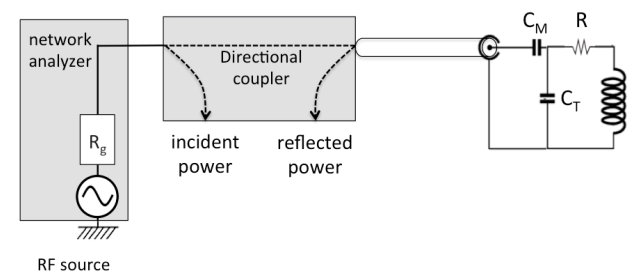
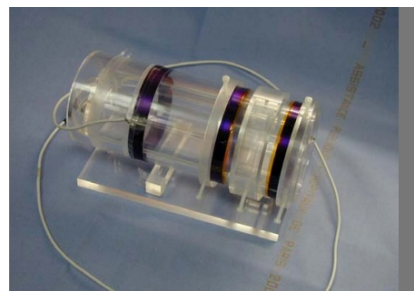
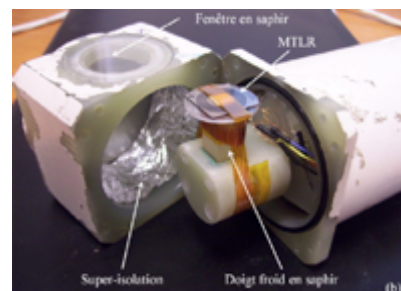
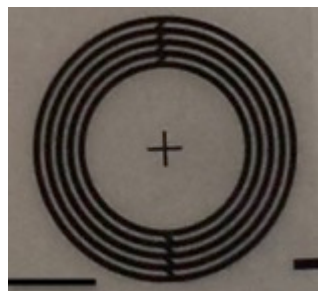




# Le kit des antennes RF en IRM



Marie Poirier-Quinot



# Objectif

- Connaître et comprendre les mécanismes d'émission et détection mis en jeu en RMN
- Les propriétés des antennes RF
- Les différents types d'antennes rencontrés en IMR
- Savoir laquelle est la mieux adaptée à nos expérimentations
- Savoir comment développer et caractériser une antenne ... simple

**rajouter un point sur le SAR**

# Literature

- Mispelter, J., Lupu, M. & Briguet, A. NMR Probeheads *for biophysical and biomedical experiments*; Imperial College Press (2006)
- Bart van de Bank – MR Hardware RF Coils

# Objectif

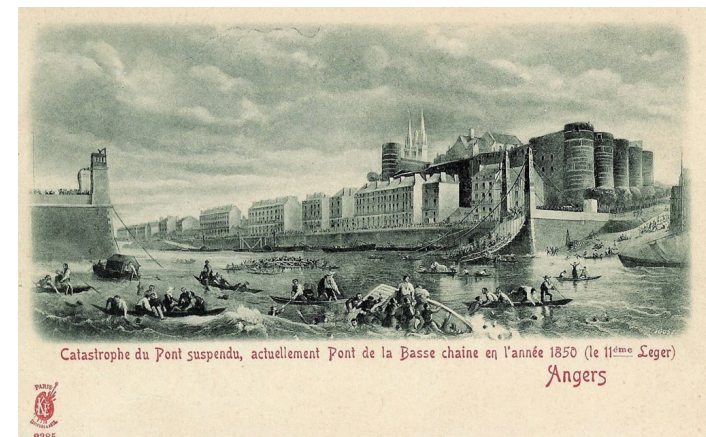
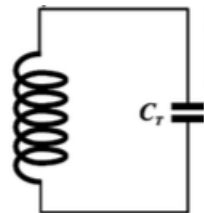
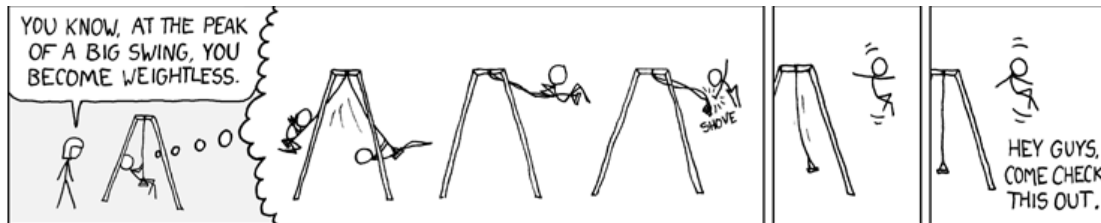
- Un peu de Physique Physics (only a few)
  - Résonance
  - Larmor
  - Principes
  - B1 field
  - Limitations
- Antennes RF, conception et mesures de leurs caractéristiques RF
- Différents types d'antennes RF

# Phénomène de résonance

Particularité d'un système de pouvoir emmagasiner temporairement de l'énergie :

- potentielle
- Cinétique

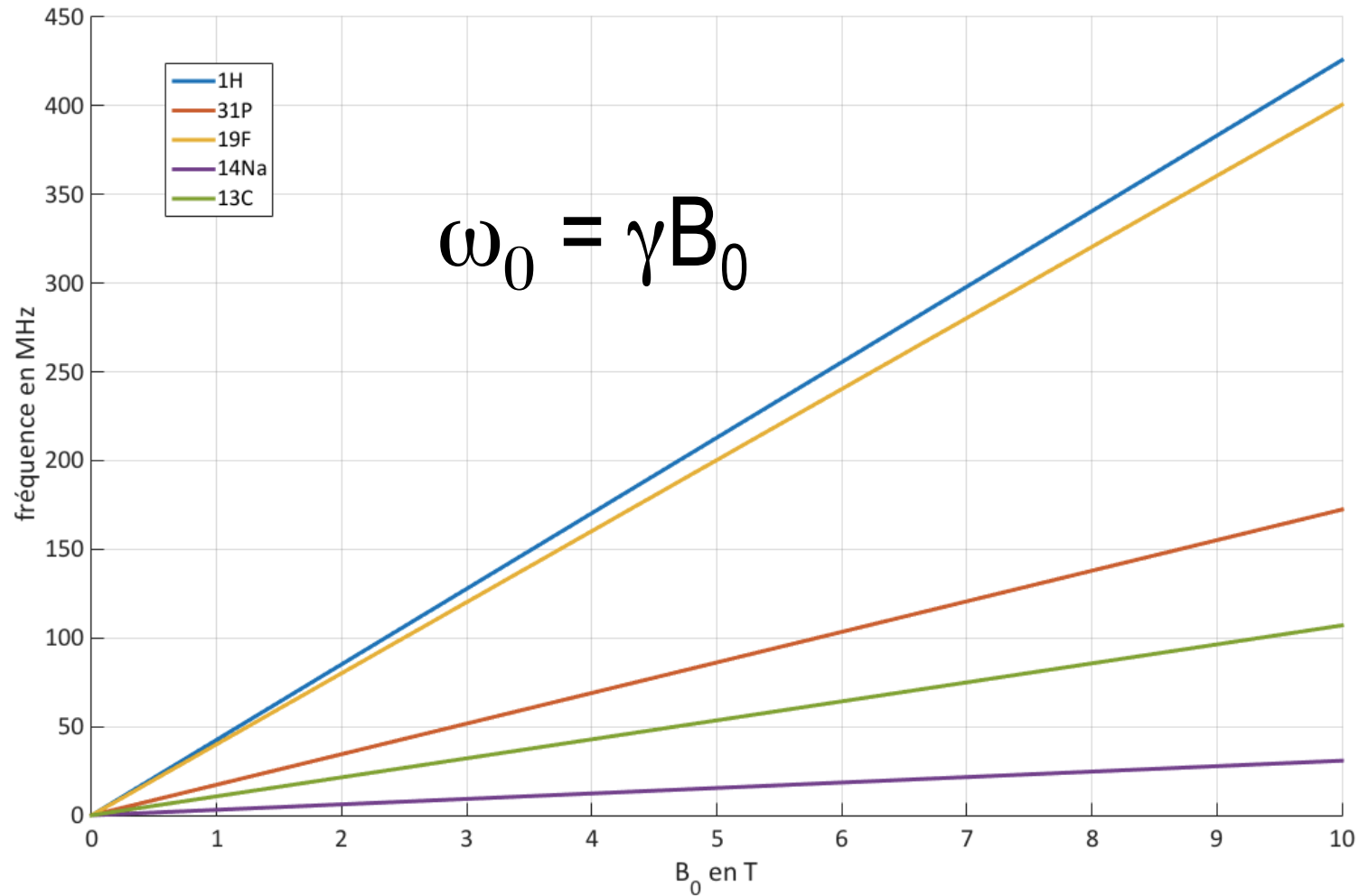
L'oscillation est le phénomène par lequel l'énergie du système passe d'une forme à l'autre, de façon périodique.



# La résonance en IRM

$$\omega_0 = \gamma B_0$$

# Larmor equation



# Aimantation Macroscopique





# Aimantation Macroscopique

$$M_0 = \rho \cdot \chi \cdot B_0$$

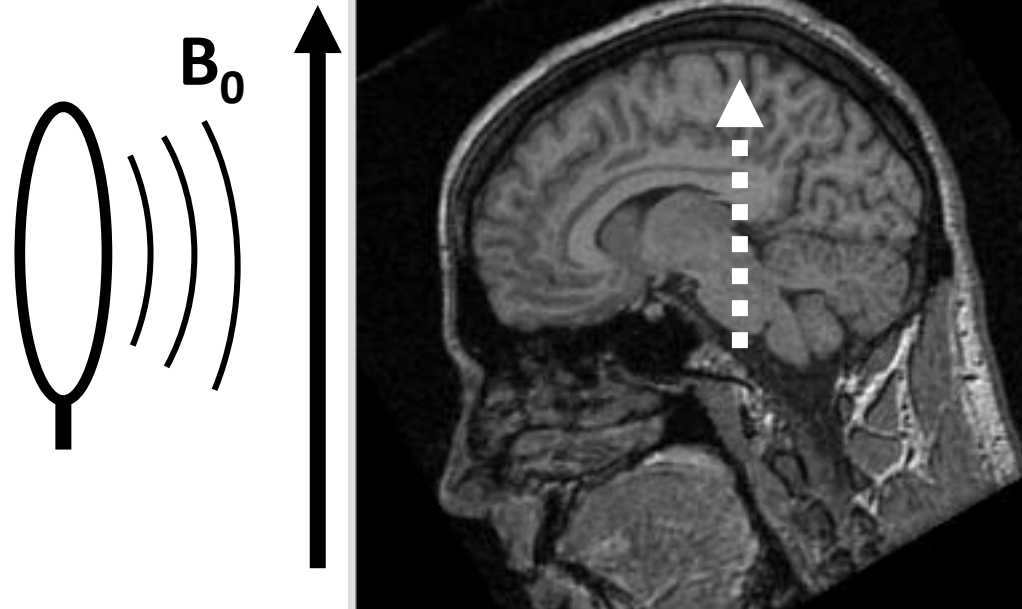


$M_0$  aimantation macroscopique  
 $\rho$  densité de proton  
 $\chi$  Susceptibilité magnétique

À l'équilibre thermodynamique

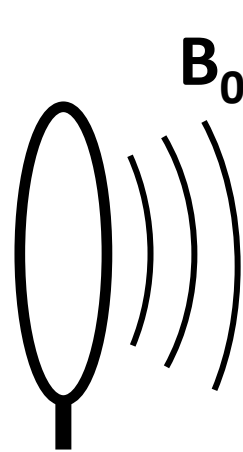
# Excitation des spins

champ  $B_1$  RF intense,  
perpendiculaire à  $B_0$  et de  
fréquence  $\omega_1$



# Excitation des spins

champ  $B_1$  RF intense,  
perpendiculaire à  $B_0$  et de  
fréquence  $\omega_1 = \omega_0$



$B_0$



$M_{xy}$

M bascule alors d'un angle  $\alpha = \gamma B_1 \tau$ ,  $\tau$  durée de l'impulsion RF

# Impulsion RF

- Quelle devra être l'amplitude de  $B_1$  pour obtenir un pulse de  $90^\circ$  en  $100 \mu\text{s}$ , pour l'IRM de noyaux d'  $^1\text{H}$  à  $1,5 \text{ T}$ ?
- Quel serait l'angle si ce pulse avait une durée deux fois plus longue?

# Impulsion RF

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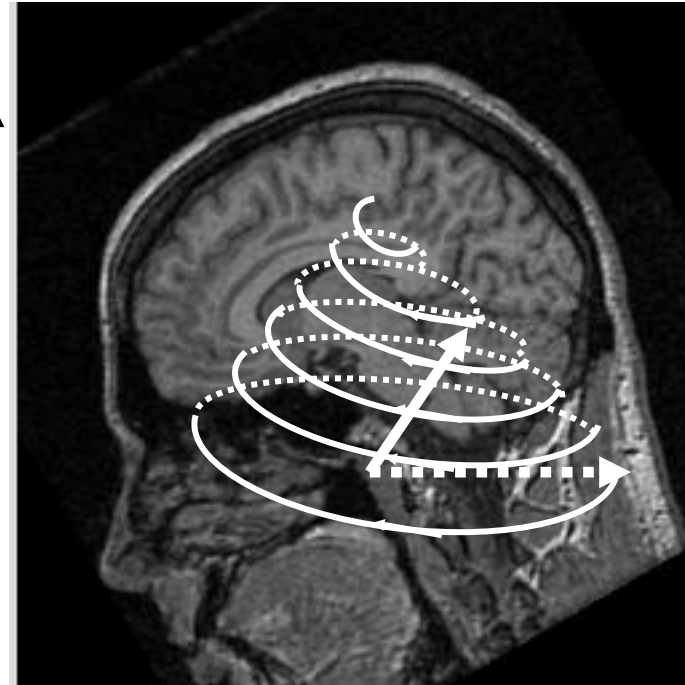
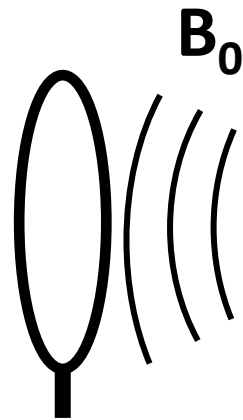
$$B_1 = \frac{\alpha}{\gamma\tau}$$

$$B_1 = \frac{\pi/2}{2\pi \times 42.58 \times 10^6 \times 100 \times 10^{-6}} = 59 \mu\text{T}$$

