

Receive Arrays

Titus Lanz

PHELINET 2010, Krakow



Receive Arrays

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RAPID Biomedical

Rimpar, Germany

Content

Motivation

Geometry
Decoupling
Preamplifier Dec
Active Dec
Balancing
Characterization
Tips
Examples

- § Motivation
- § Array Geometry
- § Element Decoupling
- § Preamplifier Decoupling
- § Active Decoupling
- § Balancing
- § Characterization in the MR System
- § Tips
- § Some Examples

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Motivation

Receive Arrays

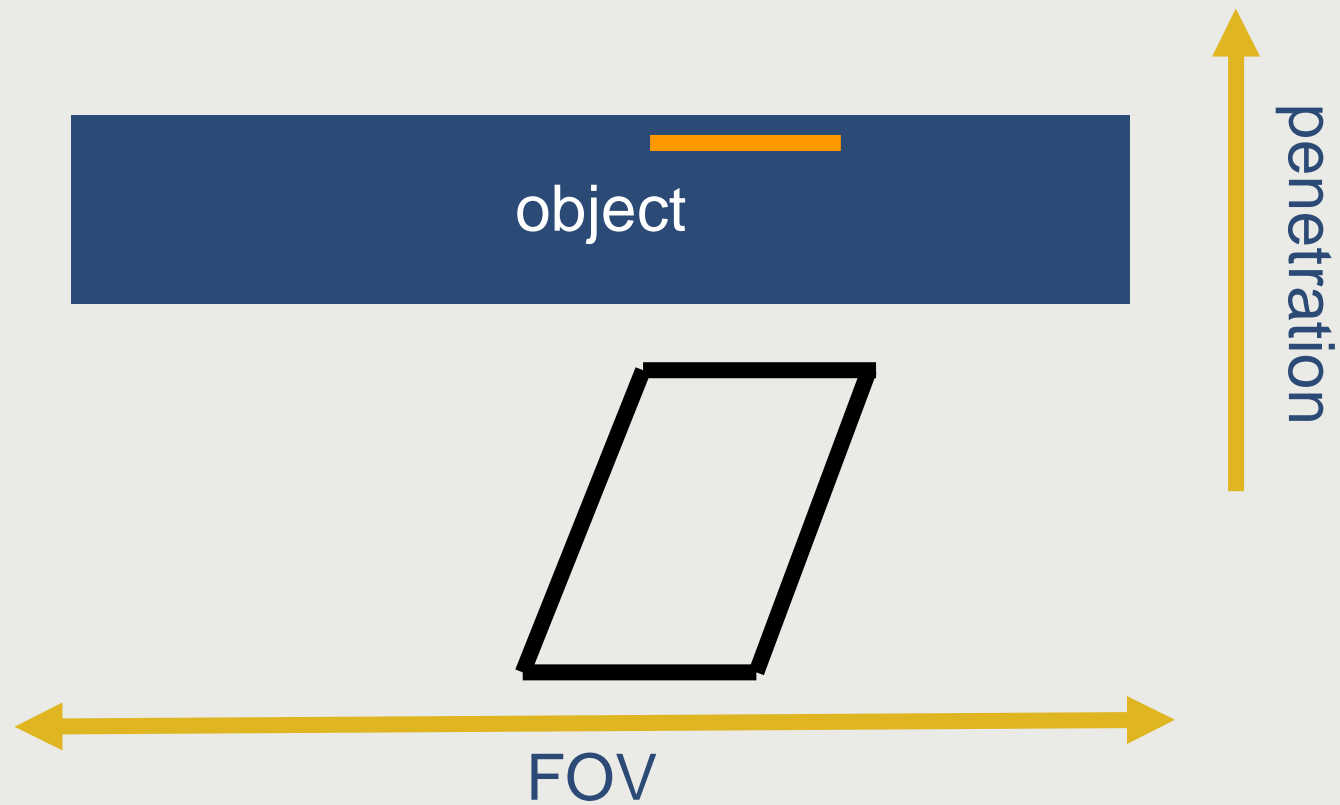
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SNR

Motivation

- Geometry
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- Examples



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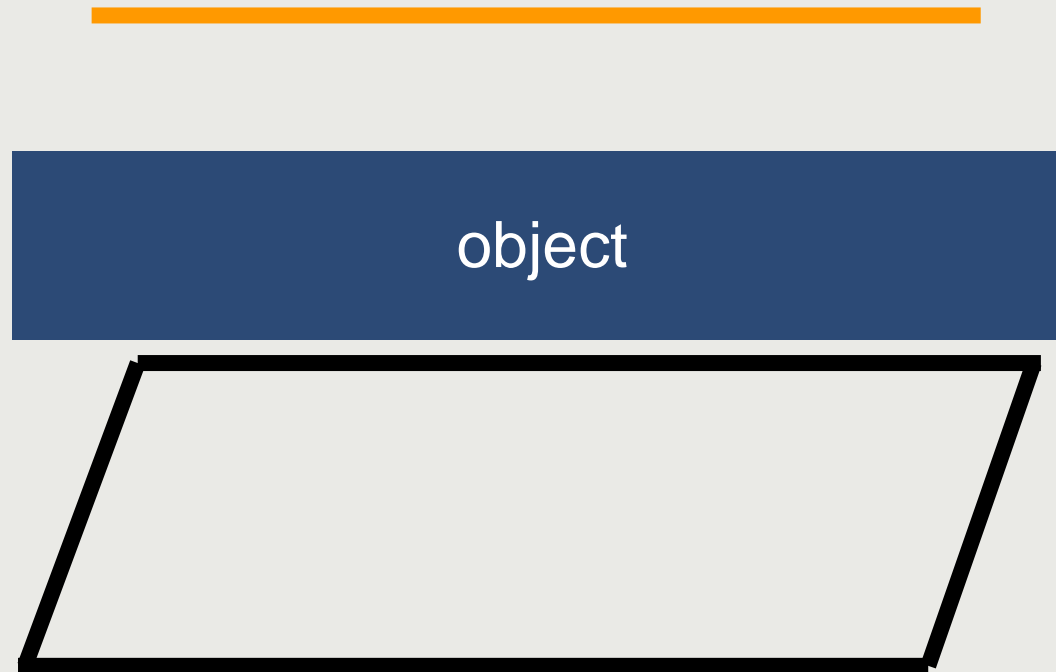
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SNR



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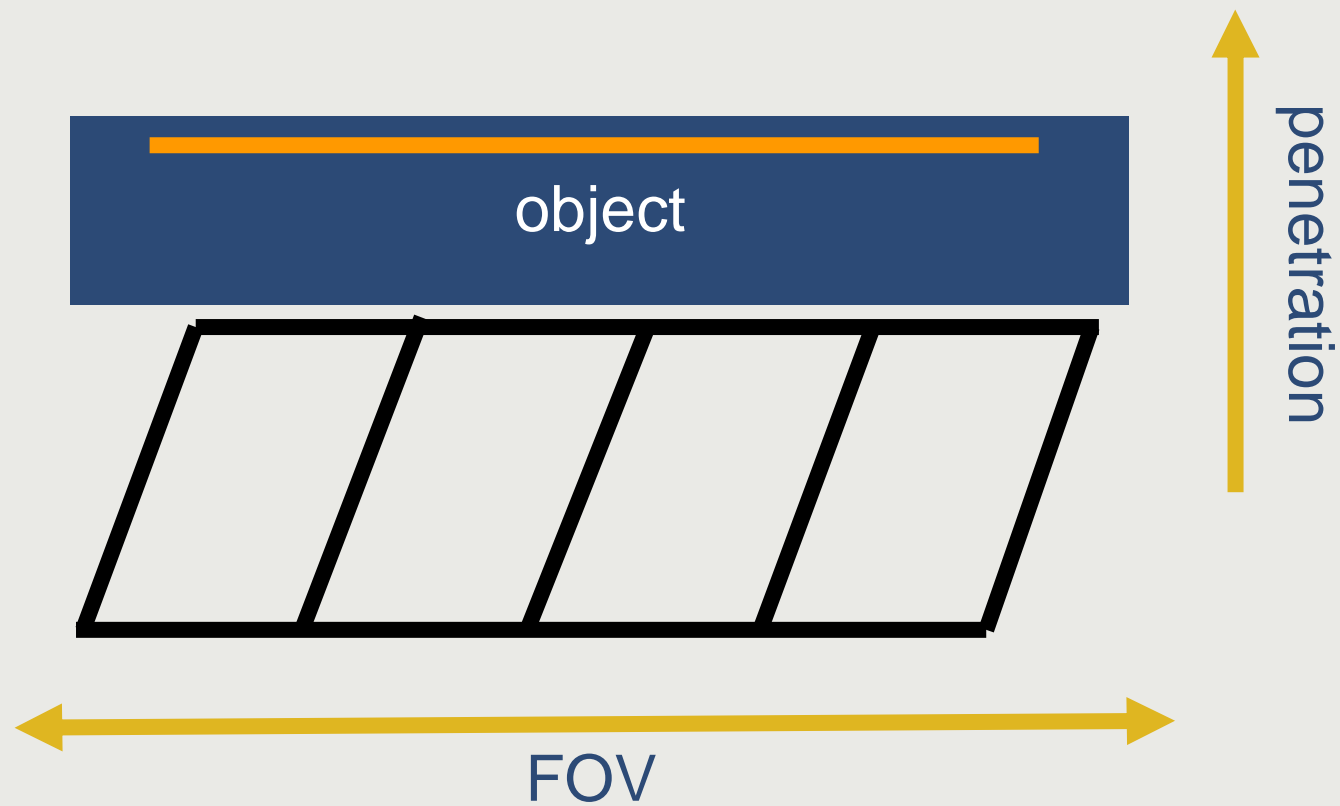
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SNR

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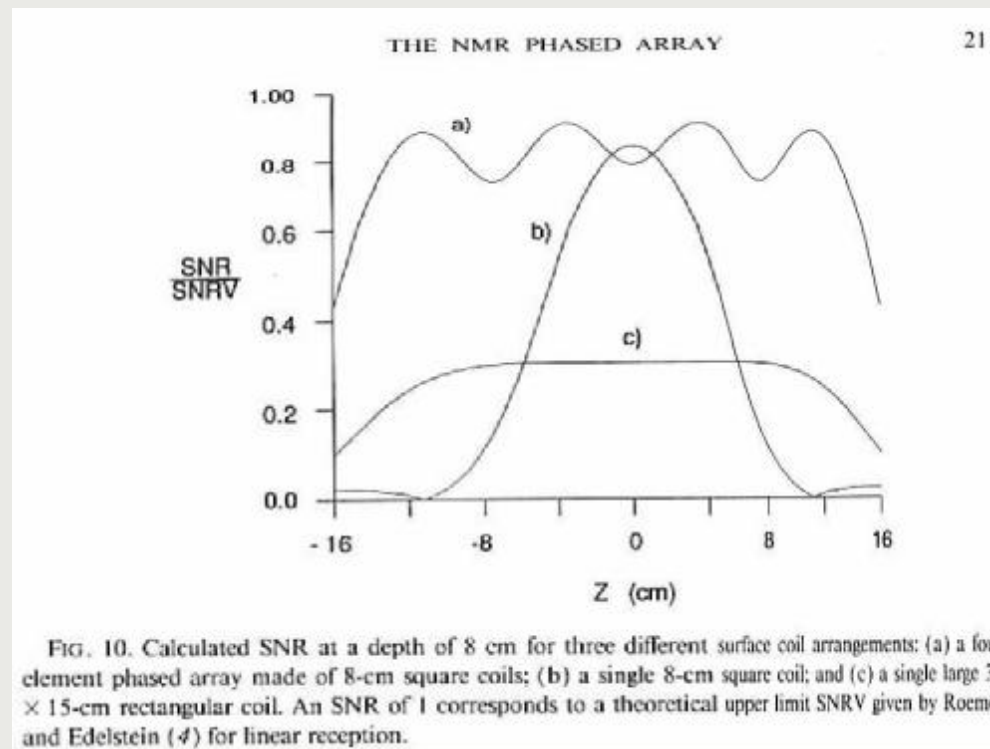


Roemer et al., MRM 16, 192 (1990)

SNR

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Roemer et al., MRM 16, 192 (1990)

SNR

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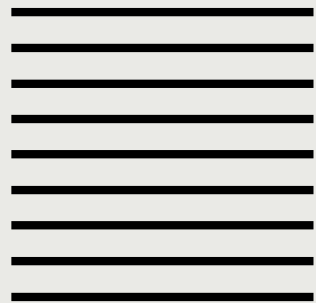
FIG. 16. Four sagittal images taken with the spine array shown in Fig. 13. Although all four coils are simultaneously receiving data, there is no sign of coupling between coils. FOV = 48 cm, 512 × 512 pixels, NEX = 2, 5 mm slice, $T_R = 400$ ms, $T_E = 20$ ms, imaging time = 6:50, $B = 1.5$ T. Phase encoding is in the y direction. Only the central 256 points in the horizontal direction are shown. Artifacts at the top and bottom of the images are due to wraparound.

