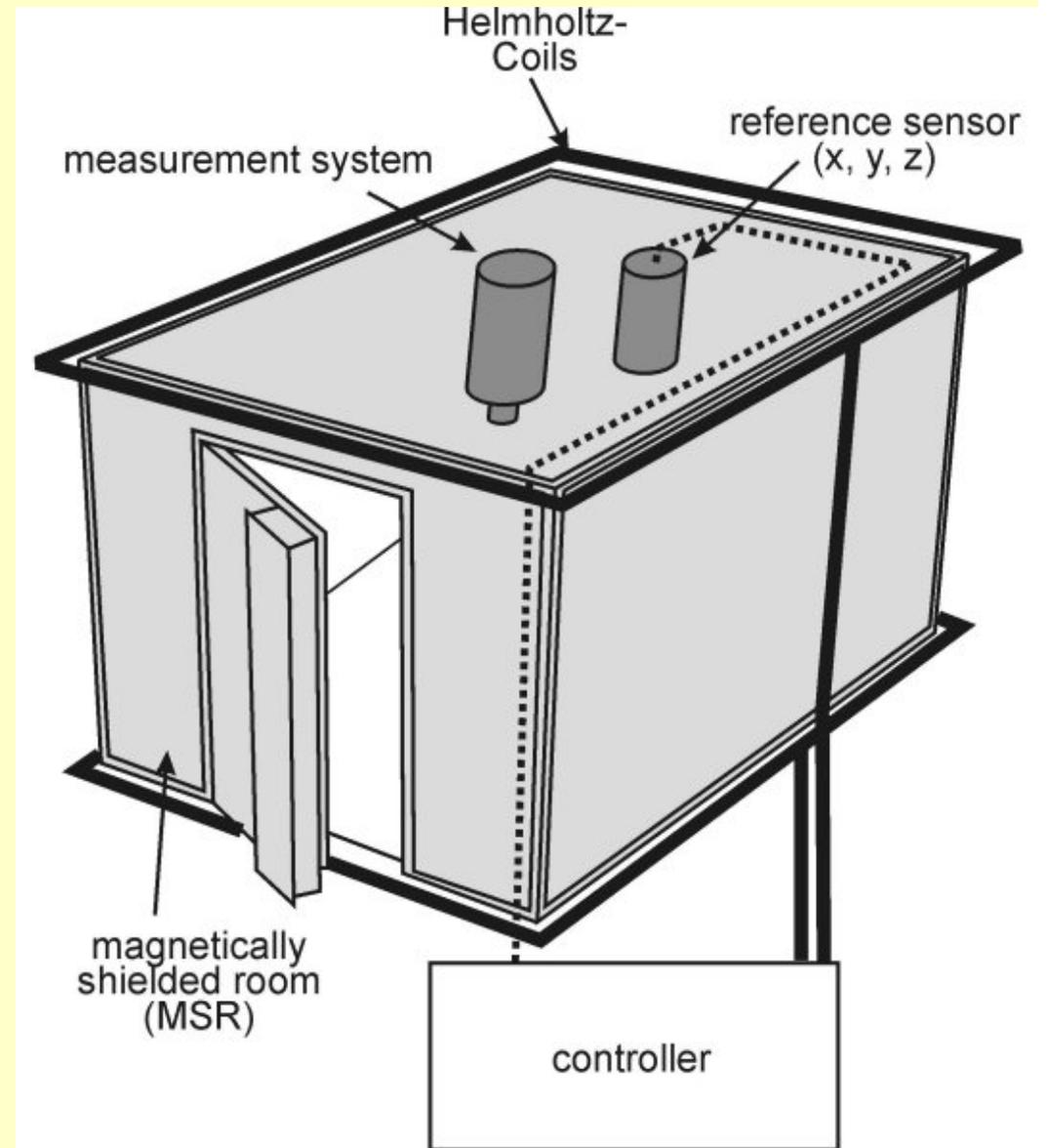
IEEE Tran. Appl. Supercond. 13, 360 (2003)