$$B_1 = \pi$$

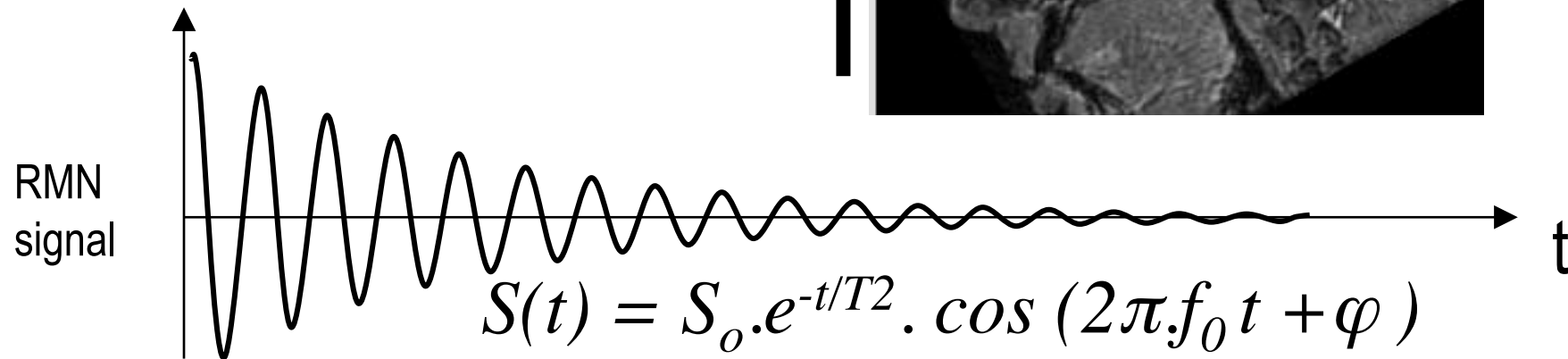
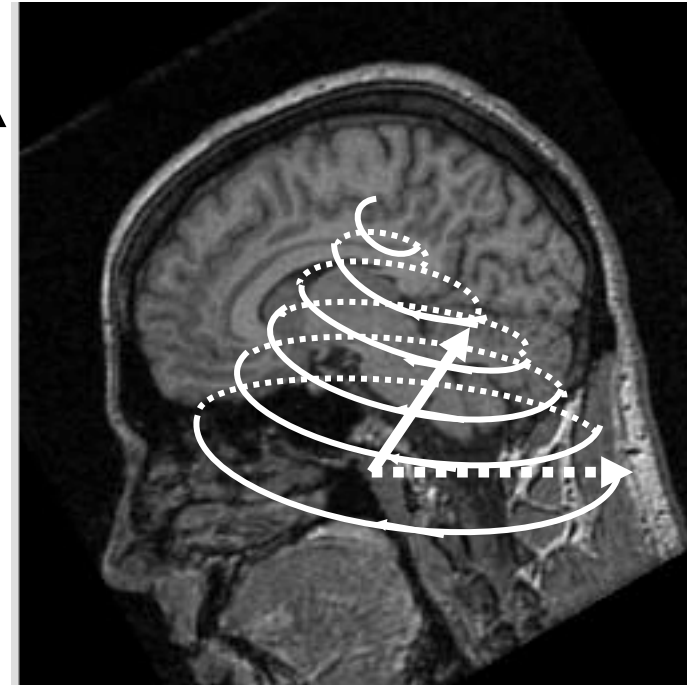
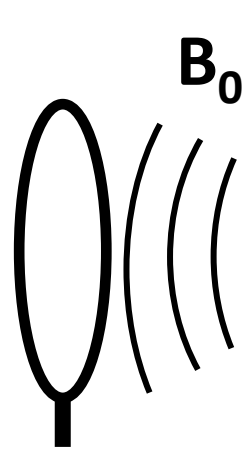
# Précession libre et relaxation