Roemer et al., MRM 16, 192 (1990)

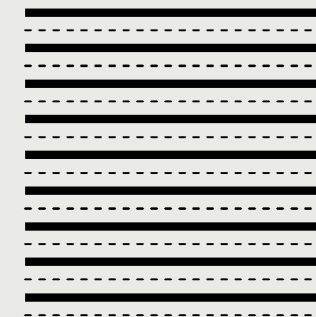
Parallel Imaging

Motivation

- Geometry
- Decoupling
- Preamplifier Dec
- Active Dec
- Balancing
- Characterization
- Tips
- Examples



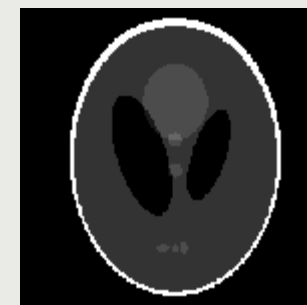
e.g. GRAPPA



k space



e.g. SENSE



image

Pruessmann et al., MRM 42, 952 (1999)

Griswold et al., MRM 47, 1202 (2002)

Parallel Imaging

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$$t_{aq} = \frac{t_{R=1}}{R}$$

$$SNR_R = \frac{SNR_{R=1}}{g\sqrt{R}}$$

Receive Arrays

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Array Geometry

Shapes

mouse spine: 1D, planar



Motivation

Geometry

Decoupling

Preamplifier Dec

Active Dec

Balancing

Characterization

Tips

Examples

Shapes

human cardiac: 2D, curved



Motivation

Geometry

Decoupling

Preamplifier Dec

Active Dec

Balancing

Characterization

Tips

Examples

Shapes

human torso: 2D, curved

Motivation

Geometry

Decoupling

Preamplifier Dec

Active Dec

Balancing

Characterization

Tips

Examples

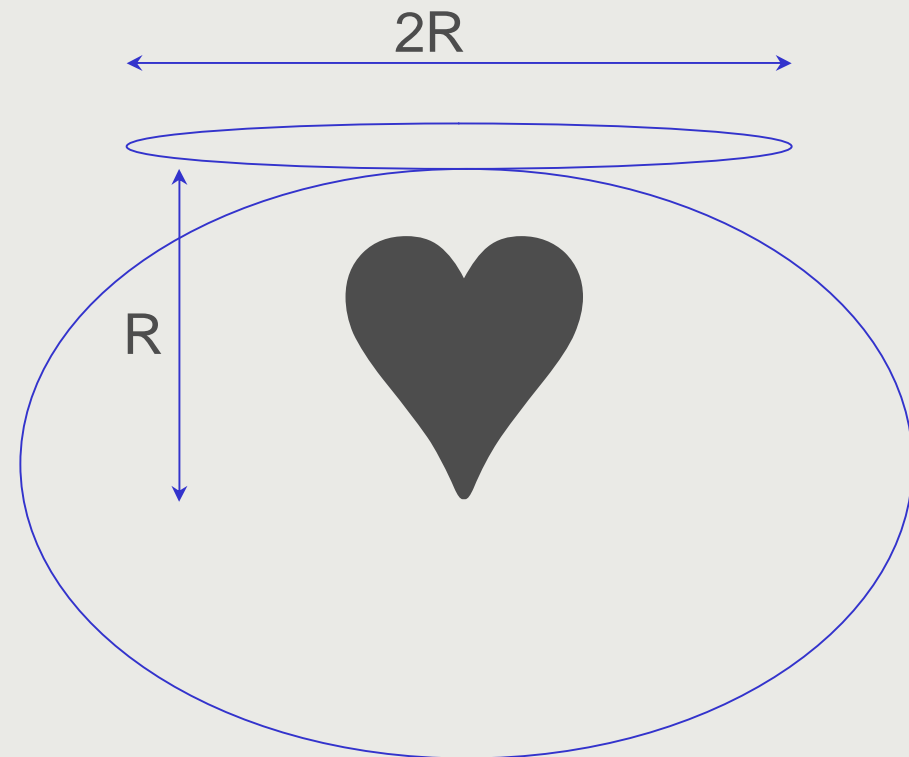


image courtesy: Melanie Schmitt, MGH

Size

§ optimum array size
(SNR):

$$D=2R$$



Motivation

Geometry

Decoupling

Preamplifier Dec

Active Dec

Balancing

Characterization

Tips

Examples

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Size: Penetration Depth

Motivation

Geometry

Decoupling

Preamplifier Dec

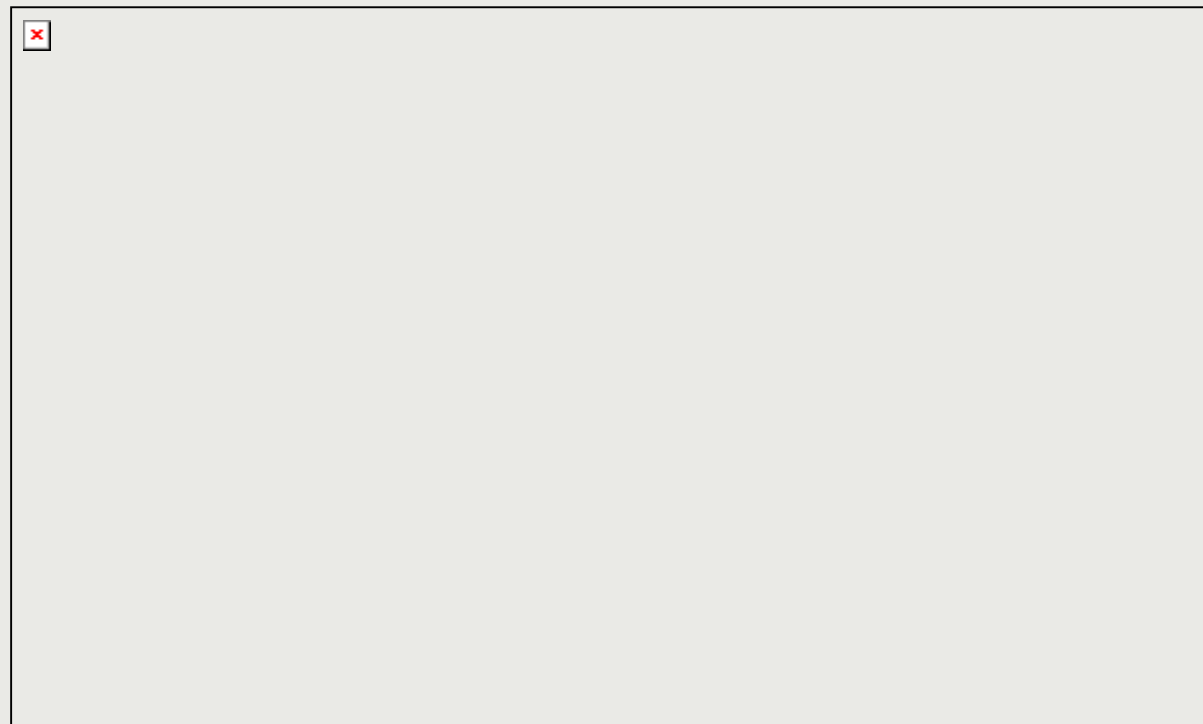
Active Dec

Balancing

Characterization

Tips

Examples



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Size: Penetration Depth

Motivation

Geometry

Decoupling

Preamplifier Dec

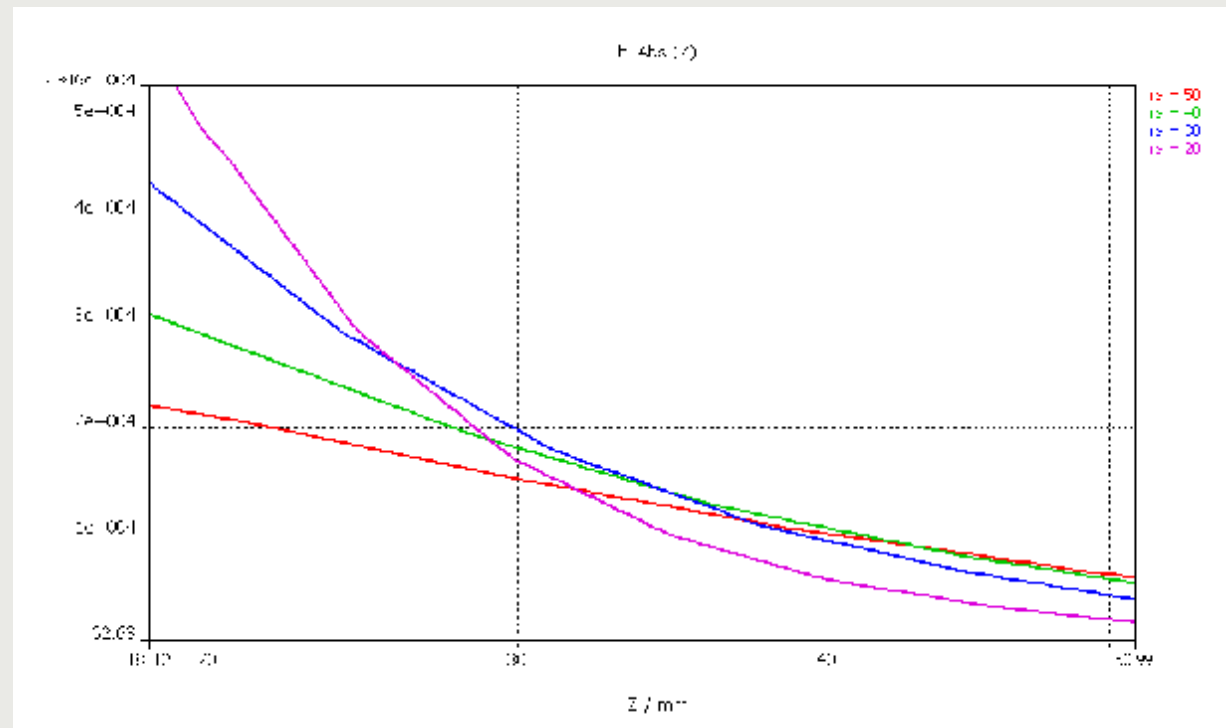
Active Dec

Balancing

Characterization

Tips

Examples



Size: Penetration Depth

Motivation

Geometry

Decoupling

Preamplifier Dec

Active Dec

Balancing

Characterization

Tips

Examples

sample noise dominated:

penetration depth = radius

coil noise dominated:

penetration depth = 1.5 * radius

Raghuraman et al, ESMRMB 2009: #714

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Size: sample noise domination