## (2) 磁屏蔽 (magnetic shielding)

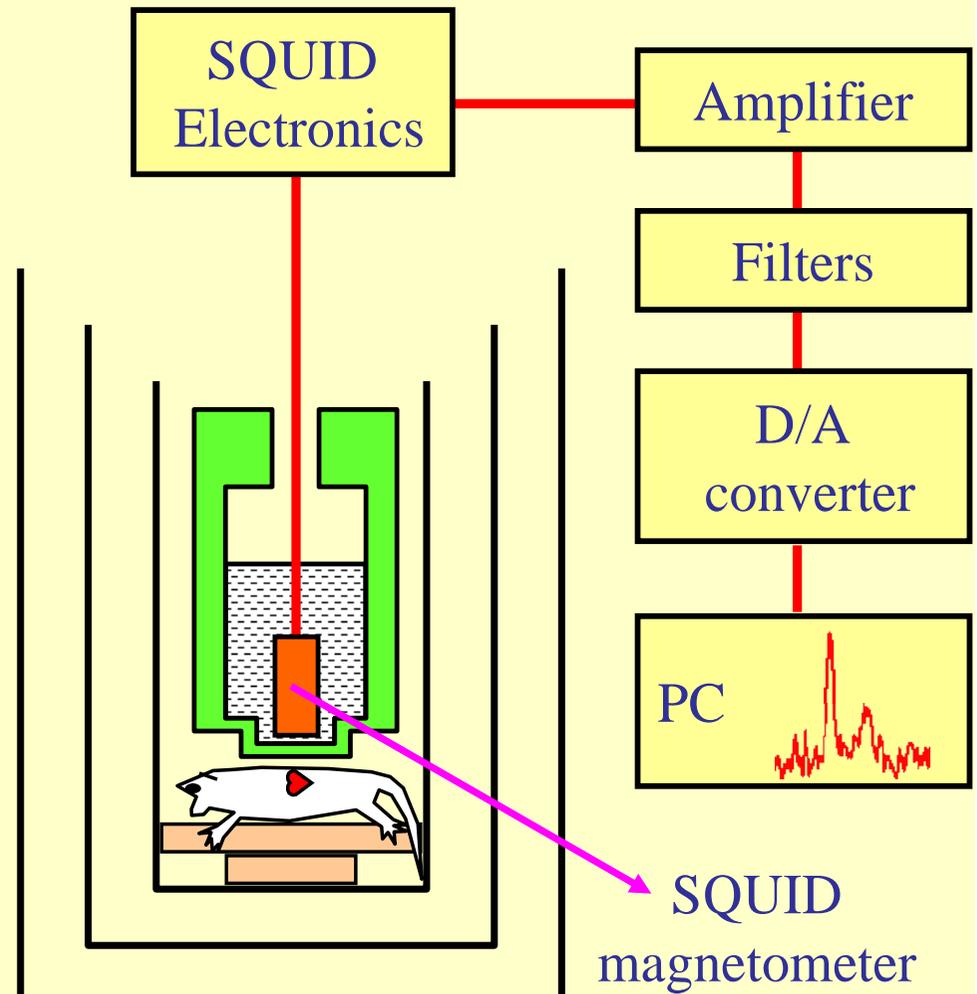
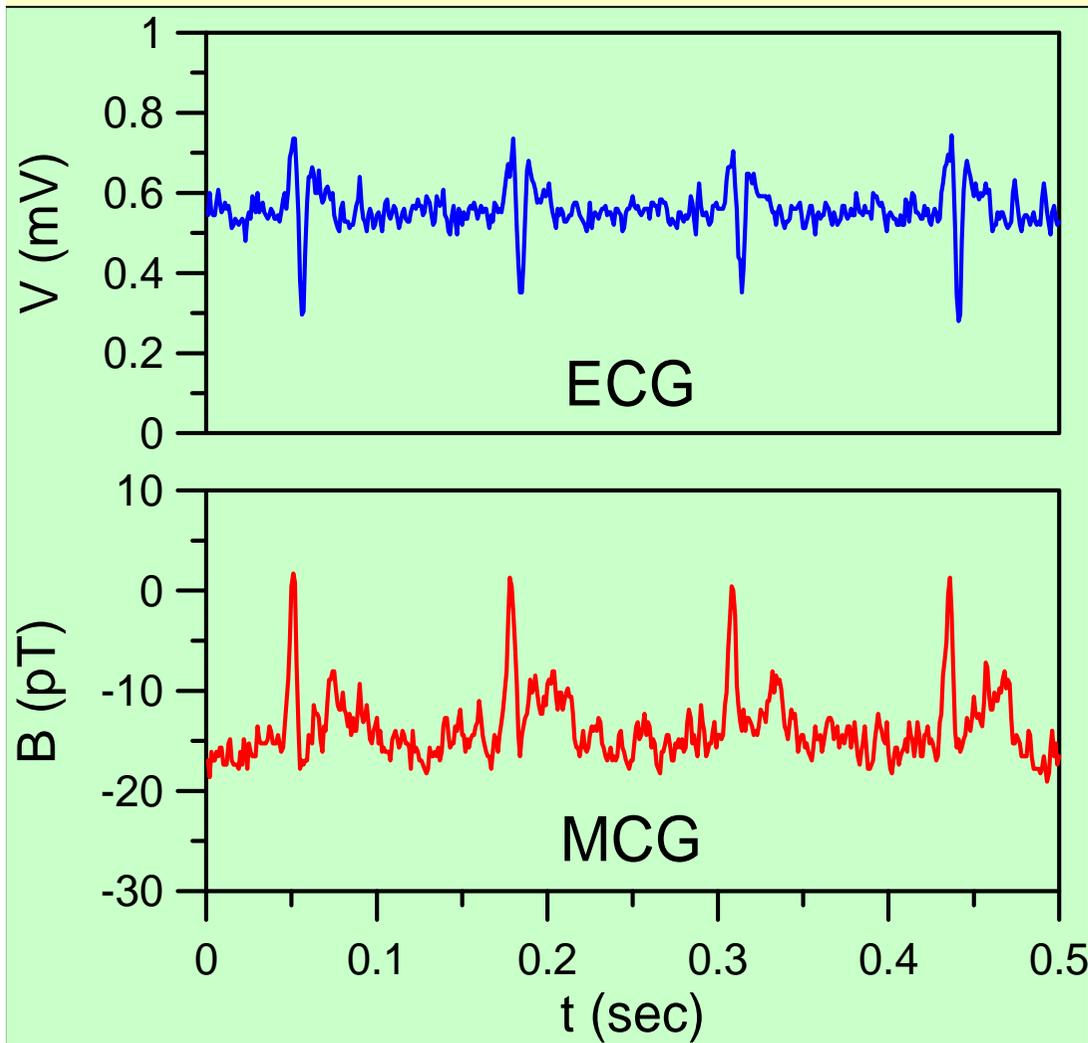


<http://www.lightandmatter.com>



<http://www.biomag.uni-jena.de>

# MCG & ECG of a rat's heart (in a shielded environment)



*IEEE Tran. Appl. Supercond. 13, 381 (2003)*

# 主動式磁屏蔽(Active Magnetic Shielding)