$$\omega_0 = \gamma B_0$$

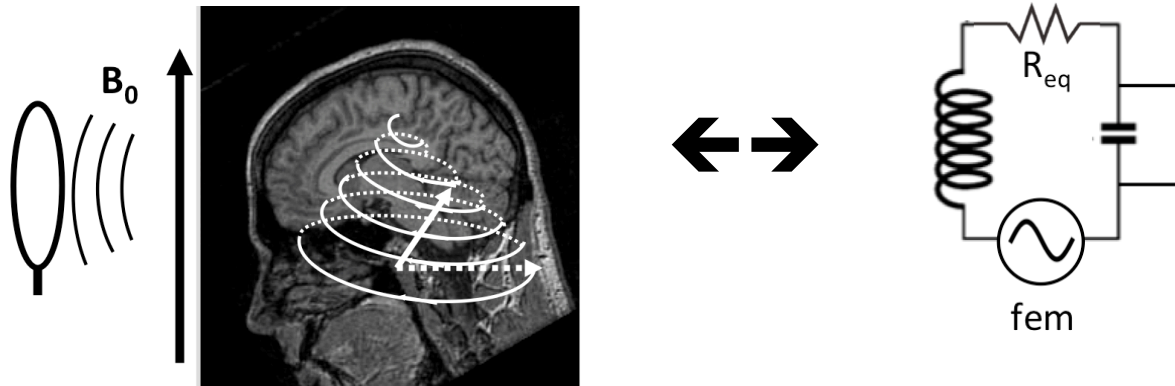


# Précession libre et relaxation

$$\omega_0 = \gamma B_0$$

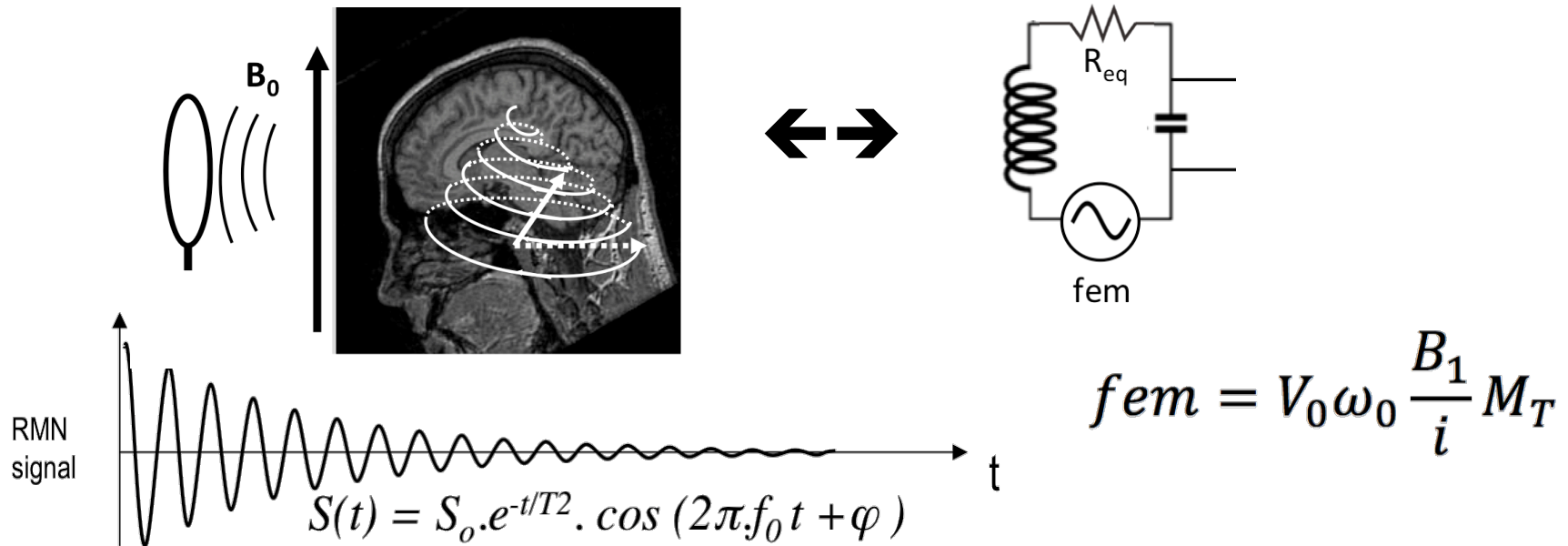


# Sensibilité du détecteur

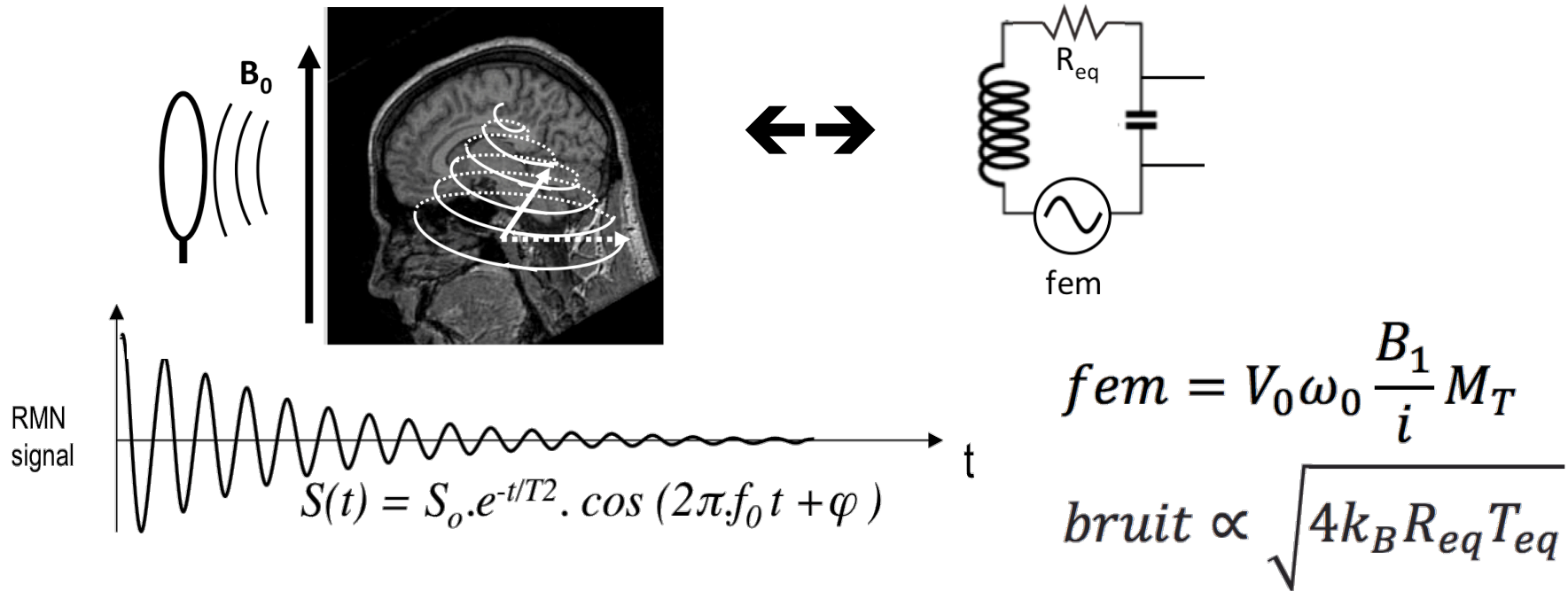




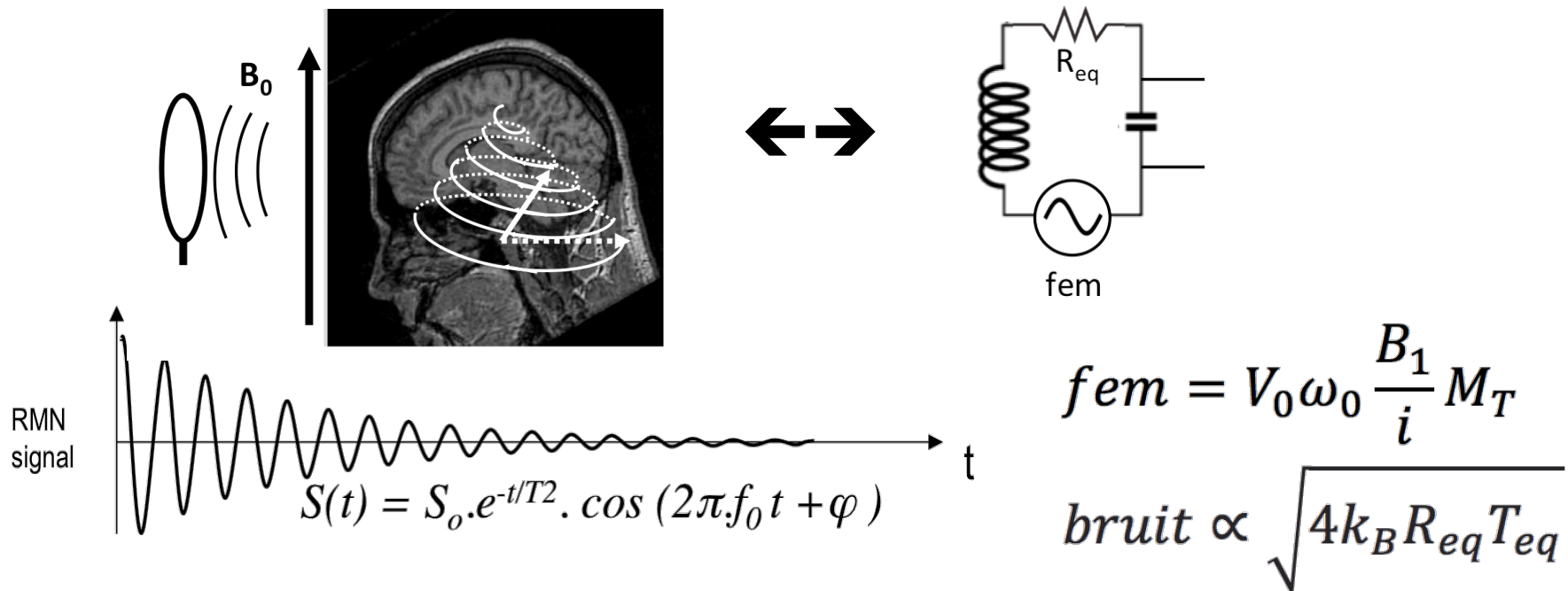
# Sensibilité du détecteur



# Sensibilité du détecteur



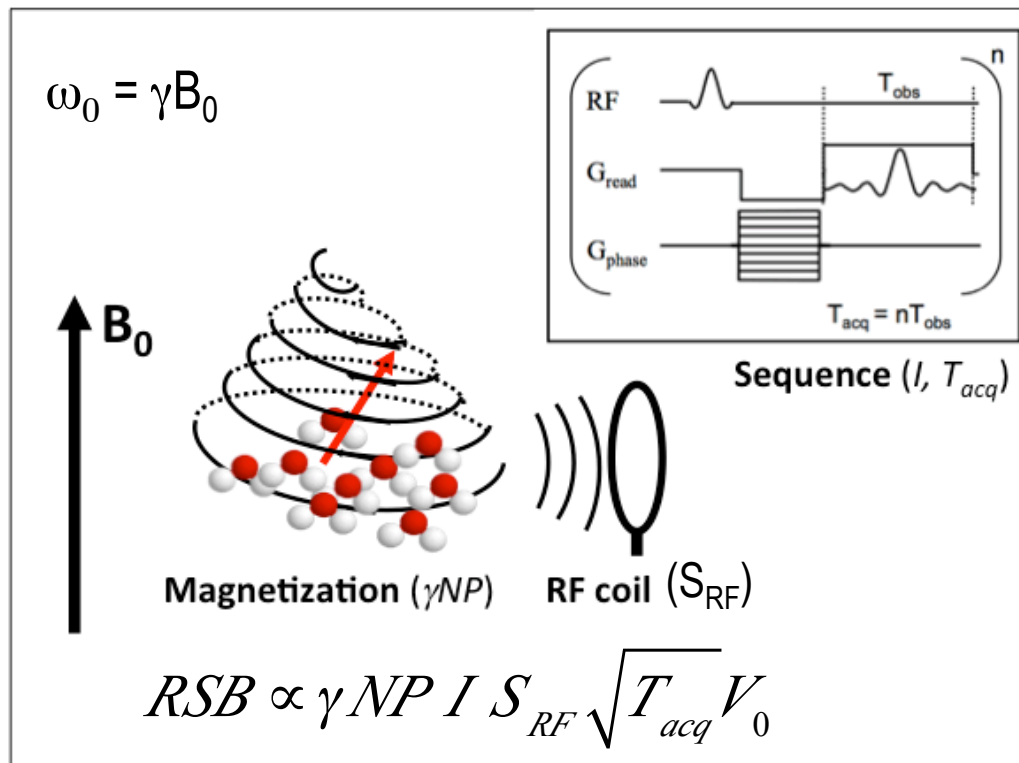
# Sensibilité du détecteur



Sensibilité Radio Fréquence

$$S_{RF} \propto \frac{B_1/i}{\sqrt{4k_B R_{eq} T_{eq}}}$$

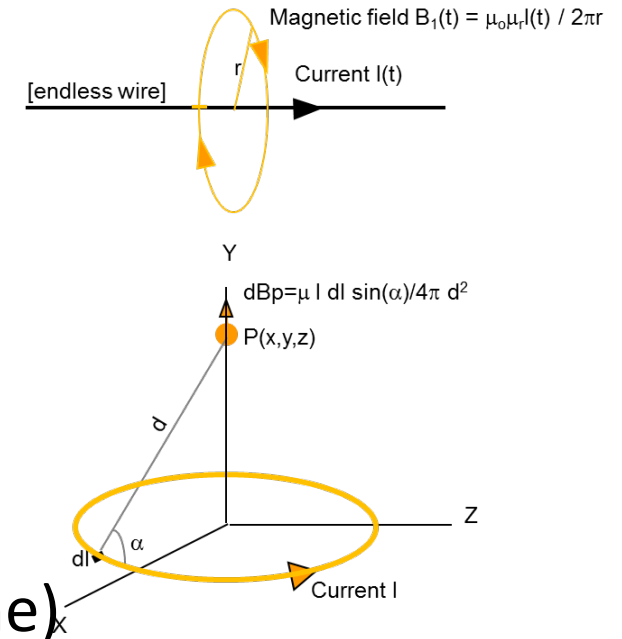
# Sensibilité en RMN



$$S_{RF} \propto \frac{B_1/i}{\sqrt{4k_B R_{eq} T_{eq}}}$$

# Champ $B_1$ RF - Equations


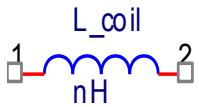
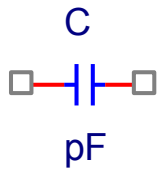
- Equation de Maxwell
  - Gaus's law for magnetism ( $\nabla \cdot \mathbf{B} = 0$ )
  - Faraday's law ( $\text{fem} = d\phi/dt$ )
  - Ampere's law (corrected,  $\text{rot} \cdot \mathbf{B} = \mu_0 \cdot \mathbf{J}$ )
- Loi de Biot-Savart's (en champ proche)
  - Relation entre courant et champ magnétique
- Règle des "3 doigts"
  - Determination de la direction de  $B_1$



# Objectif

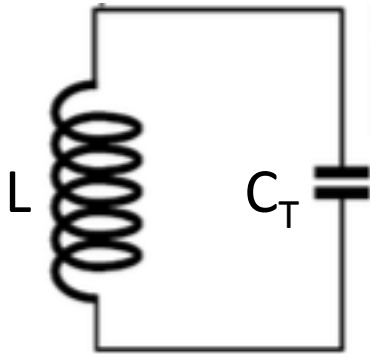
- Un peu de Physique (only a few)
- Antennes RF, conception et mesures de leurs caractéristiques RF
  - éléments de base
  - concept de circuit résonant
  - adaptation d'impédance pour maximiser le transfert de puissance
  - optimisation du RSB
  - Analyseur de réseau, mesure de facteur de qualité et de fréquence de résonance
- Différents types d'antennes RF

# Antenne RF – éléments de base

Éléments de base	Symbole et unité	Comportement en fréquence
Résistance 	R en ohm	$Z_R=R$
Inductance 	L en Henry L=10nH	$Z_L=jL\omega$ en Ohms
capacité 	C en Farad C=10pF	$Z_C=1/jC\omega$ en Ohms

Impédance totale (=profil en fréquence)

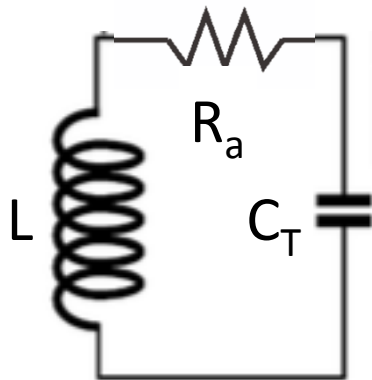
# Circuit résonant - accord



$$LC_T\omega_0^2 = 1$$



# Circuit résonant – facteur de qualité



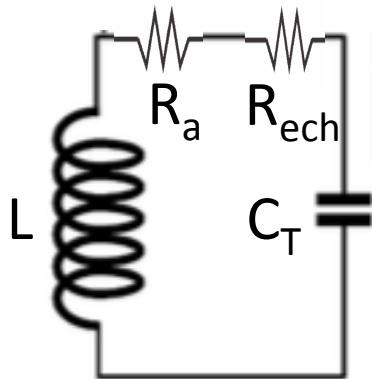
$$LC_T\omega_0^2 = 1$$

$R=R_a$  la résistance de l'antenne

Facteur de qualité

$$Q_{vide} = \frac{L\omega}{R_a}$$

# Circuit résonnant – facteur de qualité



$$LC_T\omega_0^2 = 1$$

$R=R_a$  la résistance de l'antenne

$R=R_{ech}$  la résistance équivalente de l'échantillon

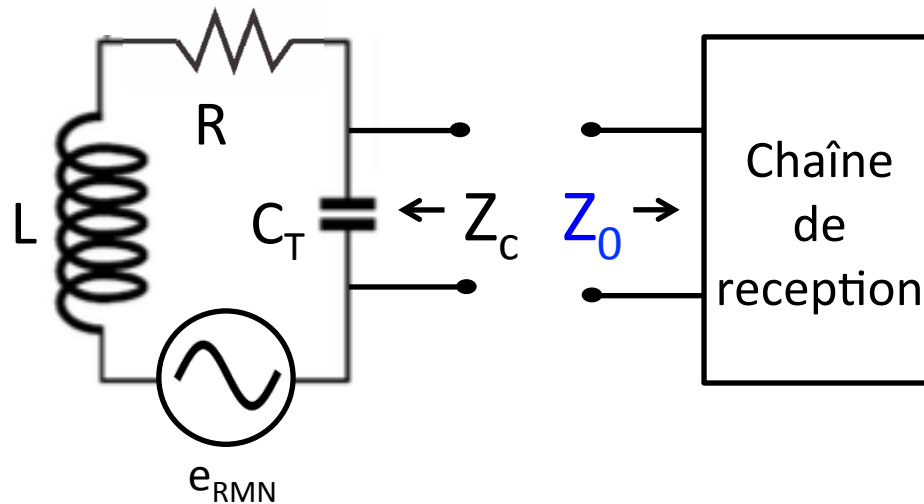
Facteur de qualité

$$Q_{vide} = \frac{L\omega}{R_a}$$

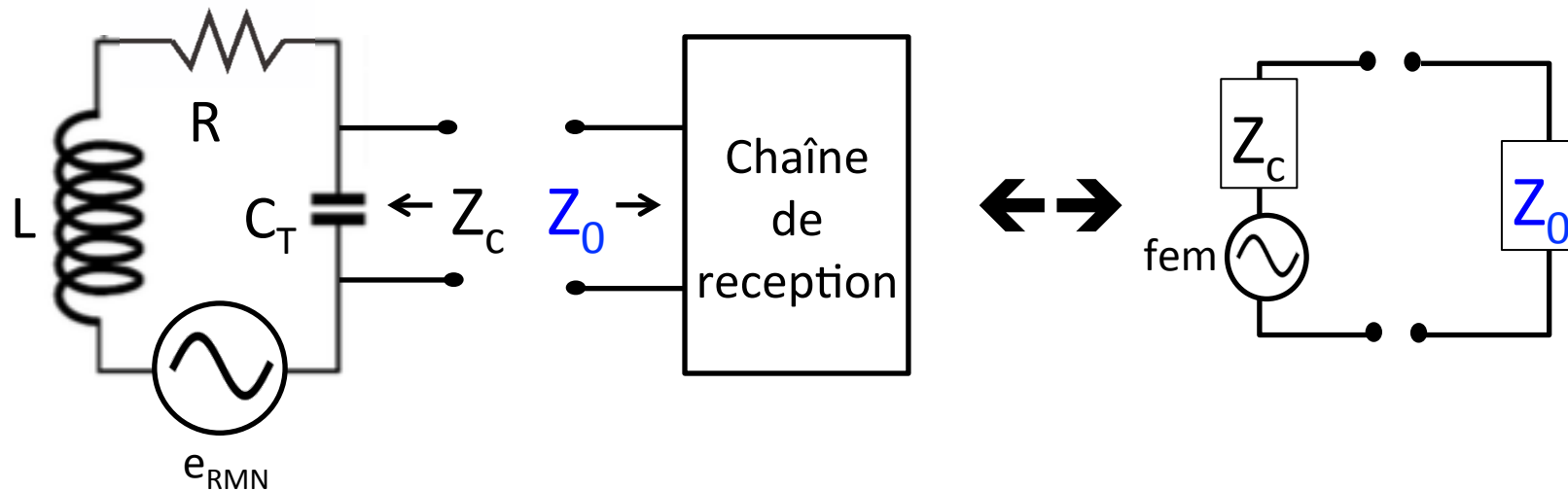
$$Q_{charge} = \frac{L\omega}{R_a + R_{éch}}$$

# Circuit résonant - adaptation

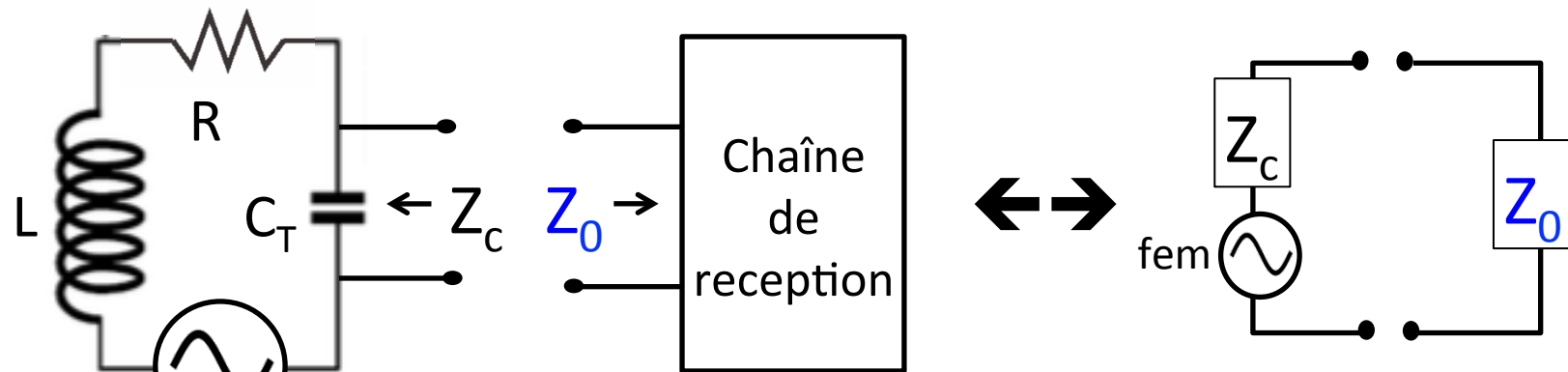
But: transmettre le maximum de puissance