Motivation

Geometry

Decoupling

Preamplifier Dec

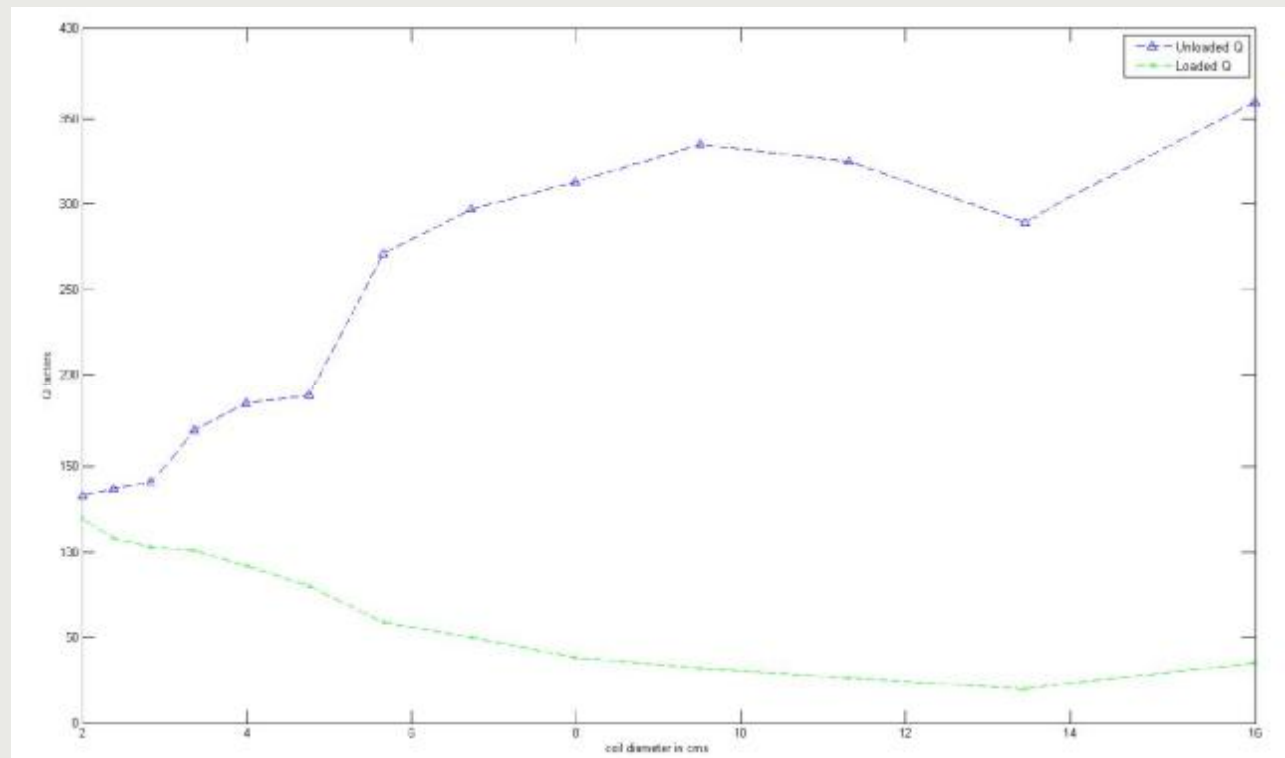
Active Dec

Balancing

Characterization

Tips

Examples

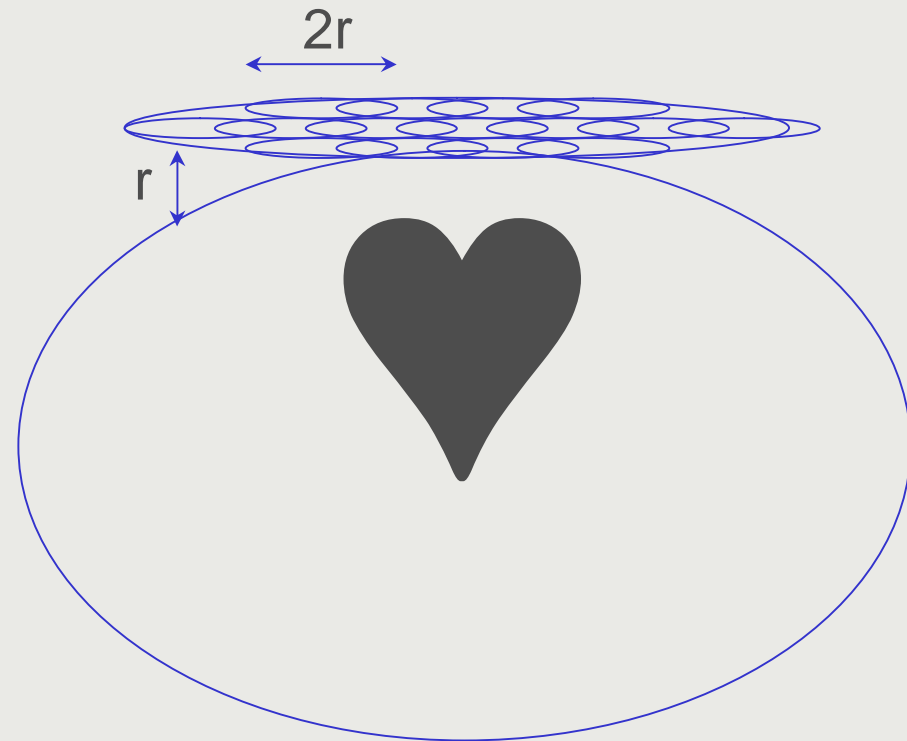


Size

§ optimum element size
(SNR):

$$d=2r$$

§ sample noise
domination



Motivation

Geometry

Decoupling

Preamplifier Dec

Active Dec

Balancing

Characterization

Tips

Examples



Size

Motivation

Geometry

Decoupling

Preamplifier Dec

Active Dec

Balancing

Characterization

Tips

Examples

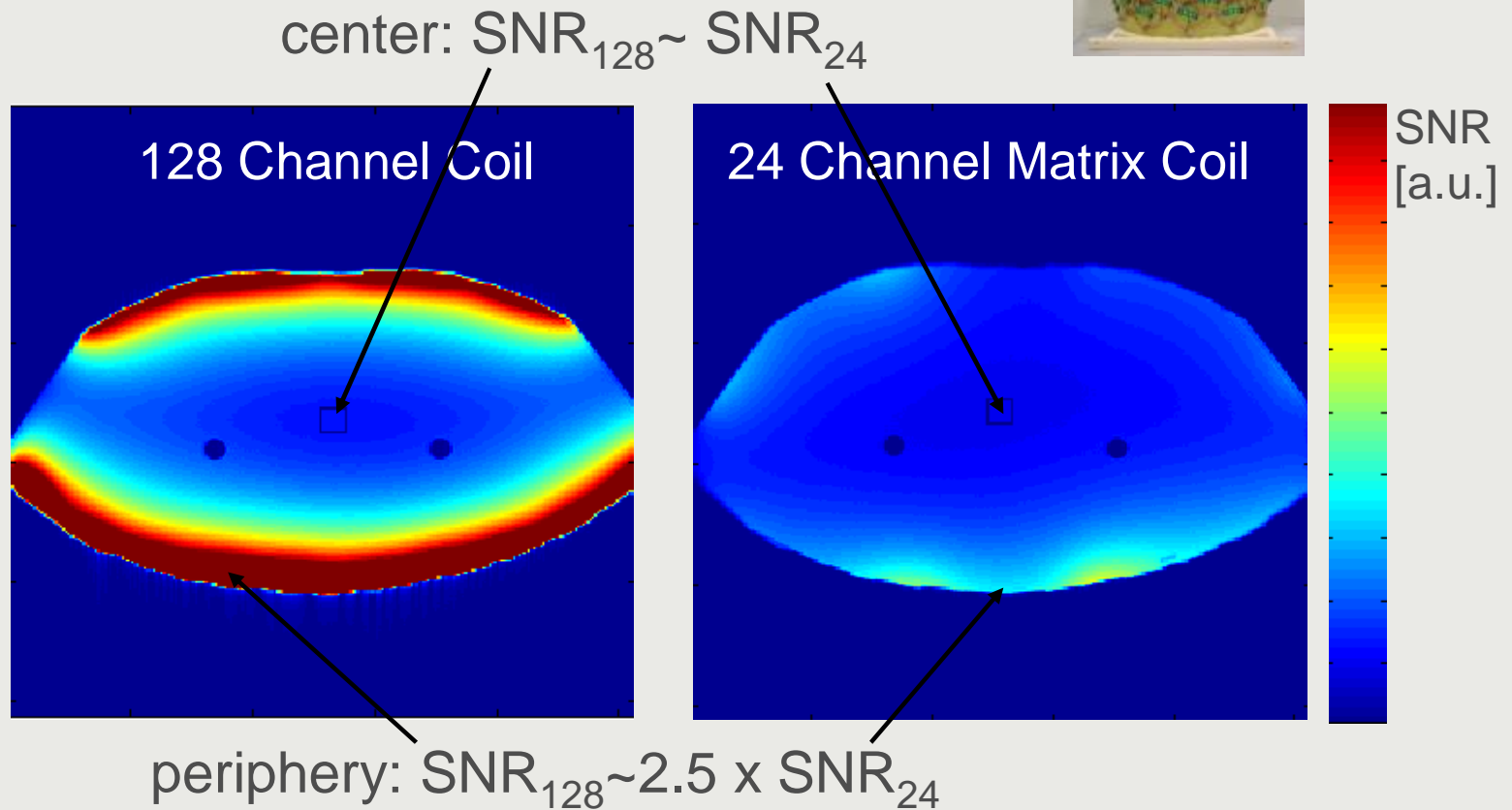


image courtesy: Melanie Schmitt, MGH

- Motivation
- Geometry
- Decoupling
- Preamplifier Dec
- Active Dec
- Balancing
- Characterization
- Tips
- Examples