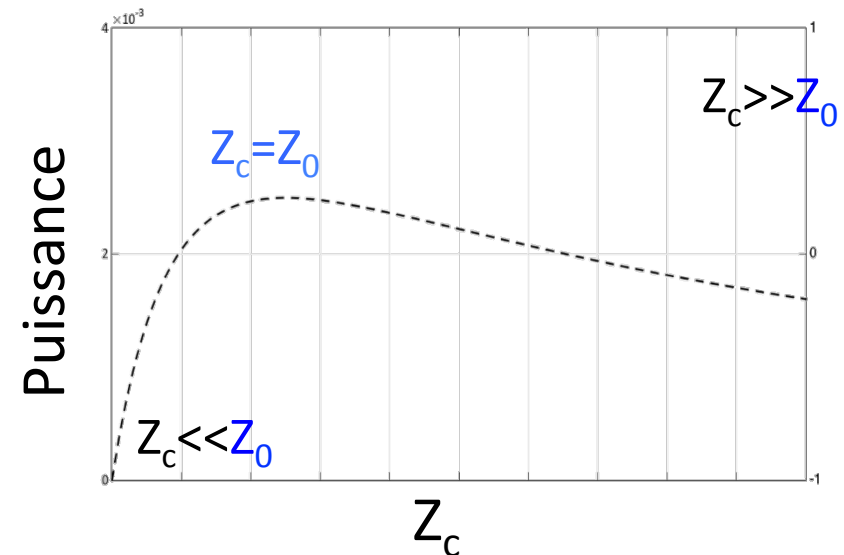
# Circuit résonant - adaptation



# Circuit résonant - adaptation

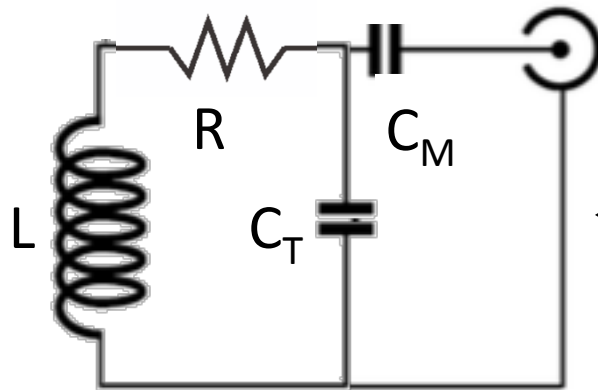


$$P = \frac{fem^2}{4} \frac{Z_0}{(Z_0 + Z_c)^2}$$



# Circuit résonant - adaptation

## Couplage capacitif



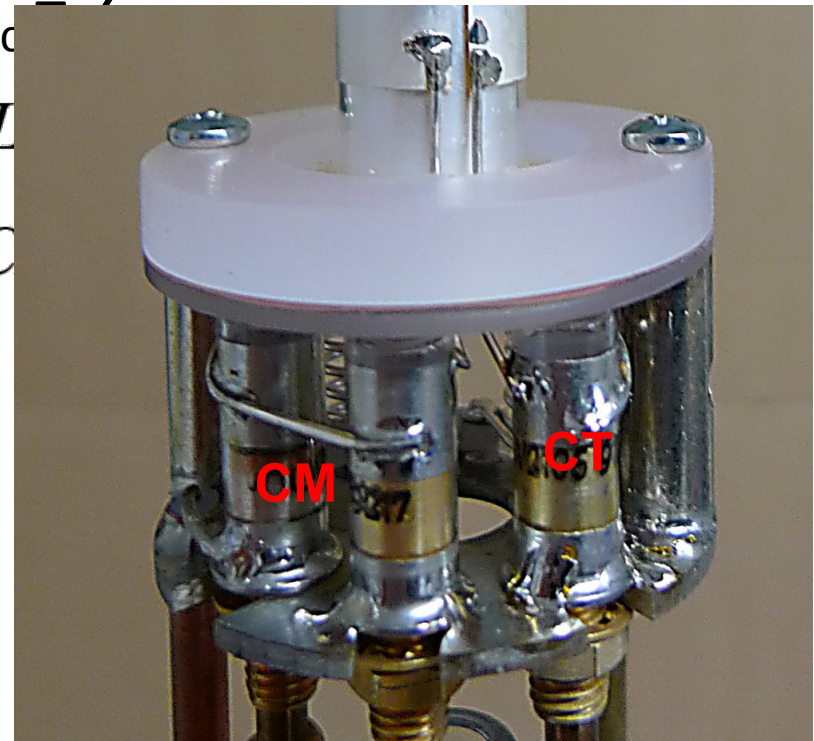
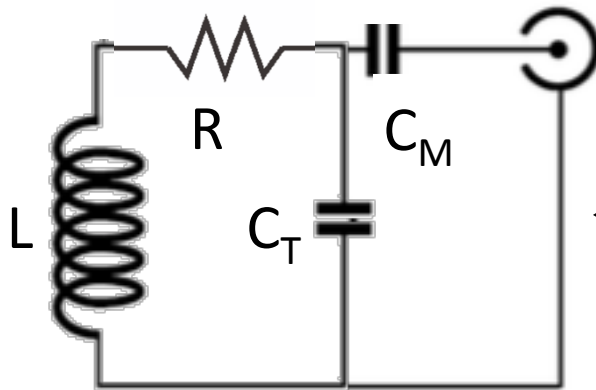
$$\leftarrow Z_c = Z_0$$

$$L(C_T + C_M)\omega_0^2 \approx 1$$

$$C_M \approx 1/\omega_0 \sqrt{Z_0 Q L \omega_0}$$

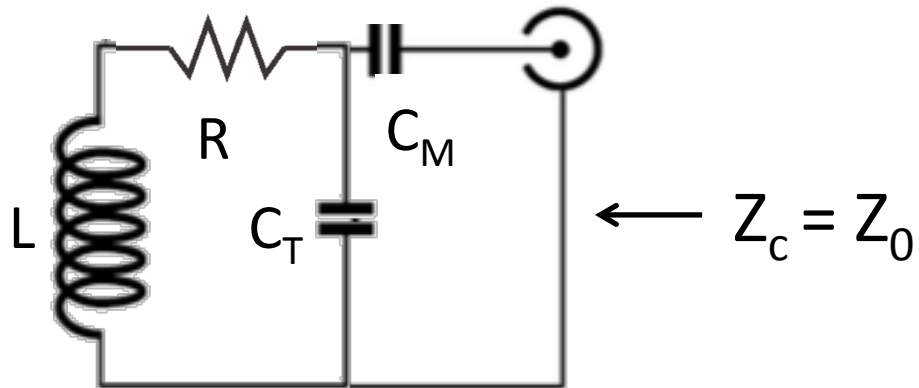
# Circuit résonant - adaptation

## Couplage capacitif

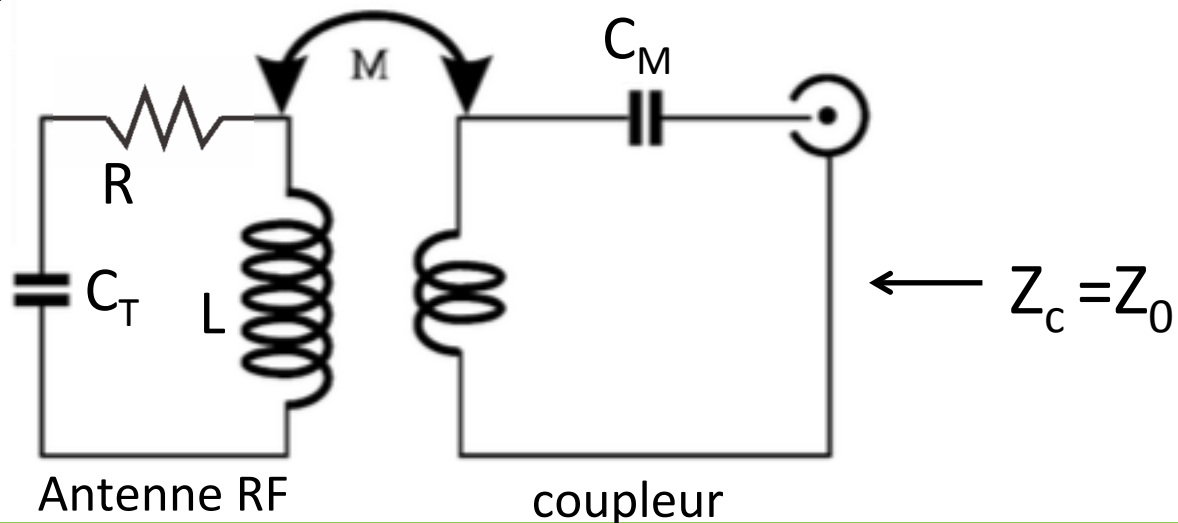


# Circuit résonant - adaptation

## Couplage capacitif



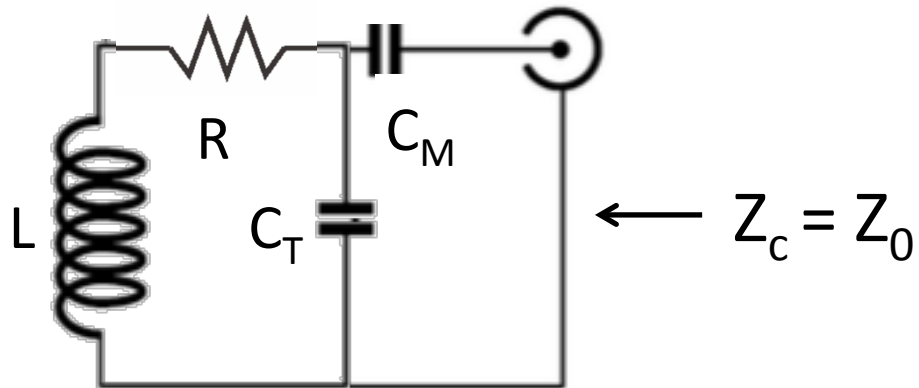
## Couplage inductif



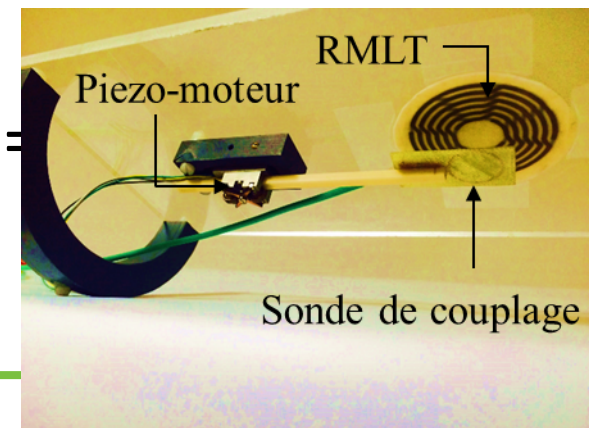
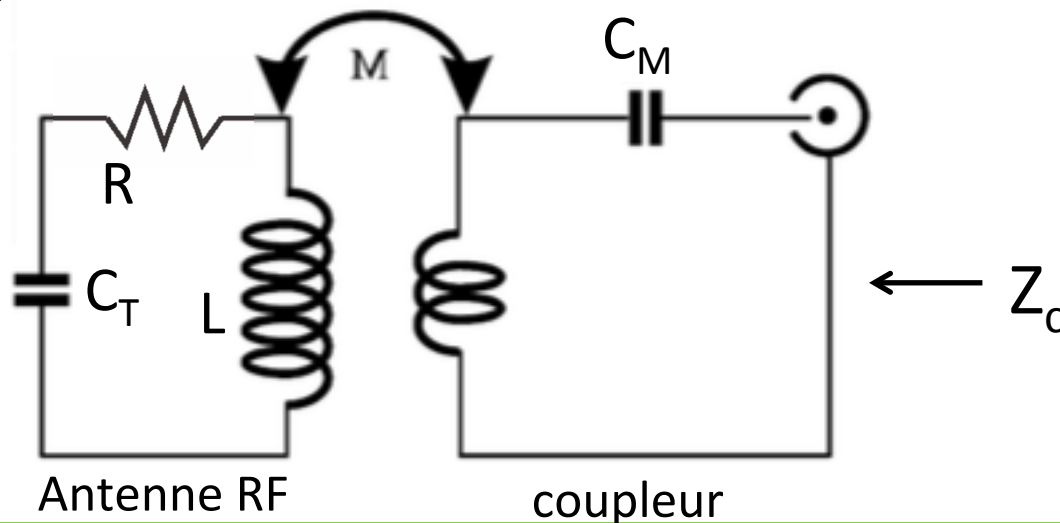


# Circuit résonant - adaptation

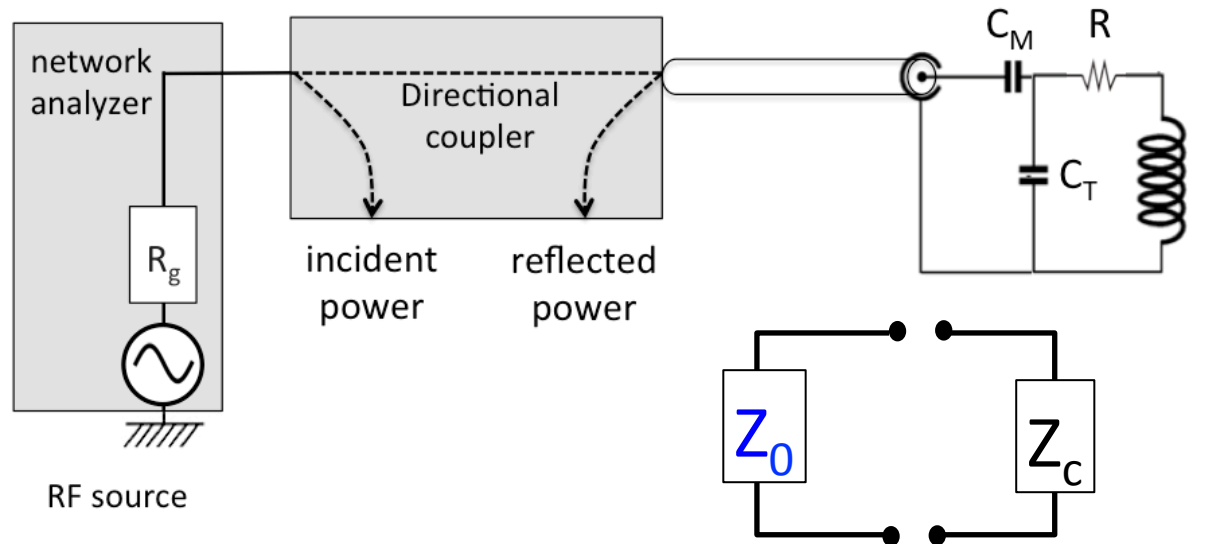
## Couplage capacitif



## Couplage inductif



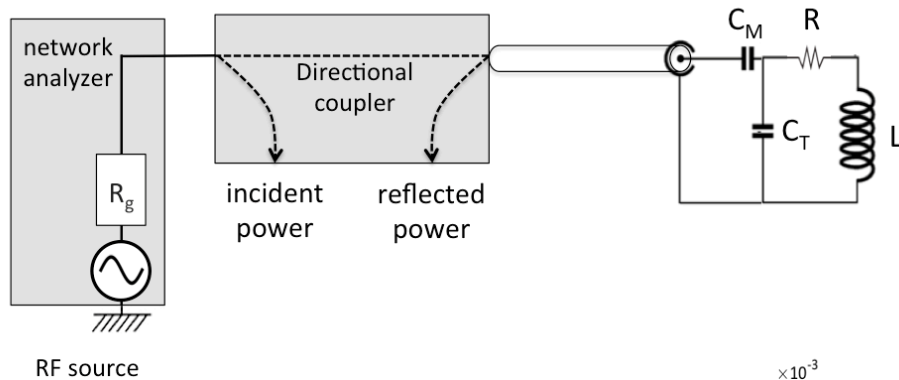
# Adaptation et coefficient de réflexion



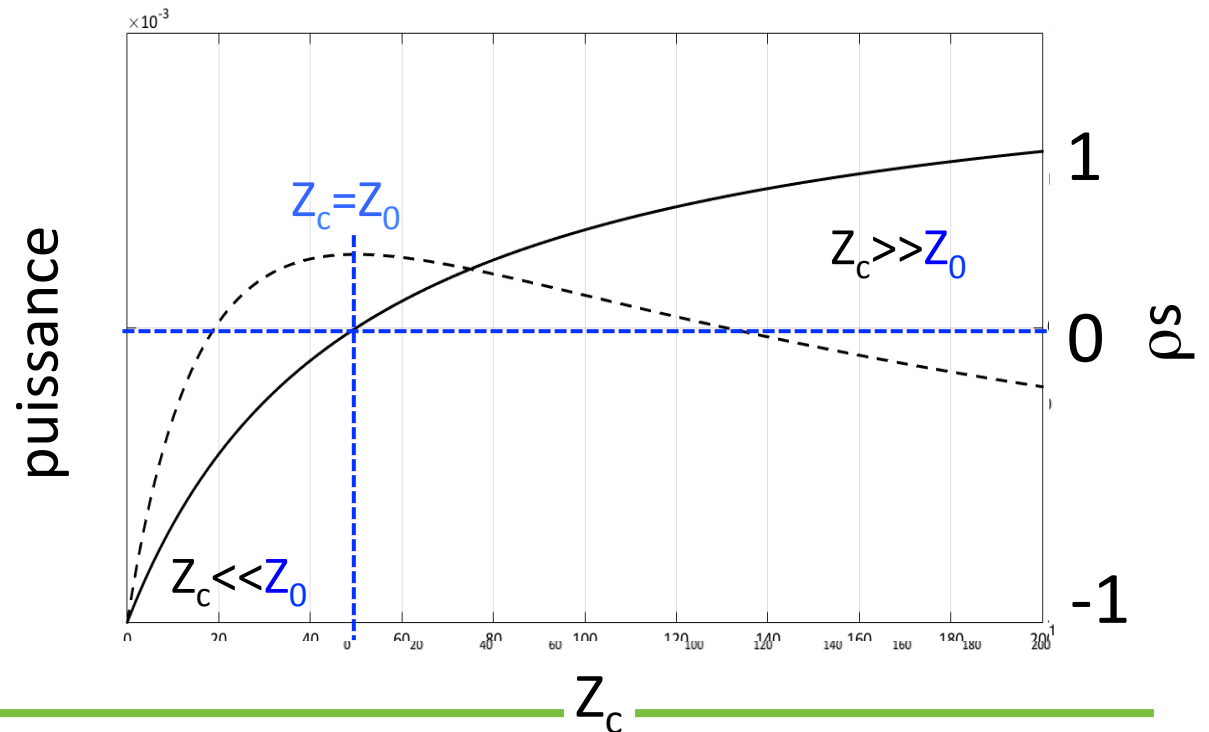
Coefficient de réflexion

$$\rho = \frac{V_{ref}}{V_{inc}} = \frac{Z_c - Z_0}{Z_0 + Z_c}$$

# Adaptation et coefficient de reflexion



$$\rho = \frac{Z_c - Z_0}{Z_0 + Z_c}$$

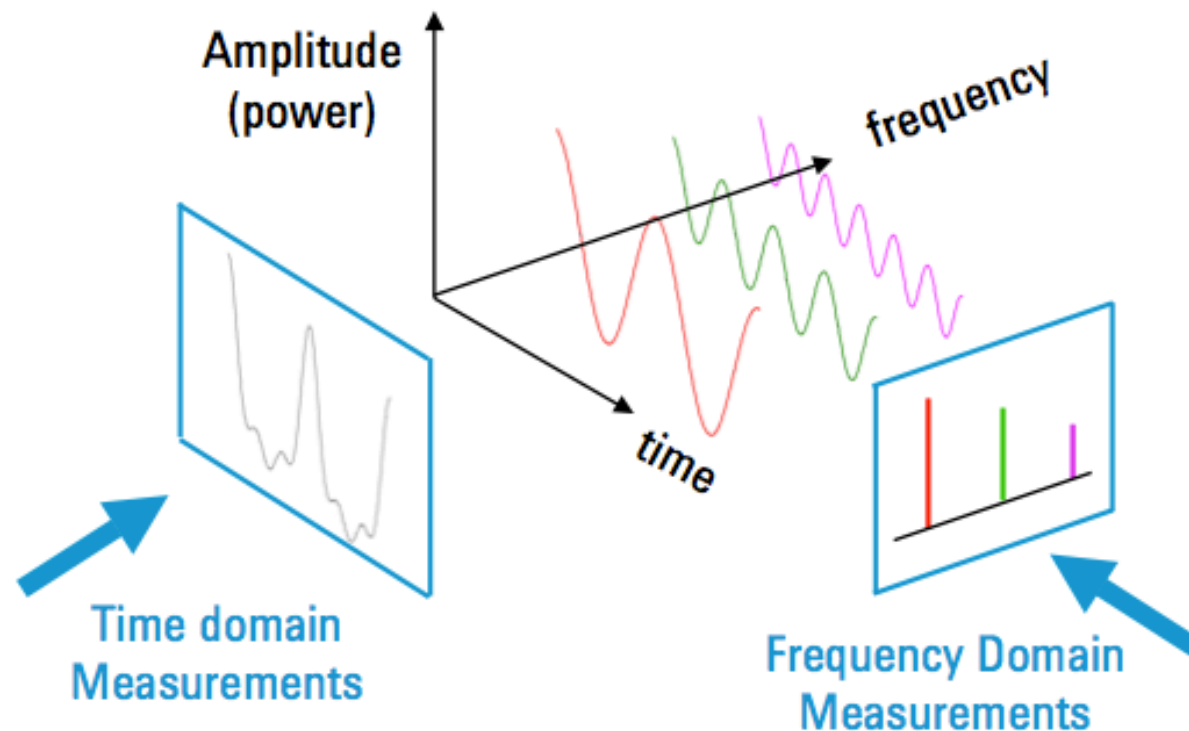


# Adaptation et coefficient de reflexion

## Analyseur Vectoriel

### Overview

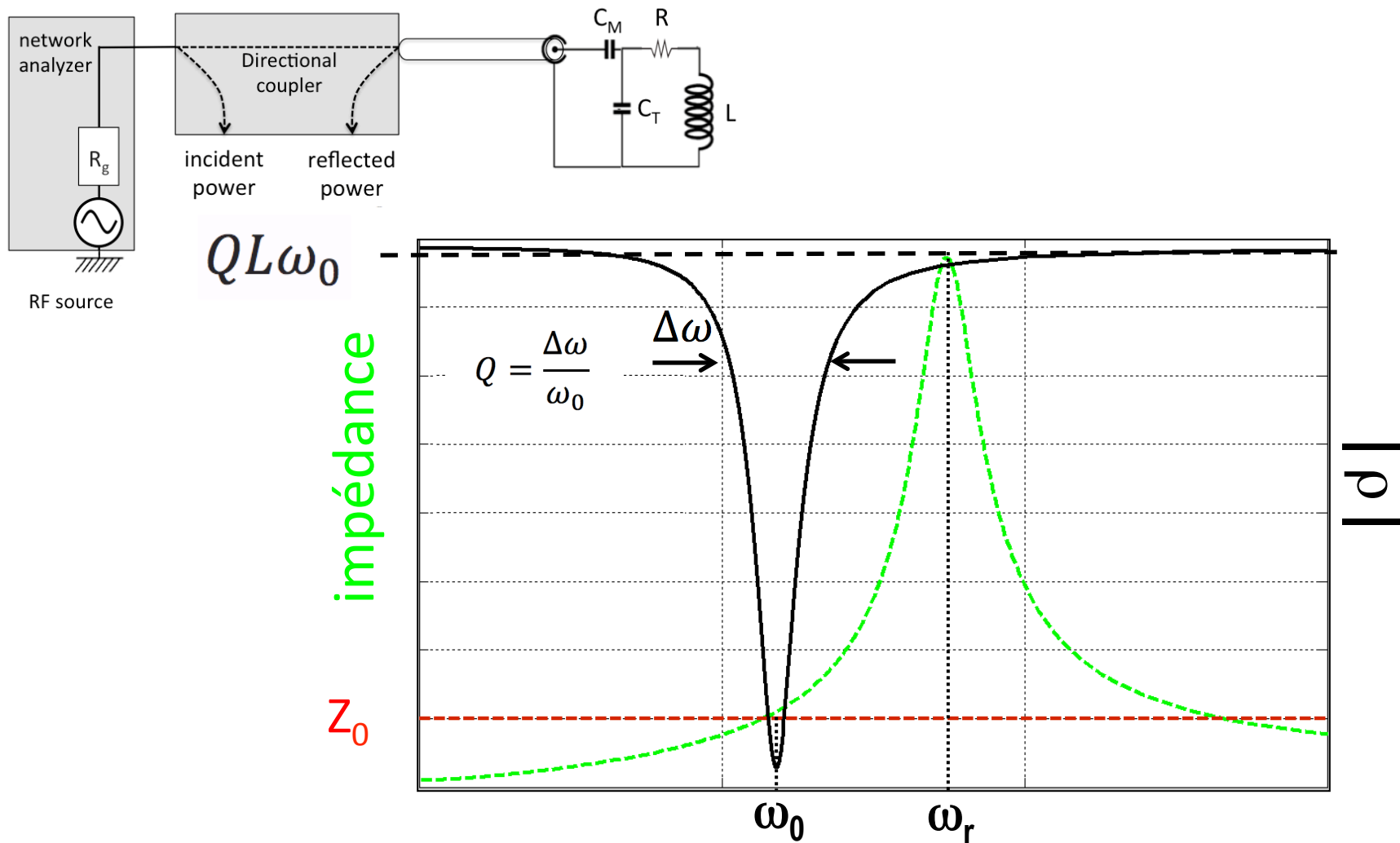
#### Frequency Vs Time Domain





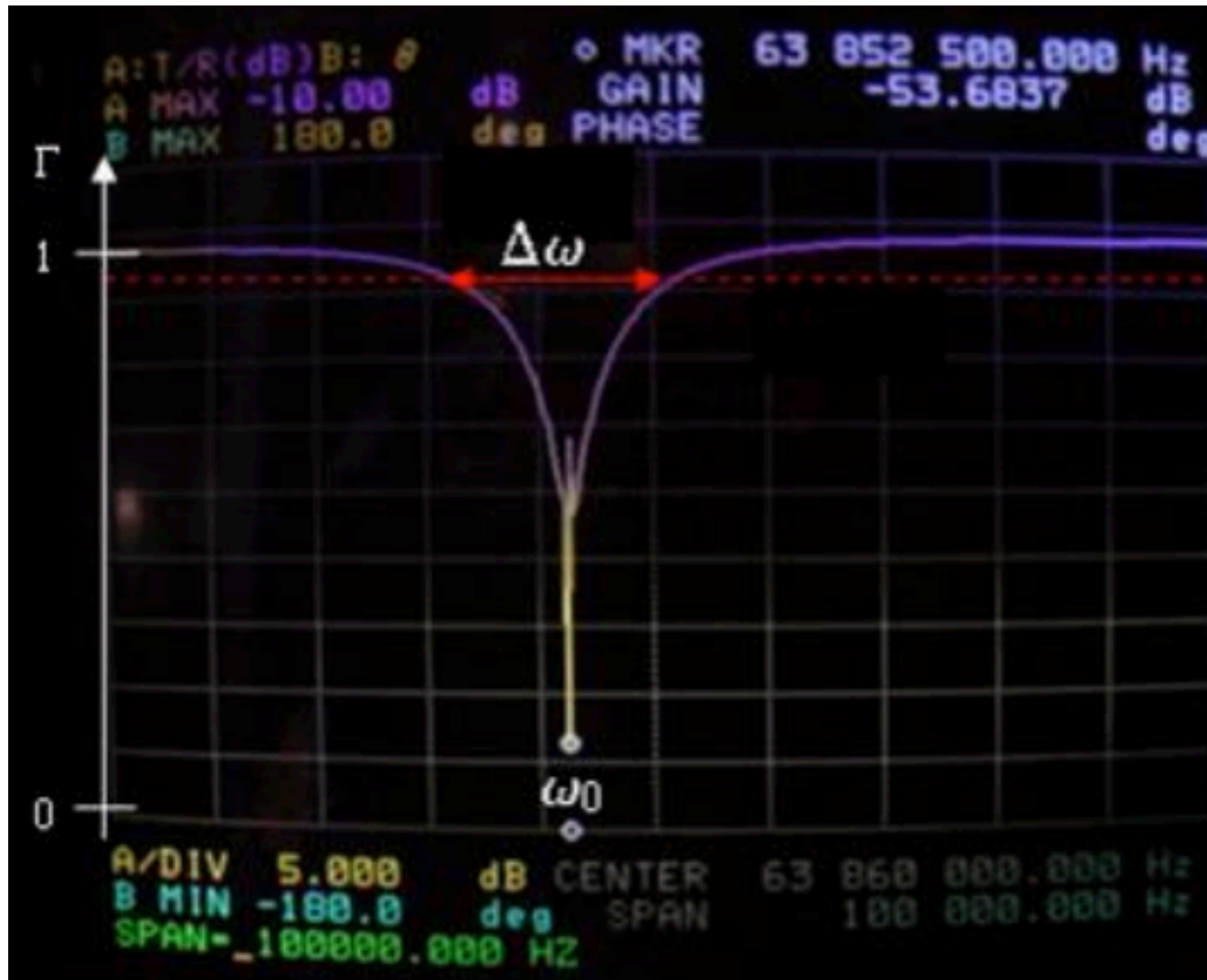
*Merci à Philippe Massot et Jean-Michel Franconi*

# facteur de qualité et de fréquence de résonance



# Mesure du facteur de qualité

$$Q = \frac{\Delta\omega}{\omega_0}$$



# conclusion

- Accord: fréquence d'émission ou de réception différente de celle de Larmor, pas de couplage magnétique possible avec l'aimantation
- Adaptation: transmission ou réception du maximum de puissance

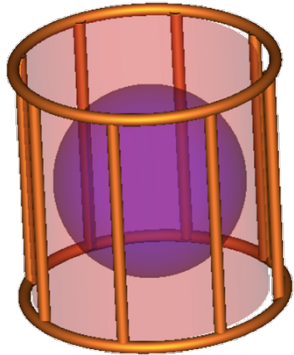


# Objectif

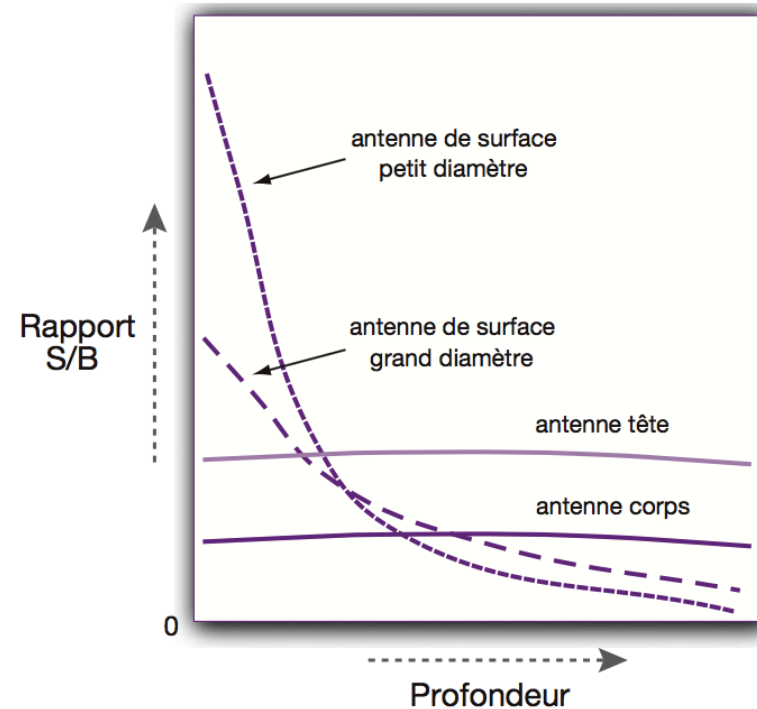
- Un peu de Physique Physics (only a few)
- Antennes RF, conception et mesures de leurs caractéristiques RF
- Différents types d'antennes RF