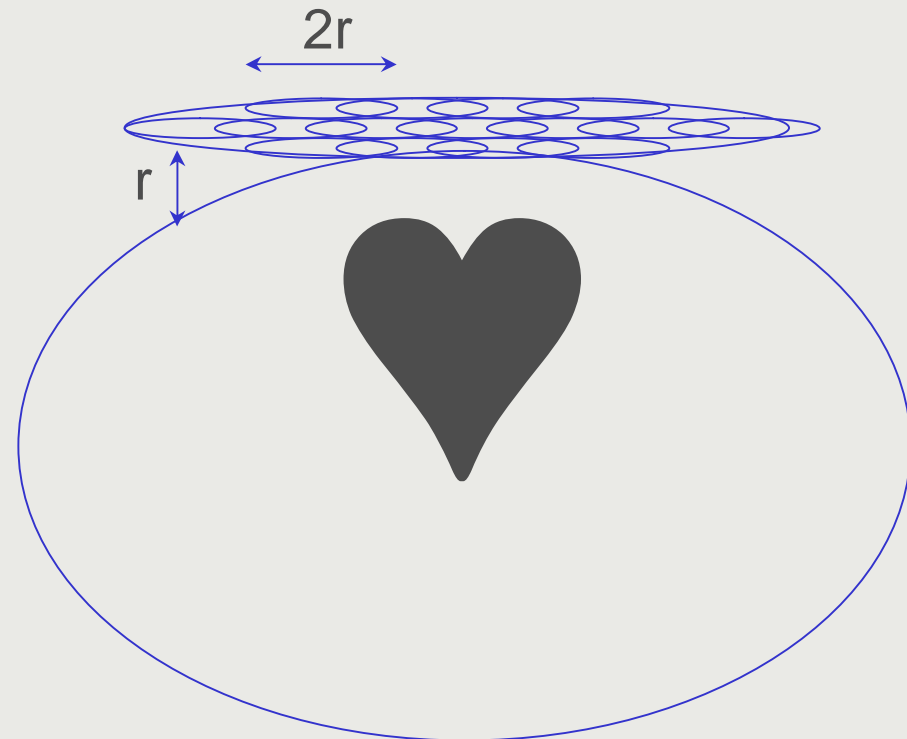
Size

§ optimum element size
(SNR):

$$d=2r$$

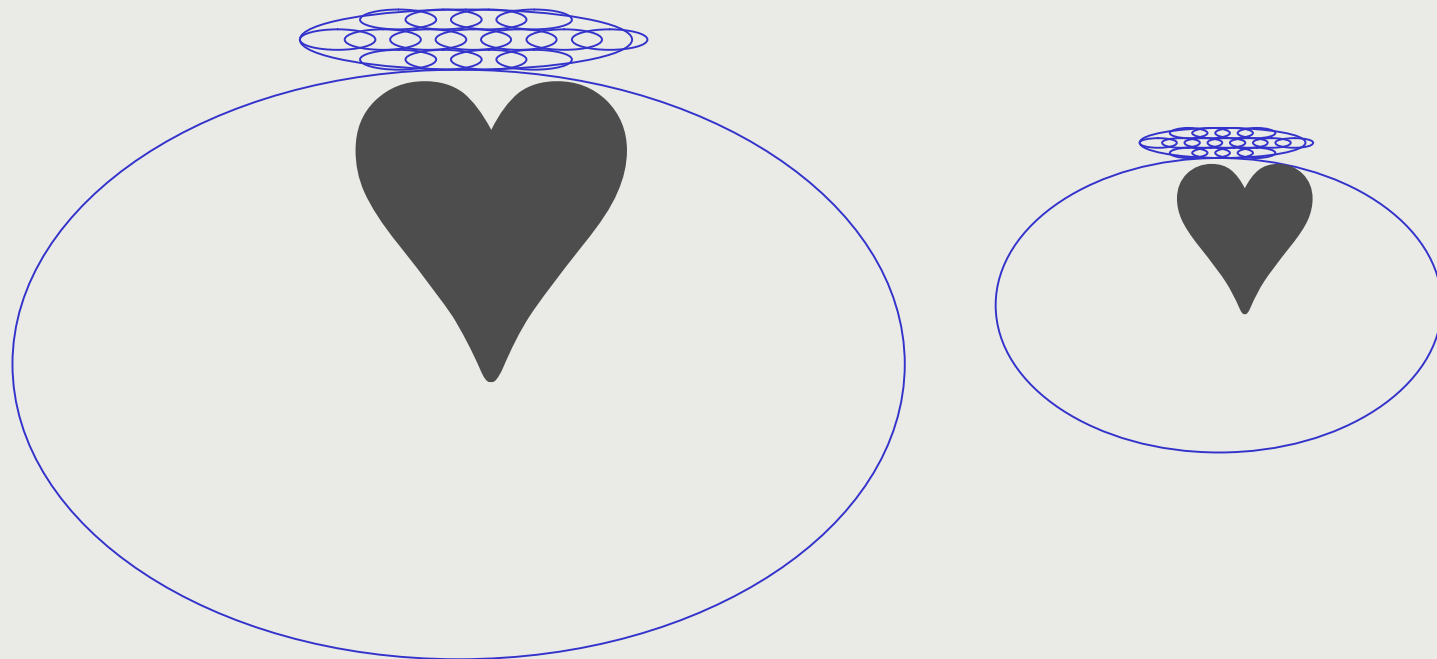
§ sample noise
domination

§ available number of
Rx channels



Size

§ adaption to patient size



Motivation

Geometry

Decoupling

Preamplifier Dec

Active Dec

Balancing

Characterization

Tips

Examples

Array Geometry: Design Criteria

§ shape: optimize filling factor

§ size: largest penetration depth

§ element number:

- smallest penetration depth
- sample noise domination
- available Rx channels
- time (money)

Motivation

Geometry

Decoupling

Preamplifier Dec

Active Dec

Balancing

Characterization

Tips

Examples

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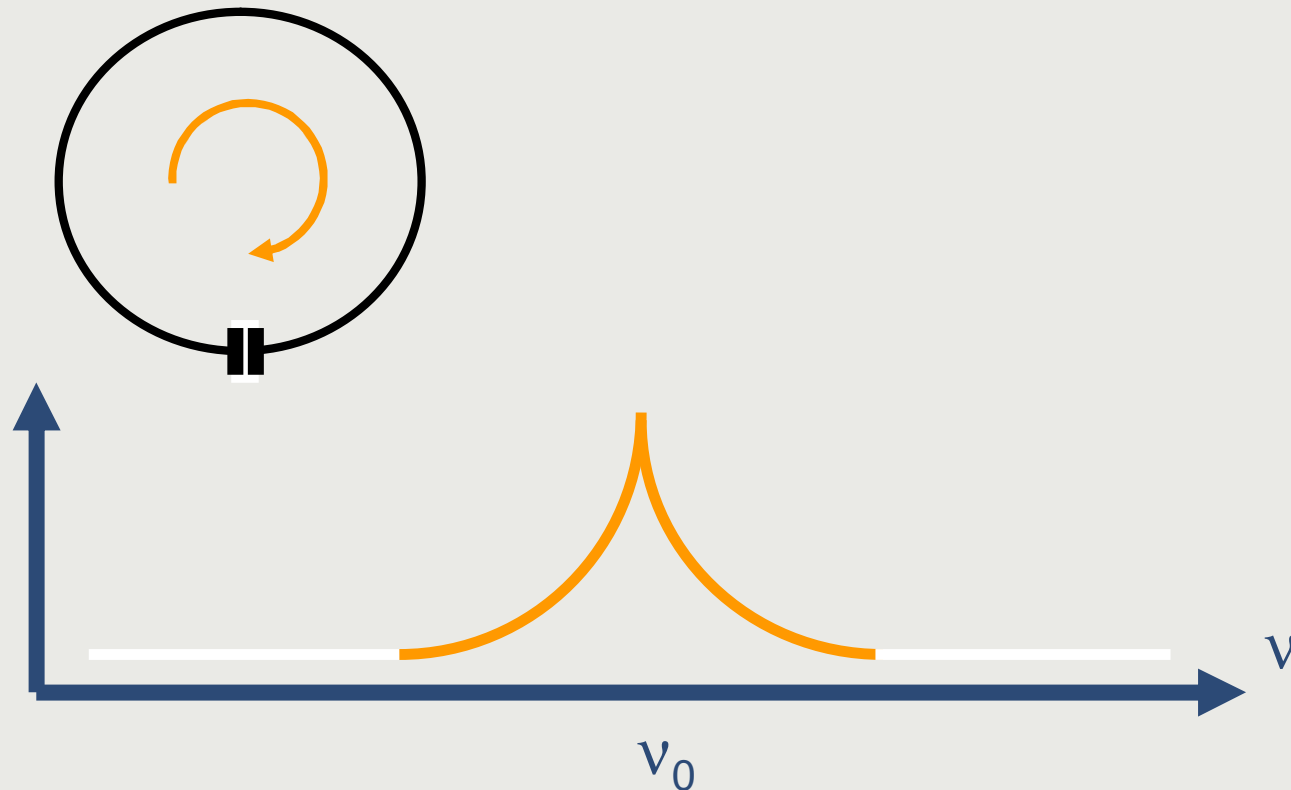
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Element Decoupling

Element Decoupling

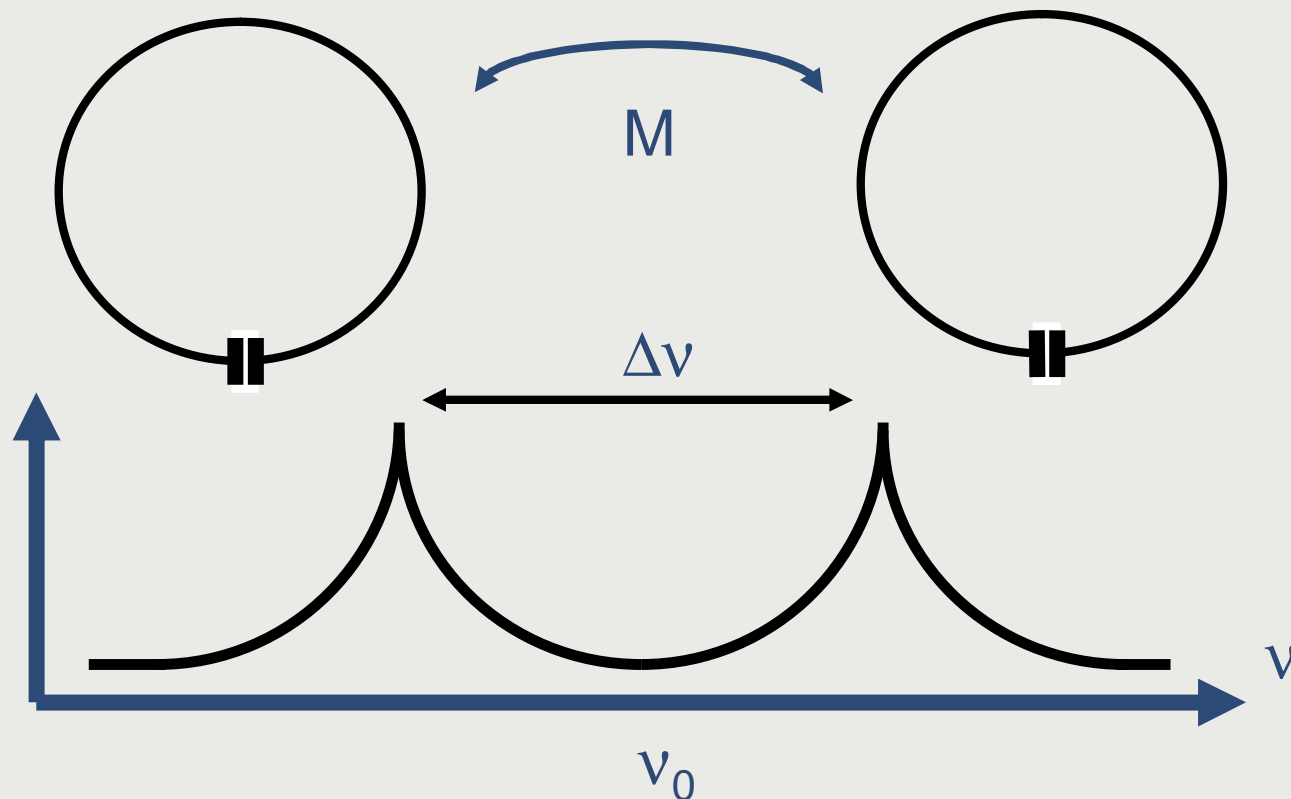
single element => single resonance



- Motivation
- Geometry
- Decoupling
- Preamplifier Dec
- Active Dec
- Balancing
- Characterization
- Tips
- Examples