# Antennes de volume et de surface

## Antenne de volume



- Réponse @uniforme
- SNR limité par l'objet



# Sensibilité - optimisation du détecteur

$$RSB \propto \gamma NP I S_{RF} \sqrt{T_{acq}} V_0$$

a : rayon de l'antenne

Bruit induit par le patient

$$R_{ech} T_{ech} \propto \omega^2 a^3 T_{ech}$$

$$S_{RF} \propto \frac{B_1/i}{\sqrt{4k_B(R_{ech}T_{ech} + R_aT_a)}}$$

# Sensibilité - optimisation du détecteur

$$RSB \propto \gamma NP I S_{RF} \sqrt{T_{acq}} V_0$$

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a : rayon de l'antenne

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$$R_{ech}T_{ech} \propto \omega^2 a^3 T_{ech}$$

Bruit propre de l'antenne

$$R_aT_a \propto \sqrt{\omega \rho_a} T_a$$

# Sensibilité - optimisation du détecteur

$$RSB \propto \gamma NP I S_{RF} \sqrt{T_{acq}} V_0$$

$a$  : rayon de l'antenne

$$S_{RF} \propto \frac{B_1/i}{\sqrt{4k_B(R_{ech}T_{ech} + R_aT_a)}}$$

Bruit induit par le patient

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Bruit propre de l'antenne

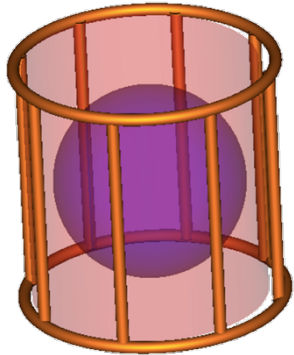
$$R_aT_a \propto \sqrt{\omega \rho_a} T_a$$

En IRM clinique,  $R_{ech}T_{ech} \gg R_aT_a$

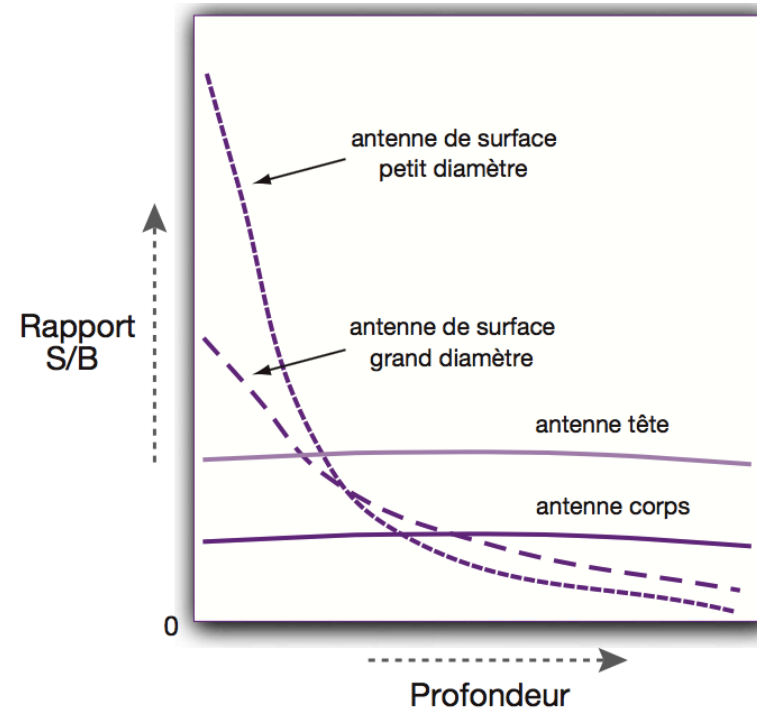
$$R_{ech}T_{ech} \propto \omega^2 a^3 T_{ech}$$

# Antennes de volume et de surface

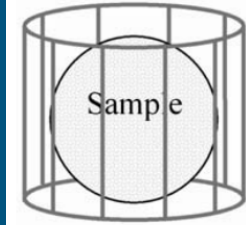
## Antenne de volume



- Réponse @uniforme
- SNR limité par l'objet



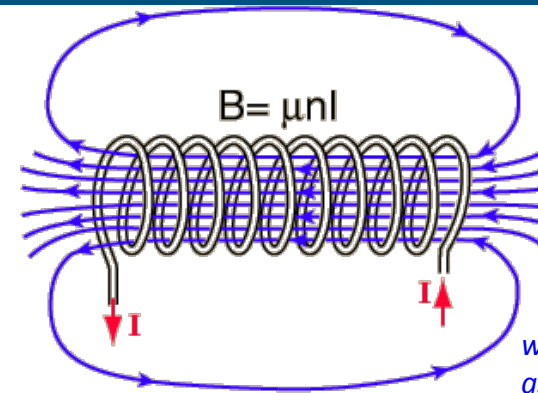
# Solenoid coil



Volume coil  
(e.g. Birdcage)

- Benefits

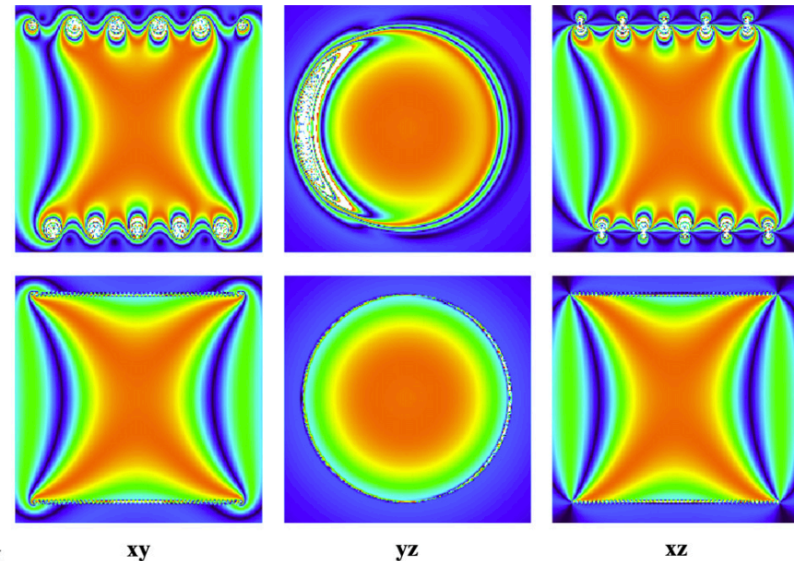
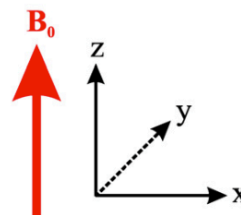
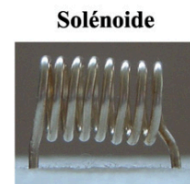
- Homogeneous  $B_1$ -field
- High  $B_1$ -field strength



[www.hyperphysics.phy-astr.gsu.edu](http://www.hyperphysics.phy-astr.gsu.edu)

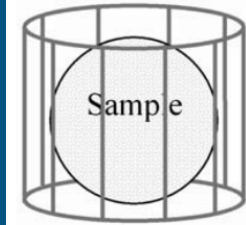
- Drawbacks

- Axial access only ( $B_1 \perp B_0$ )
- High inductance L

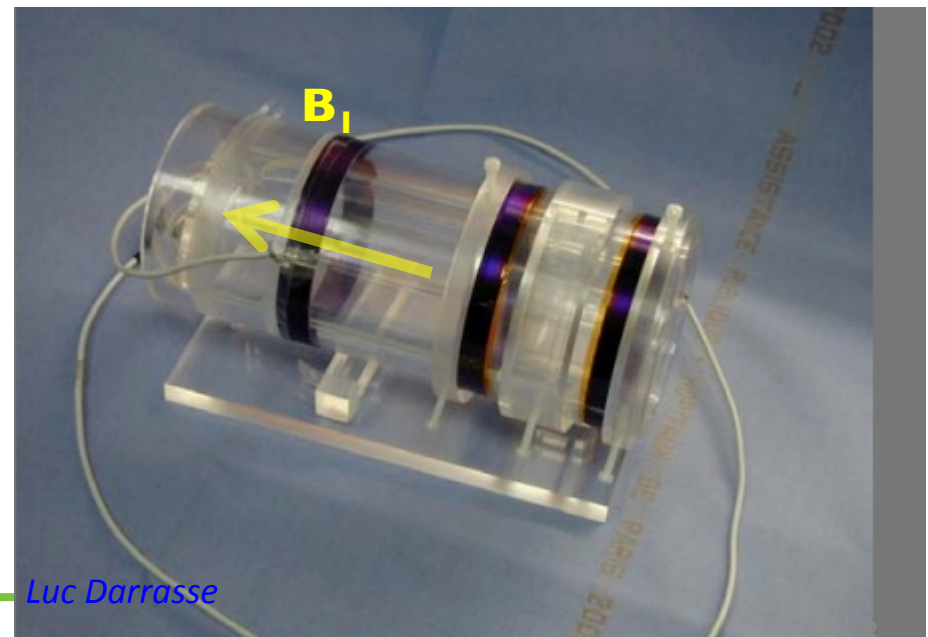
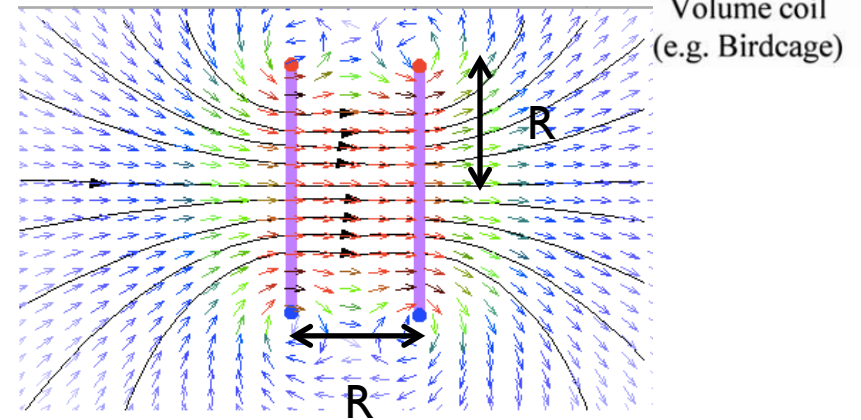


*Homogeneous resonators for magnetic resonance: A review Joe'l Mispelter\*, Mihaela Lupu*

# Helmholtz coil



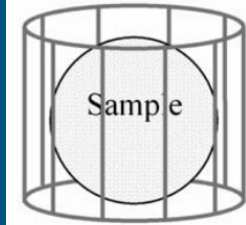
- Benefits
  - Open access
  - Fairly homogeneous B1-field
  - Reasonable SNR
- Drawbacks
  - Long lead conductors



Luc Darrasse



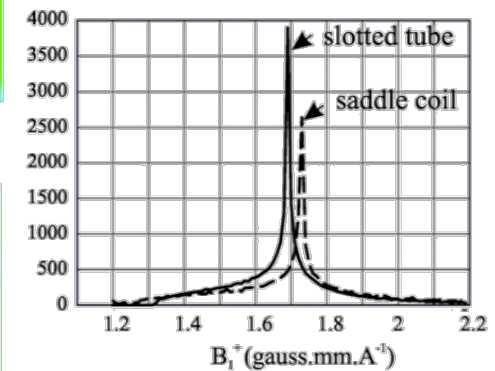
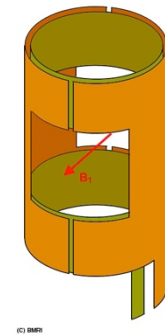
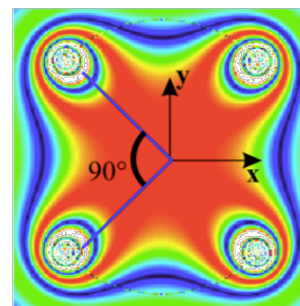
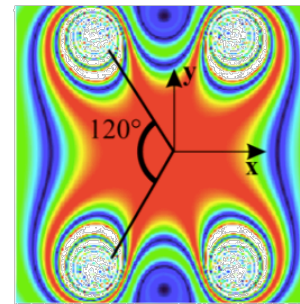
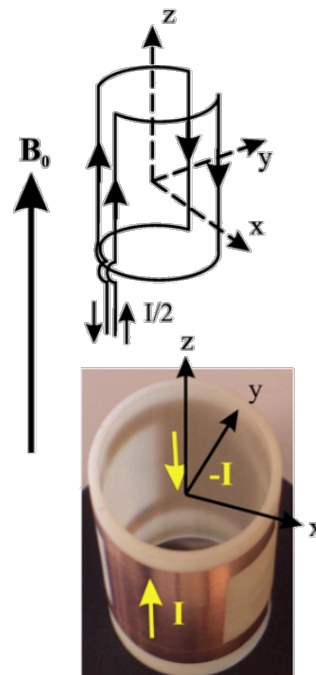
# Alderman-Grant (saddle) coil



Volume coil  
(e.g. Birdcage)

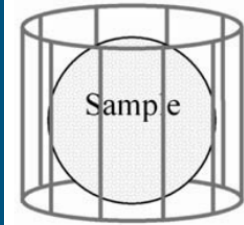
- Benefits
  - Volume setup
  - Open design
  - Easy to construct