Element Decoupling

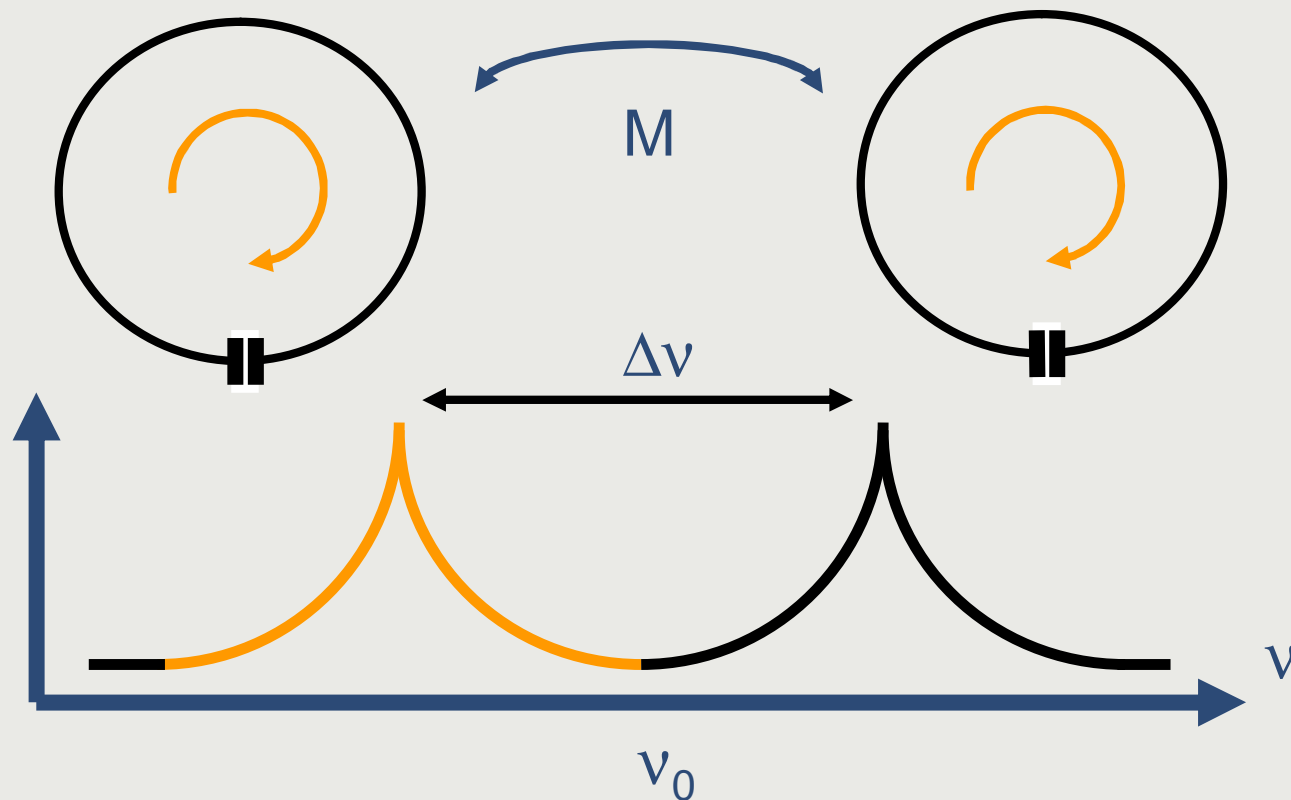
coupling elements => two resonances



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- Geometry
- Decoupling
- Preamplifier Dec
- Active Dec
- Balancing
- Characterization
- Tips
- Examples

Element Decoupling

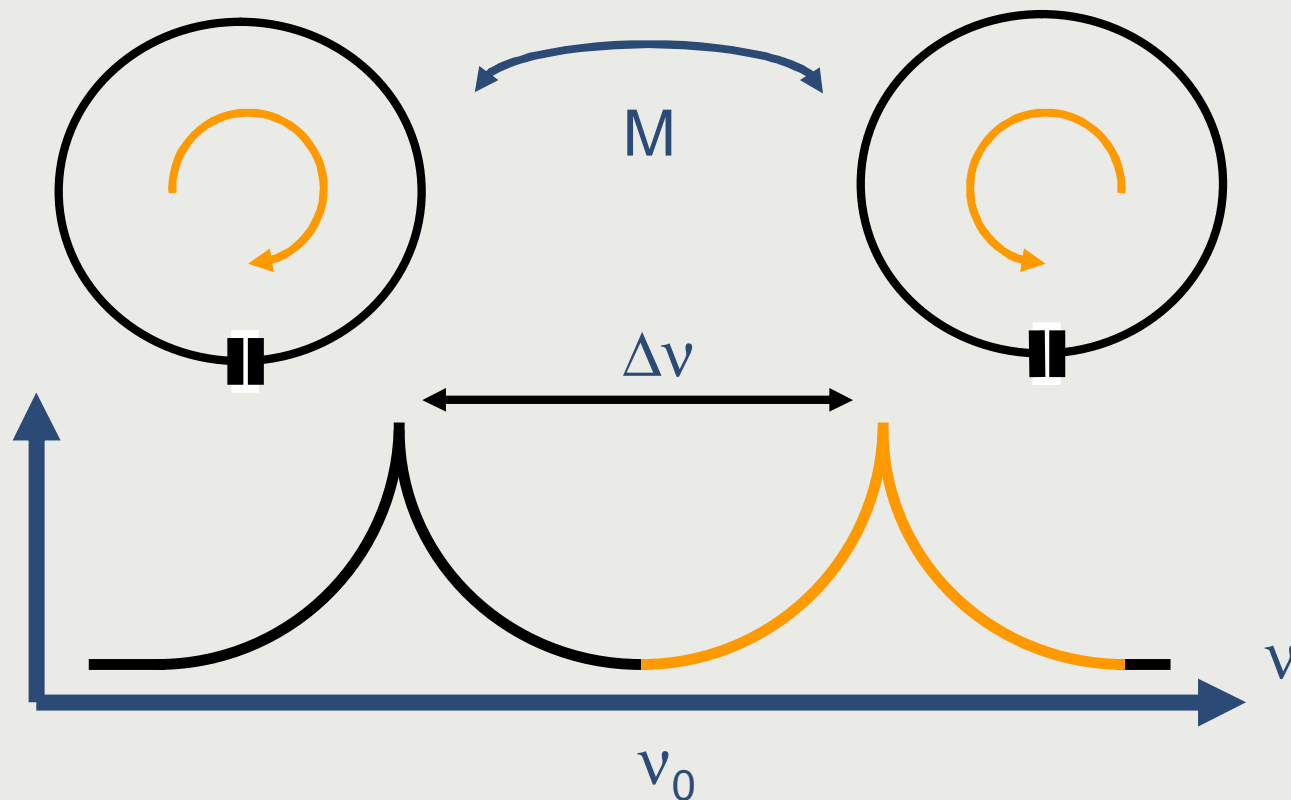
lower frequency in phase



- Motivation
- Geometry
- Decoupling
- Preamplifier Dec
- Active Dec
- Balancing
- Characterization
- Tips
- Examples

Element Decoupling

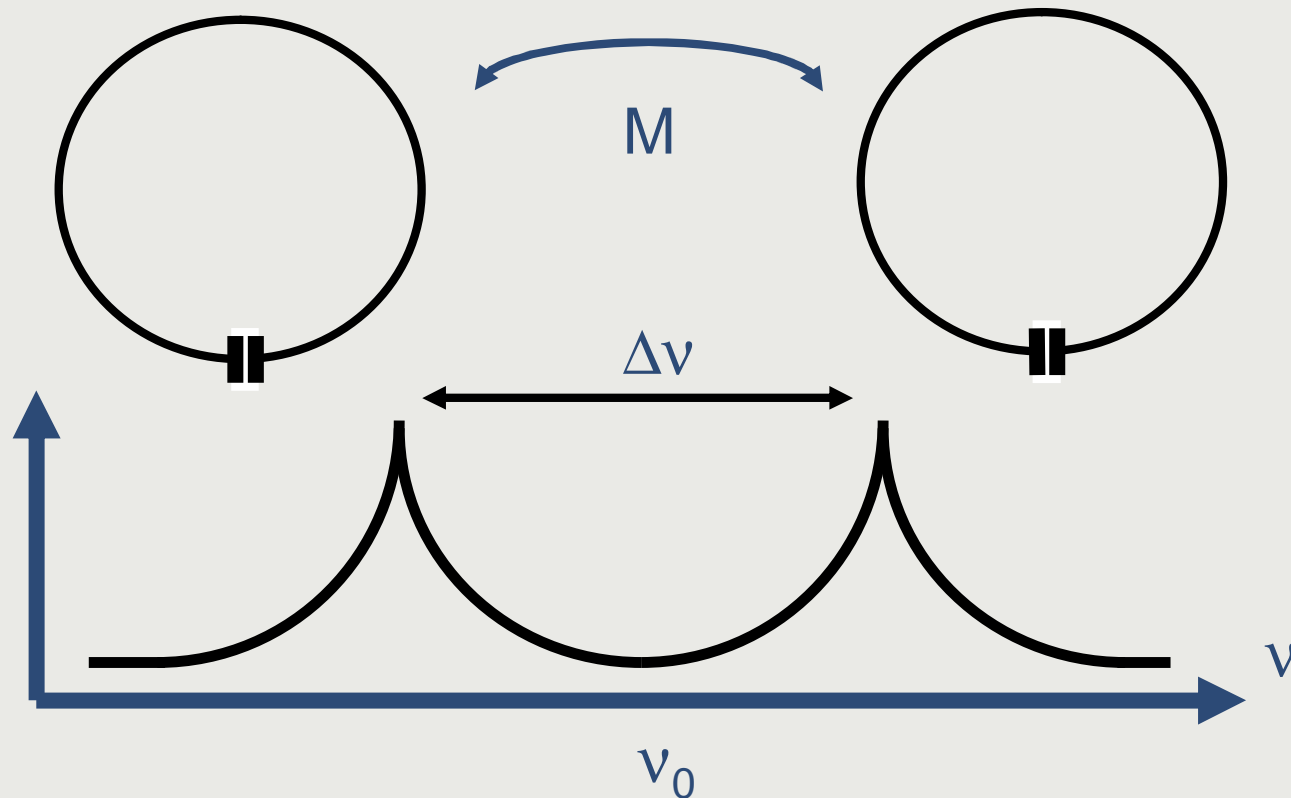
higher frequency with opposite phase



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- Geometry
- Decoupling
- Preamplifier Dec
- Active Dec
- Balancing
- Characterization
- Tips
- Examples

Element Decoupling

measure for coupling: $\Delta v/v_0$

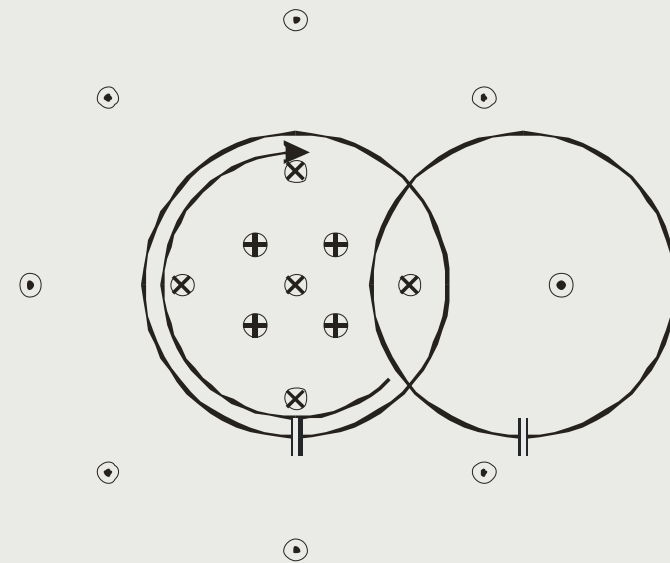


- Motivation
- Geometry
- Decoupling
- Preamplifier Dec
- Active Dec
- Balancing
- Characterization
- Tips
- Examples

Overlap Decoupling

Motivation
Geometry
Decoupling
Preamplifier Dec
Active Dec
Balancing
Characterization
Tips
Examples

- J it's an array
- J broadband
- J catches all signal flux
- J no "holes" in profile
- J series production



$$U_{ind} = -\dot{\Phi} = 0$$

Roemer et al., MRM 16, 192 (1990)

Overlap Decoupling

Motivation
Geometry
Decoupling
Preamplifier Dec
Active Dec
Balancing
Characterization
Tips
Examples

- J it's an array
- J broadband
- J catches all signal flux
- J no "holes" in profile
- J series production
- L goldsmith work
- L bad separation of profiles

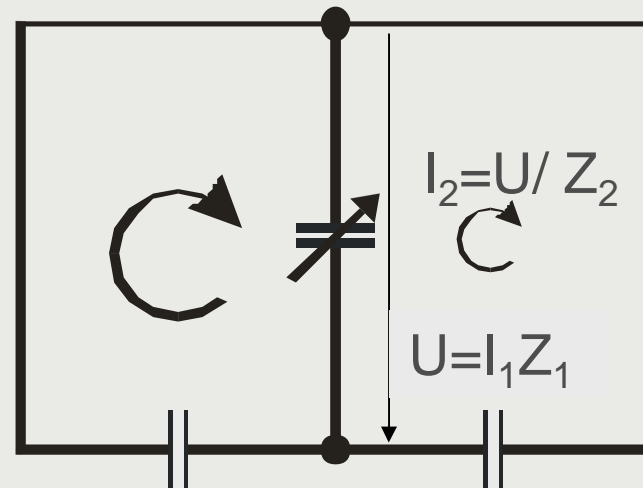


Roemer et al., MRM 16, 192 (1990)

Shared Conductor Decoupling

Motivation
Geometry
Decoupling
Preamplifier Dec
Active Dec
Balancing
Characterization
Tips
Examples

- J adjusted by C
- J one-of-a-kind coils
- J catches all signal flux
- L adjusted by C
- L narrow band

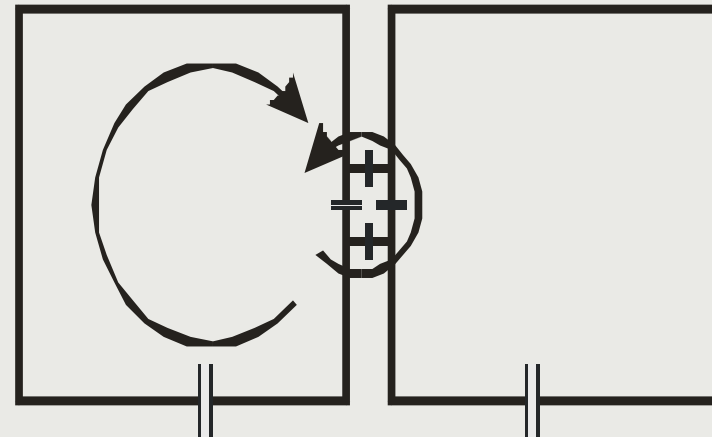


Wang et al., ISMRM 4(1996), #1434

Gap Designs

Motivation
Geometry
Decoupling
Preamplifier Dec
Active Dec
Balancing
Characterization
Tips
Examples

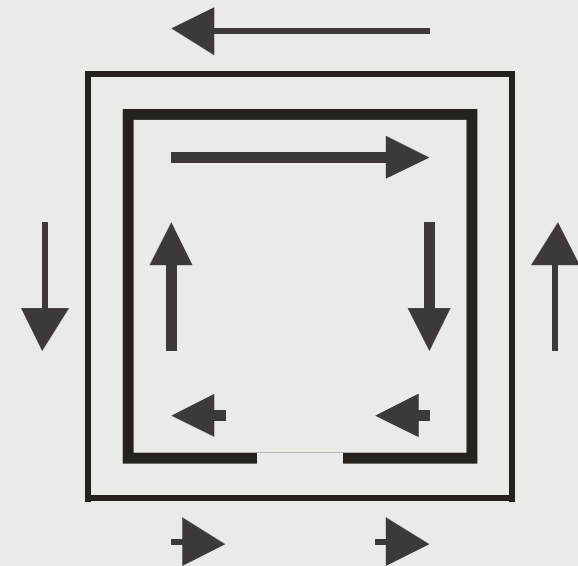
- J adjusted by C
- J one-of-a-kind coils
- J good profile separation
- L narrow band
- L signal flux lost
- L "holes" in profile
- L many parts



de Zwart et al., MRM 2002, 47:1218

Decoupling by Shielding

Motivation
Geometry
Decoupling
Preamplifier Dec
Active Dec
Balancing
Characterization
Tips
Examples



Lanz et al., ISMRM 14(2006), #217

Zhang et al., MRM 2001, 46: 443

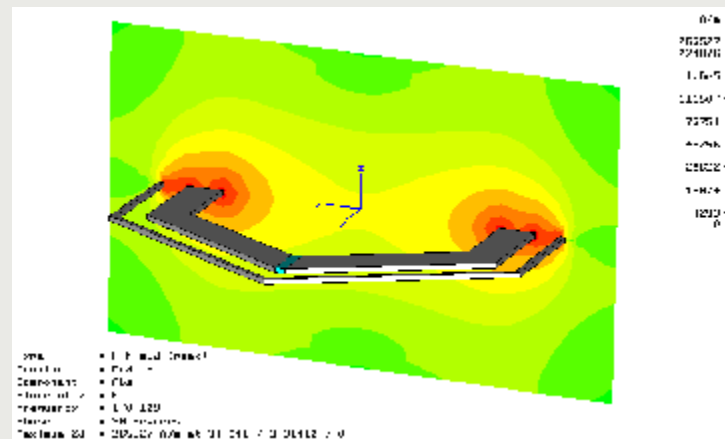
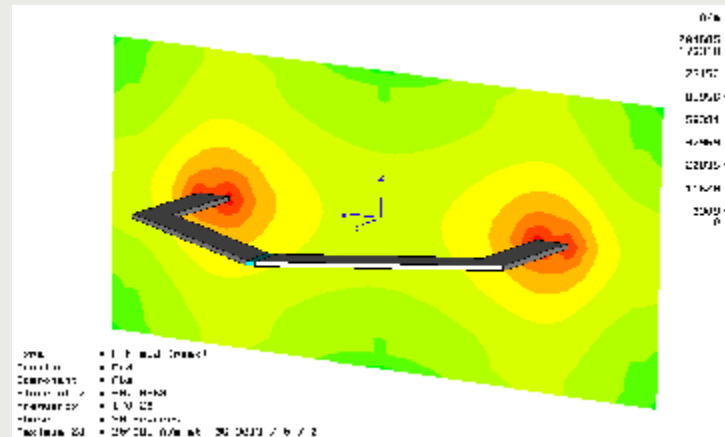
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Decoupling by Shielding

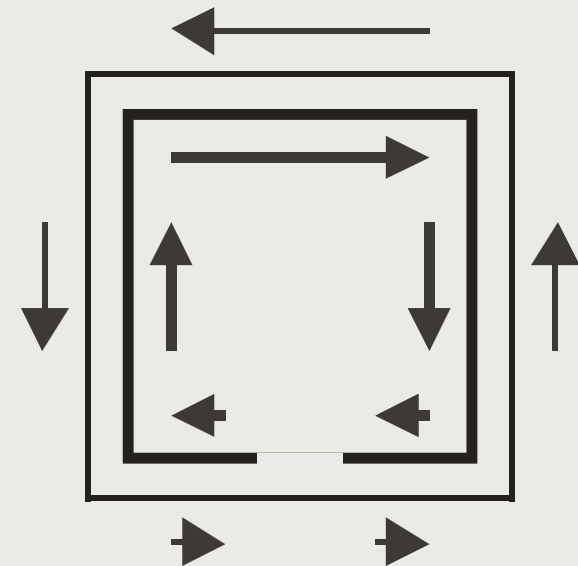
- Motivation
- Geometry
- Decoupling
- Preamplifier Dec
- Active Dec
- Balancing
- Characterization
- Tips
- Examples



Decoupling by Shielding

Motivation
Geometry
Decoupling
Preamplifier Dec
Active Dec
Balancing
Characterization
Tips
Examples

- J Tx / Rx designs
- J low effect of sample on v
- J adjust elements separately



Lanz et al., ISMRM 14(2006), #217

Zhang et al., MRM 2001, 46: 443

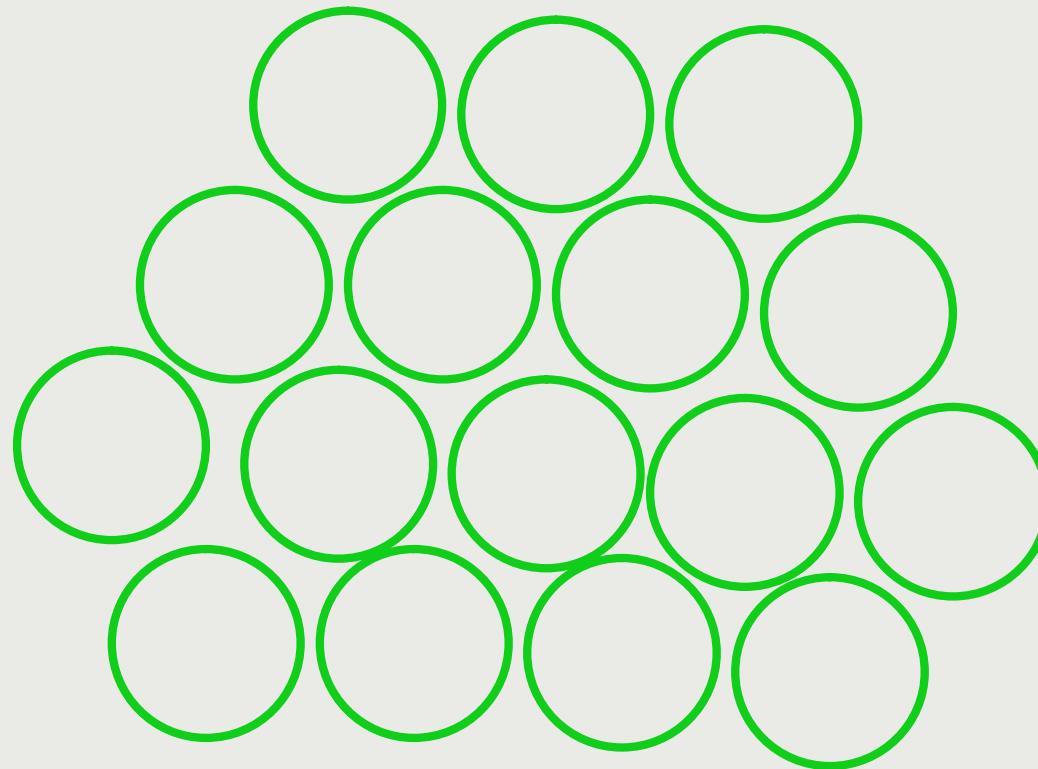
Decoupling by Shielding

- Motivation
- Geometry
- Decoupling**
- Preamplifier Dec
- Active Dec
- Balancing
- Characterization
- Tips
- Examples