- Drawbacks
  - Inhomogeneous B1-field
  - Only applicable for small objects



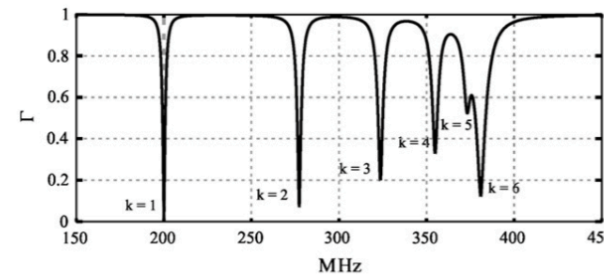
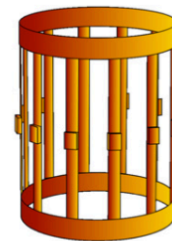
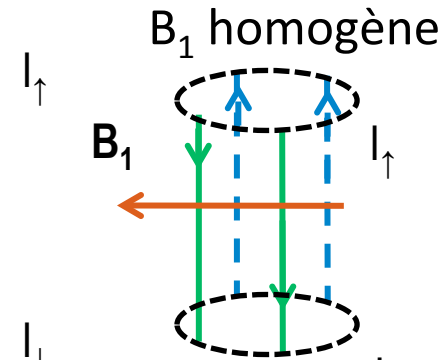
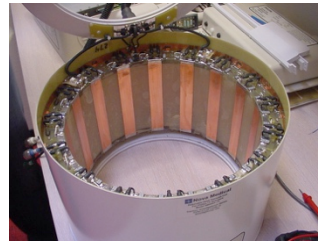
*Homogeneous resonators for magnetic resonance: A review Joe'l Mispelter\*, Mihaela Lupu*

# Birdcage coil

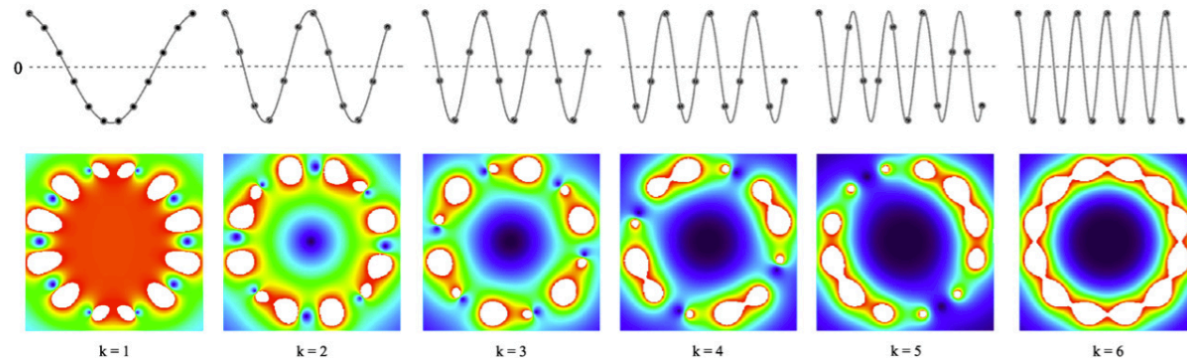


Volume coil  
(e.g. Birdcage)

- Benefits
  - Volume setup
  - Superb homogeneity
  - Applicable at high-field



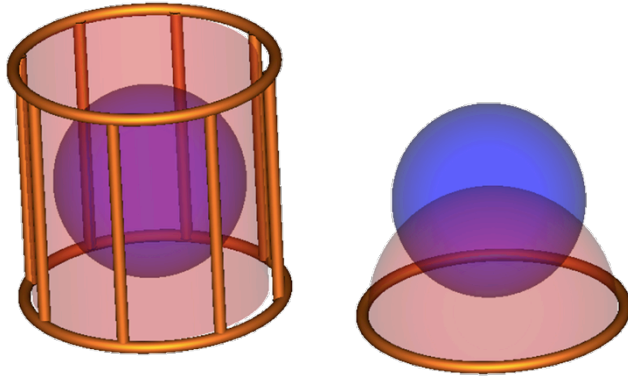
- Drawbacks
  - Very complex design
  - Double resonant tough



*Homogeneous resonators for magnetic resonance: A review Joe'l Mispelter\*, Mihaela Lupu*

# Antennes de volume et de surface

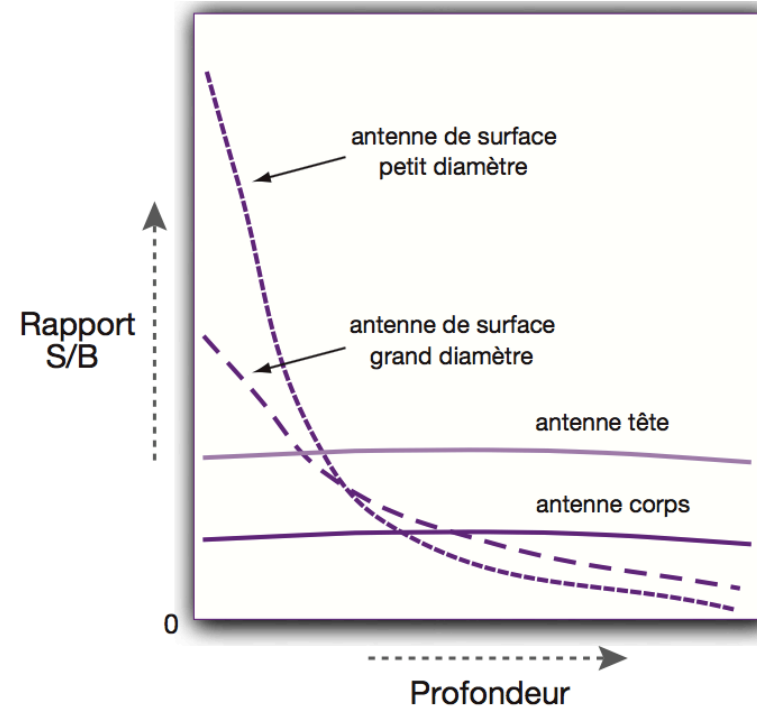
Antenne de volume



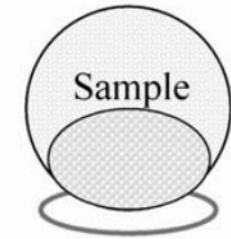
Antenne de surface

$$S_{RF} \propto \frac{\omega a^{-5/2}}{\sqrt{T_{ech}}}$$

- Réponse locale
- SNR élevé

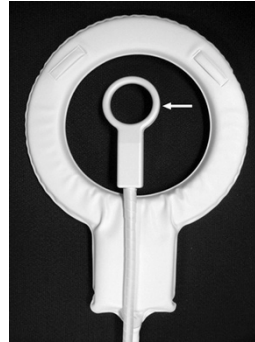


# Surface (flat) coil



Surface coil

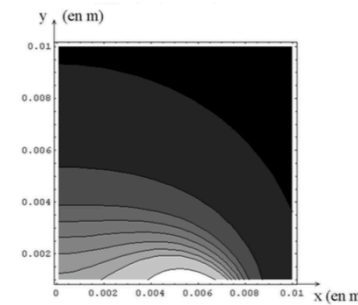
- Benefits
  - Superb SNR
  - Inherent localization



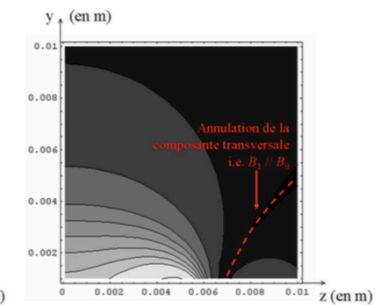
AJR june 2007 vol 188 no 6 1568-1572

- Drawbacks
  - Inhomogeneous B1-field
  - Limited penetration depth
  - Limited FOV

a) Homogénéité de  $B_1$  dans le plan transversal XoY



b) Homogénéité de  $B_1$  dans le plan transversal YoZ



c) position de l'antenne par rapport au champ  $B_0$

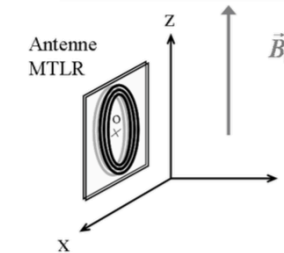
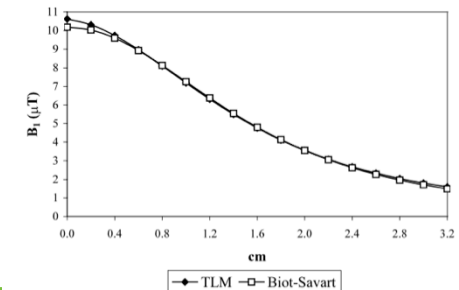


Figure II-8 : Homogénéité du champ RF créé par une antenne MTLR (Ø 12mm, 6 tours, pour  $^1\text{H}$  à 1,5 T)

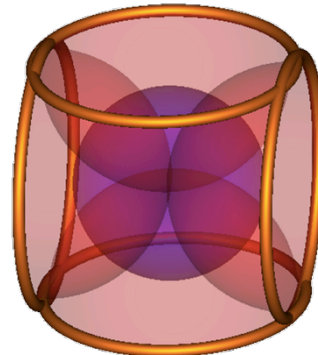
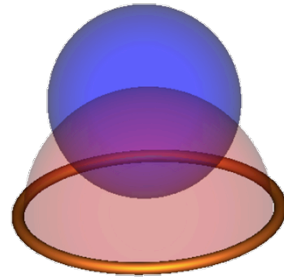
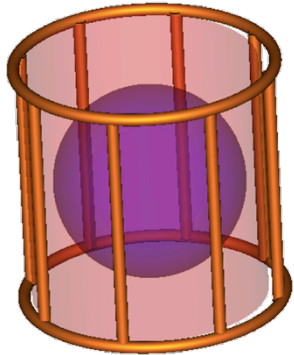
Surface Coil



Electromagnetic characterization of MR RF coils using the transmission-line modelling method, Cassidy et al. 2001

# Antennes de volume et de surface

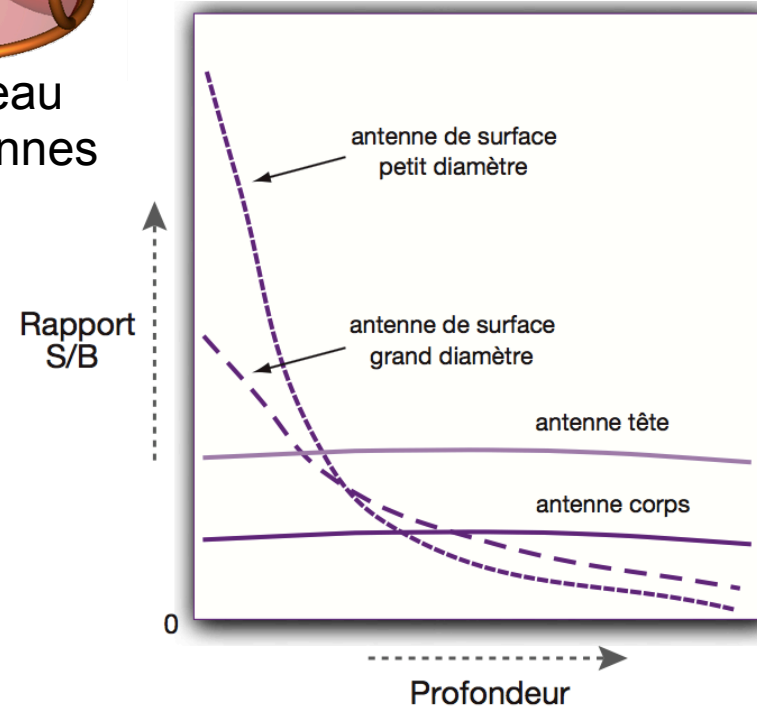
Antenne de volume



Antenne de surface

Réseau  
d'antennes

- Réponse étendue
- SNR optimale



# Réseau d'antennes

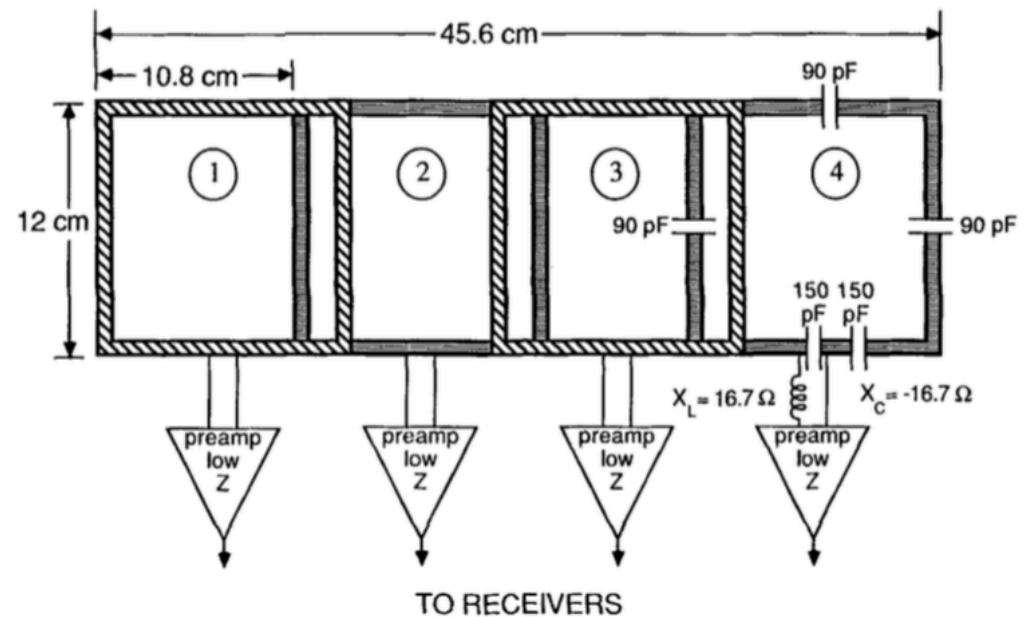
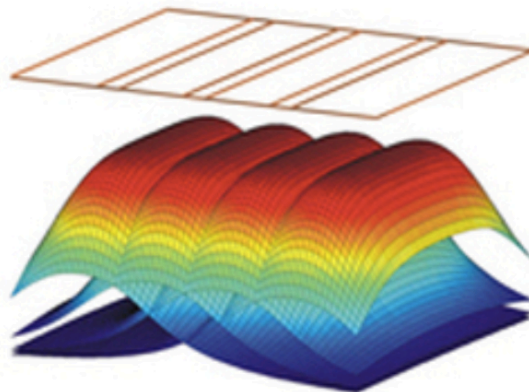
## Phased array and parallel array

MAGNETIC RESONANCE IN MEDICINE **16**, 192-225 (1990)

### The NMR Phased Array

P. B. ROEMER,\* W. A. EDELSTEIN,\* C. E. HAYES,† S. P. SOUZA,\*  
AND O. M. MUELLER\*

\*GE Corporate Research and Development Center, Schenectady, New York 12301;  
†GE Medical Systems, Milwaukee, Wisconsin 53201



# Réseau d'antennes

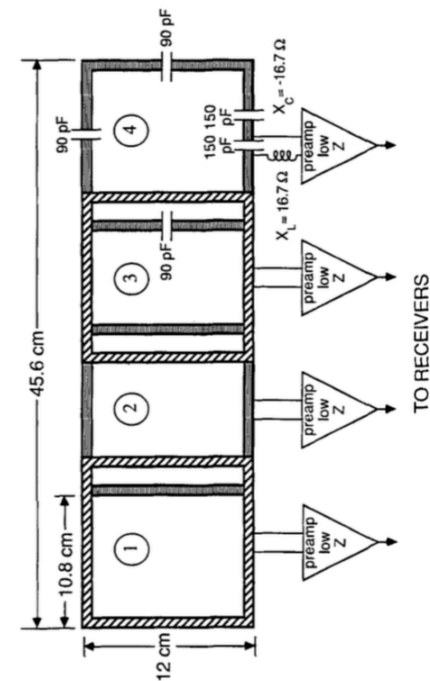
## Phased array and parallel array

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# Réseau d'antennes

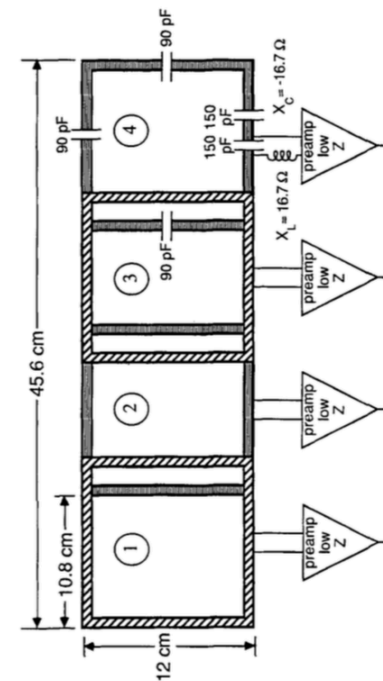
## Phased array and parallel array

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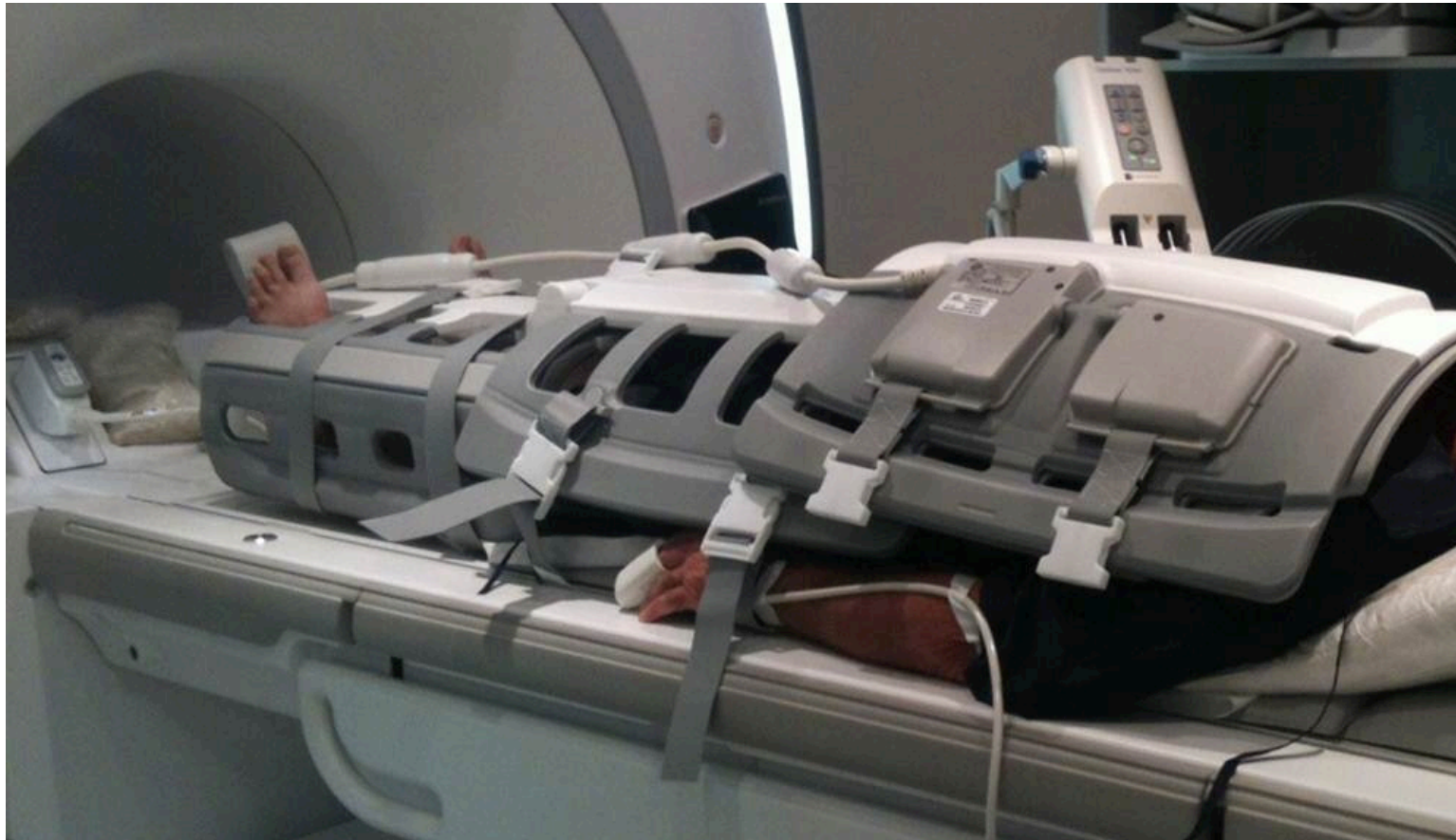




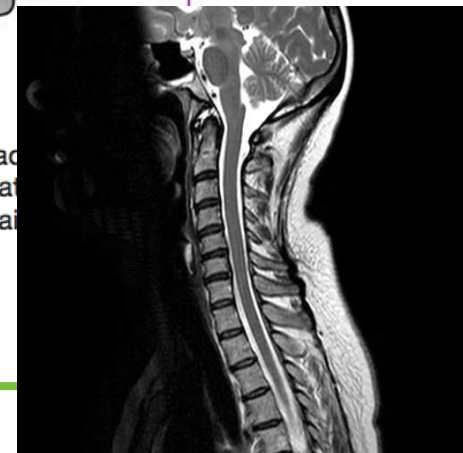
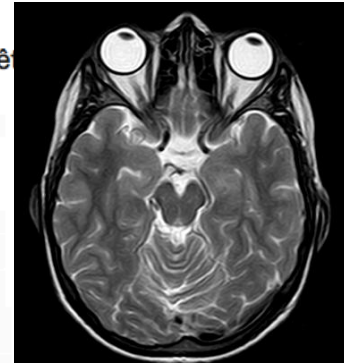
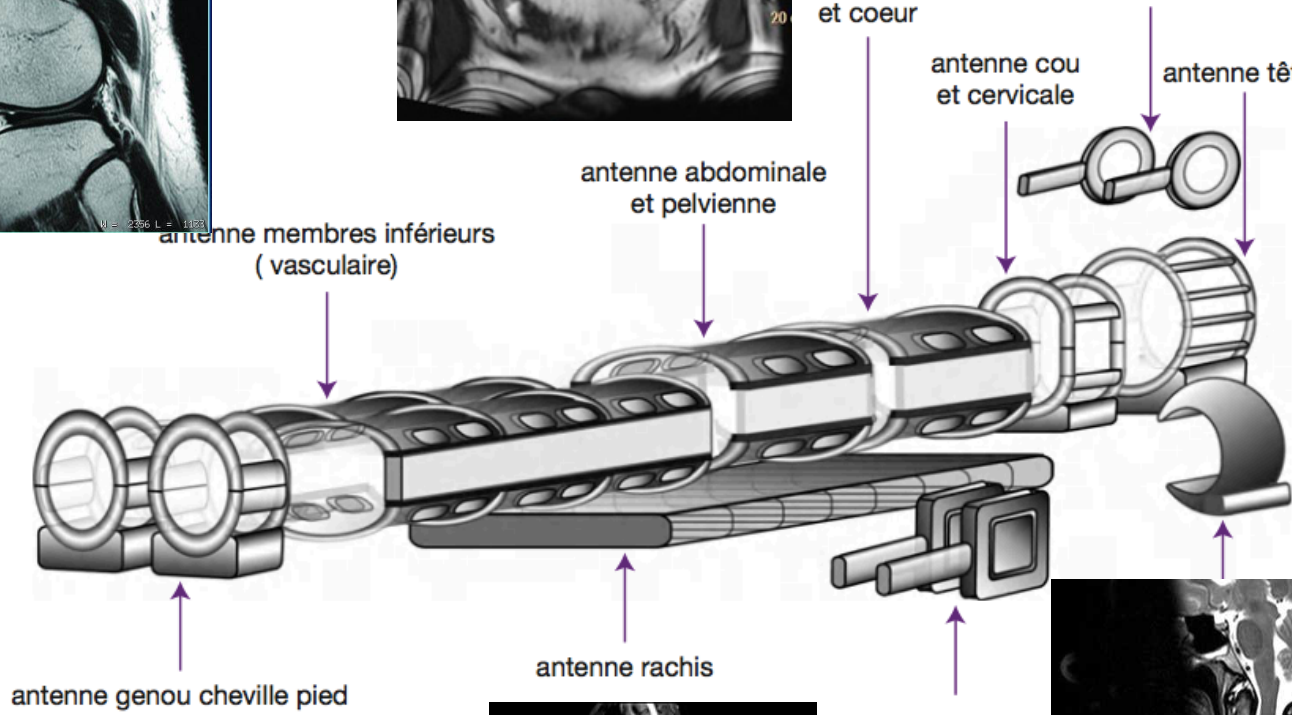
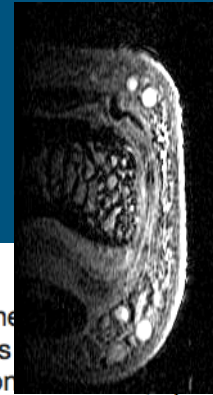
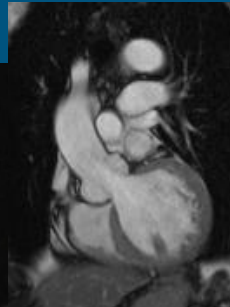
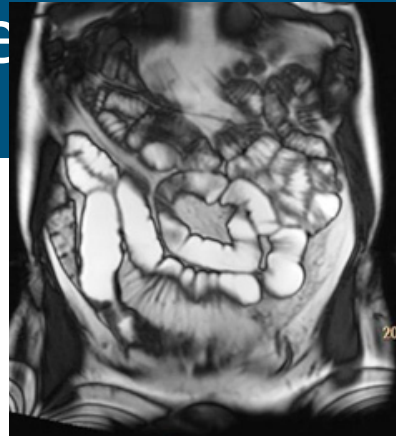
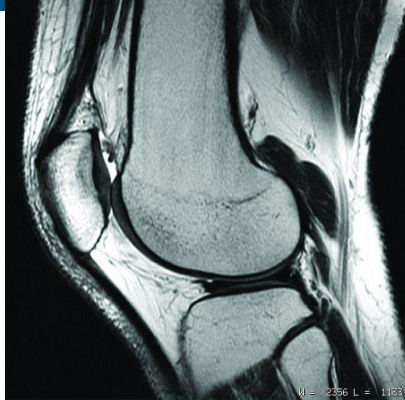
# Historique Imagerie Parallèle

- Carlson: IP → diminuer  $t_{acq}$   
JMR 1987 - vol.74 - 371
- Roemer: IP → augmenter SNR  
MRM 1989 - vol.16 – 192
- Sodickson: SMASH  
MRM 1997- vol.38 – 591
- Pruessman:SENSE  
MRM 1999- vol.42 – 952
- Griswold: GRAPPA  
MRM 2002- vol.47 – 1202

# Antennes “corps entier”



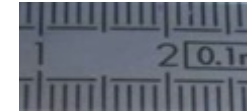
# Le



# Amélioration de la sensibilité

- Miniaturisation du capteur en cuivre
  - Diminution du bruit de l'objet observé

*Woytasik, M., et al., 2007*



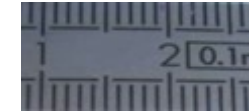
 MinaSys



# Amélioration de la sensibilité

- Miniaturisation du capteur en cuivre
  - Diminution du bruit de l'objet observé

*Woytasik, M., et al., 2007*

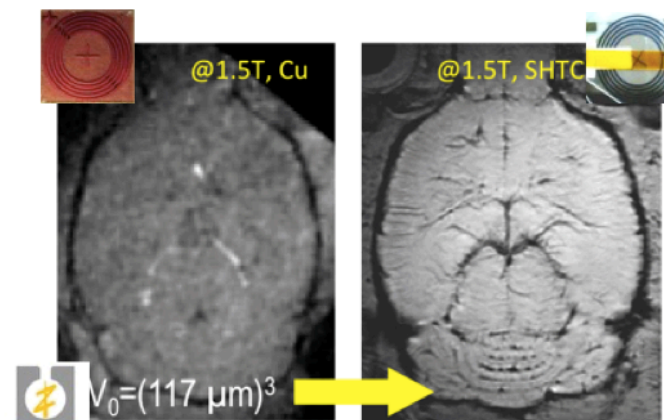
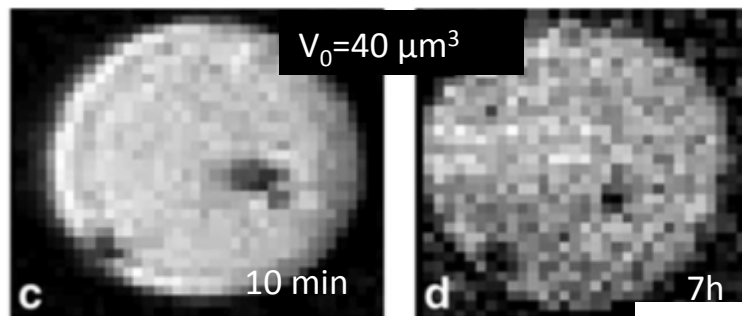


- Nouveaux matériaux, YBCO
  - Diminution du bruit du détecteur
  - Gain en RSB de 3 à 16

## A High-Temperature Superconducting Receiver for Nuclear Magnetic Resonance Microscopy

R. D. Black, T. A. Early, P. B. Roemer, O. M. Mueller, A. Mogro-Campero, L. G. Turner, G. A. Johnson

SCIENCE • VOL. 259 • 5 FEBRUARY 1993



*Présentation M. Geahel*

# Antenne multi noyau

- Measure different nuclei with MR
  - $^{31}\text{P}$ ,  $^{23}\text{Na}$ ,  $^{19}\text{F}$ ,  $^{13}\text{C}$  etc.
- Always need  $^1\text{H}$  coil
  - shimming, decoupling, localization, magnetization transfer, multi-nuclei (time interleaved), quantification, ...

# Merci