Decoupling by Shielding

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- Geometry
- Decoupling**
- Preamplifier Dec
- Active Dec
- Balancing
- Characterization
- Tips
- Examples



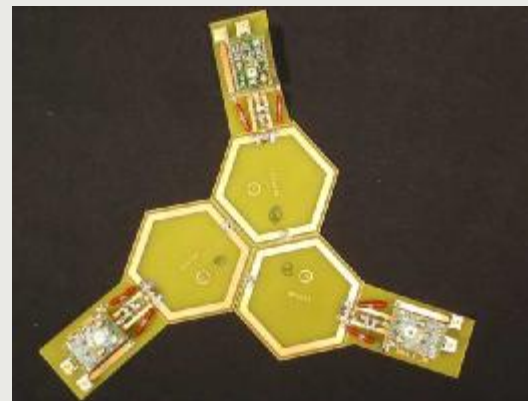
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Decoupling by Shielding

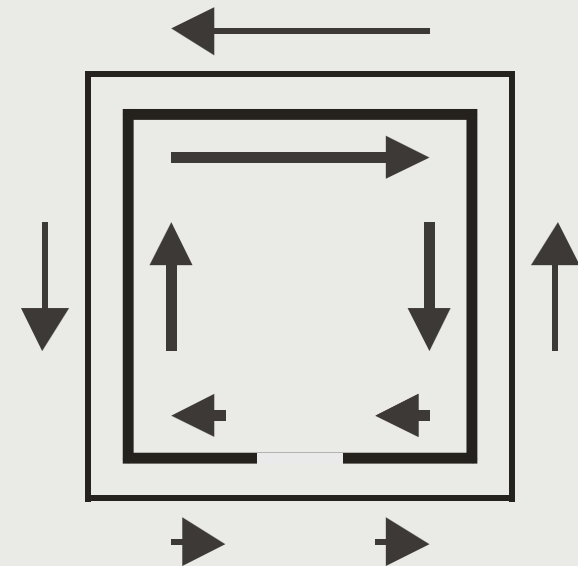
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- Geometry
- Decoupling
- Preamplifier Dec
- Active Dec
- Balancing
- Characterization
- Tips
- Examples



Decoupling by Shielding

Motivation
Geometry
Decoupling
Preamplifier Dec
Active Dec
Balancing
Characterization
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Examples

- J Tx / Rx designs
- J low effect of sample on v
- J adjust elements separately
- L lower SNR
- L many parameters
- L asymmetric B1 field
- L lower sensitivity



Lanz et al., ISMRM 14(2006), #217

Zhang et al., MRM 2001, 46: 443

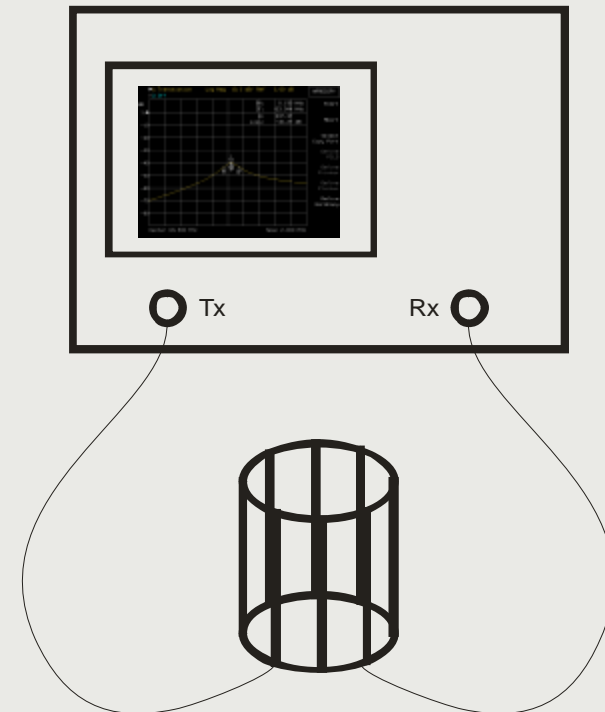
Measure Element Decoupling

Motivation
Geometry
Decoupling
Preamplifier Dec
Active Dec
Balancing
Characterization
Tips
Examples

§ Channels independent

§ goal: $< -20\text{dB}$ (usually)

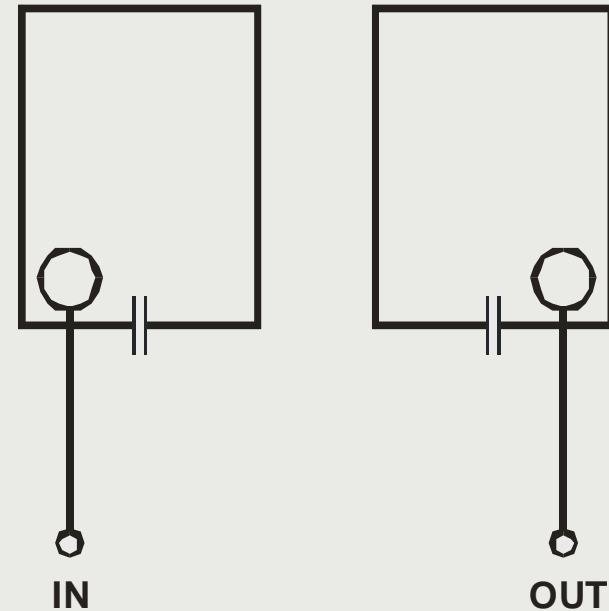
§ measure S_{12}



Measure Element Decoupling

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- Geometry
- Decoupling
- Preamplifier Dec
- Active Dec
- Balancing
- Characterization
- Tips
- Examples

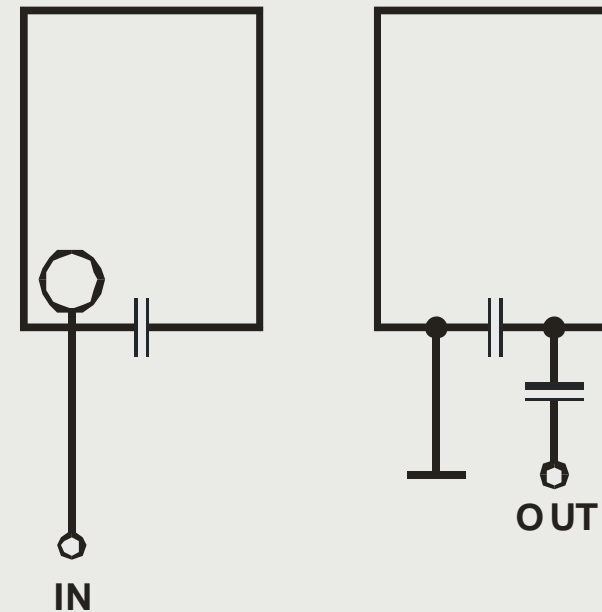
§ two weakly coupled loops



Measure Element Decoupling

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- Geometry
- Decoupling
- Preamplifier Dec
- Active Dec
- Balancing
- Characterization
- Tips
- Examples

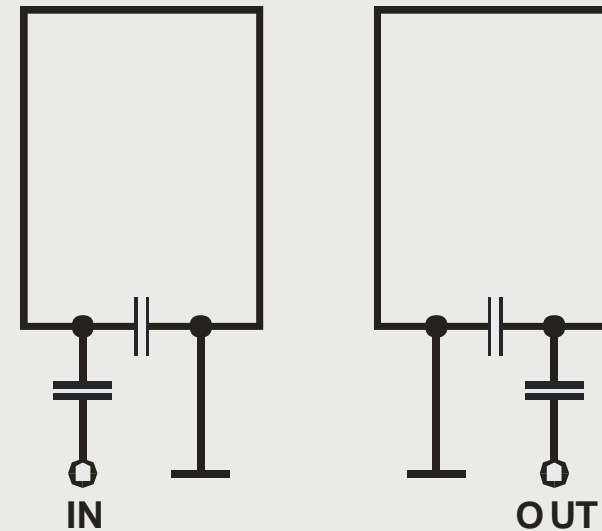
§ one loop, one coupling network



Measure Element Decoupling

- Motivation
- Geometry
- Decoupling
- Preamplifier Dec
- Active Dec
- Balancing
- Characterization
- Tips
- Examples

§ two coupling networks



Preamplifier Decoupling

Preamplifier Decoupling

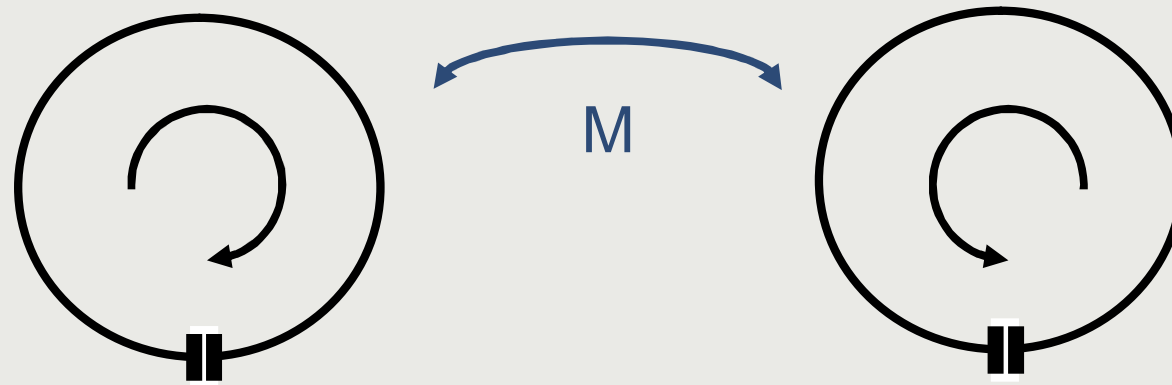
§ next neighbours decoupled by overlap / shared inductor

§ need decoupling of other element pairs

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- Geometry
- Decoupling
- Preamplifier Dec**
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- Balancing
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- Tips
- Examples

Preamplifier Decoupling

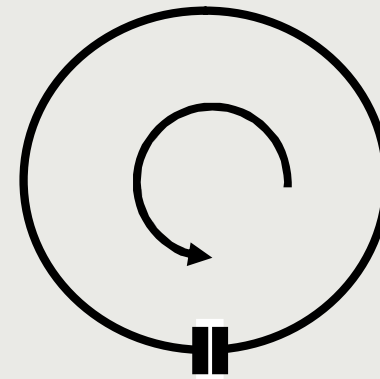
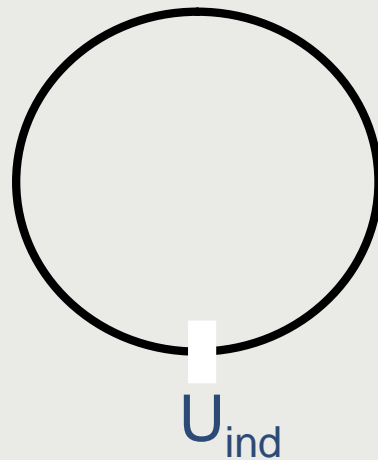
§ coupling means inducing current



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- Geometry
- Decoupling
- Preamplifier Dec
- Active Dec
- Balancing
- Characterization
- Tips
- Examples

Preamplifier Decoupling

§ coupling means inducing current

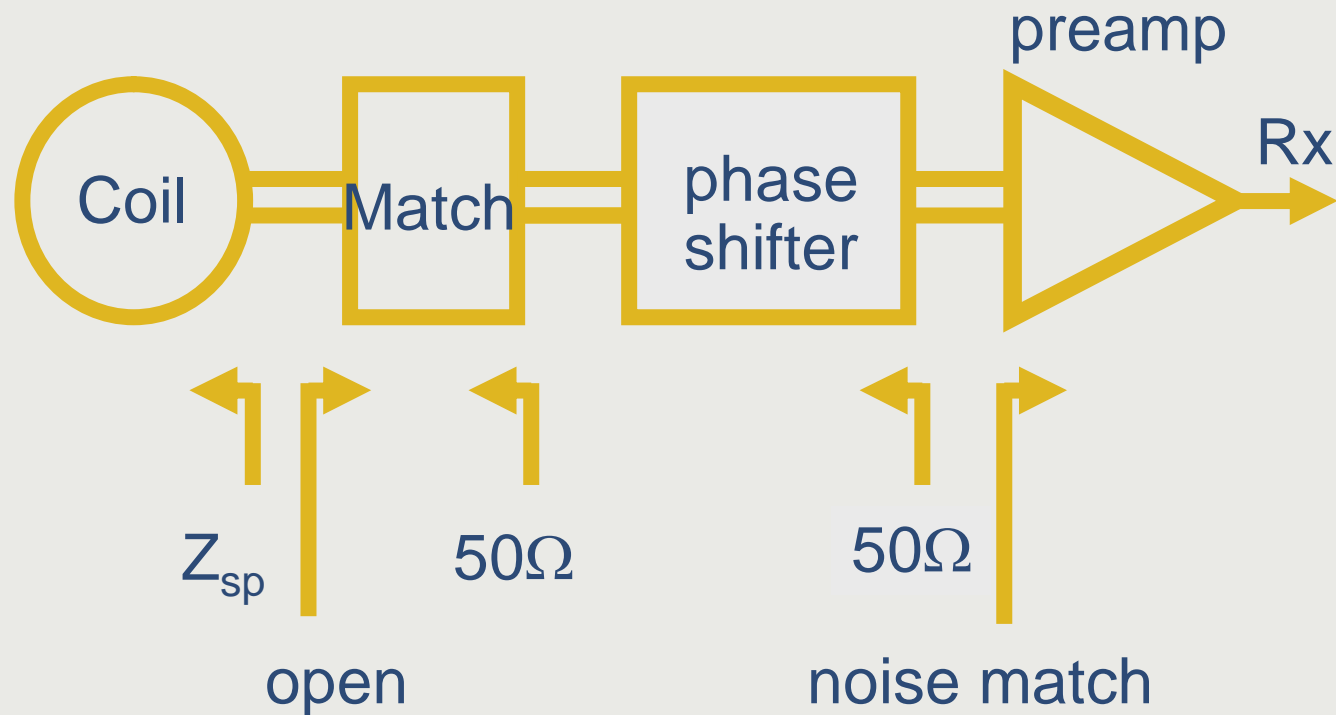


§ idea: no current needed for signal detection (voltage!)

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- Geometry
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- Preamplifier Dec
- Active Dec
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- Examples

Preamplifier Decoupling

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- Geometry
- Decoupling
- Preamplifier Dec**
- Active Dec
- Balancing
- Characterization
- Tips
- Examples

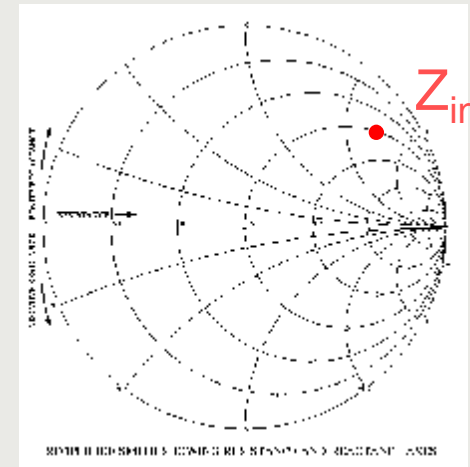


Roemer et al., MRM 1990, 16:192

Preamplifier decoupling

§ phase shift:

- _ 50Ohm line rotates around 50Ohm
- _ cable
- _ lumped elements



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- Preamplifier Dec
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- Characterization
- Tips
- Examples

Measure Preamplifier Decoupling

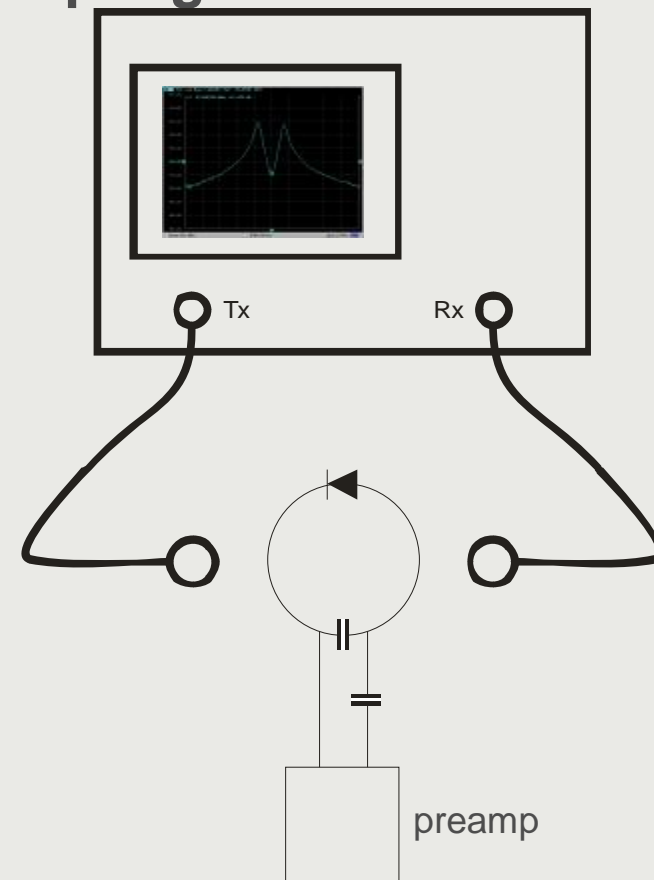
§ setup as active decoupling

§ no saturation!

§ measure S12

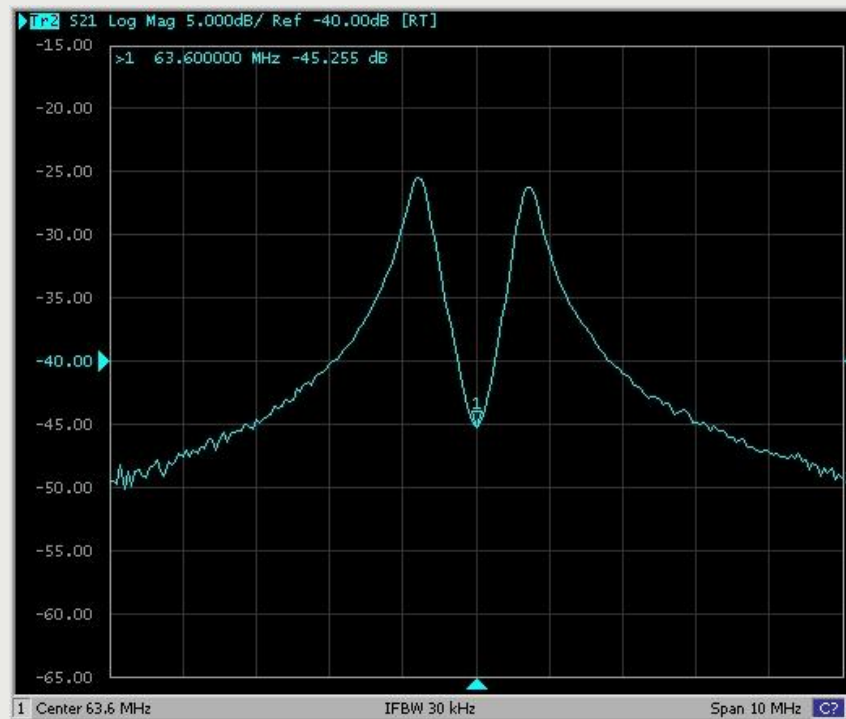
_ minimum frequency at
working frequency

_ difference > 20 dB



Measure Preamplifier Decoupling

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- Preamplifier Dec**
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- Examples



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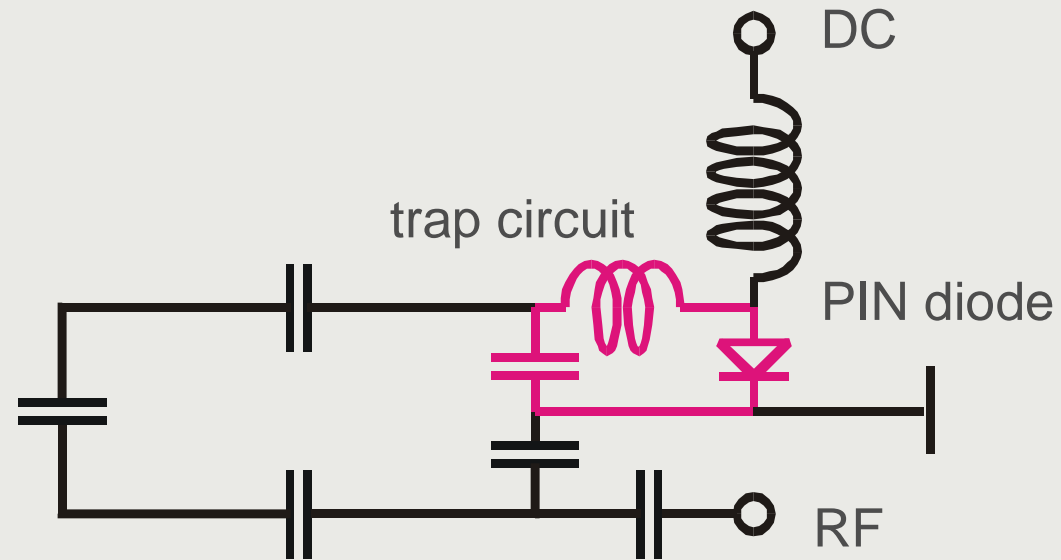
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Active Decoupling

Active Decoupling

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- Geometry
- Decoupling
- Preamplifier Dec
- Active Dec
- Balancing
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Active Decoupling

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- § Rx: PIN diode in trap circuit
 - _ Tx: current (off)
 - _ Rx: reverse voltage (on)
- § Tx: PIN diode in circuit
 - _ Tx: current (on)
 - _ Rx: reverse voltage (off)
- § PIN diodes
 - _ control current DC
 - _ controlled current RF

Active Decoupling

§ blocking efficiency

– $Z_{\max} \sim QL$

– rule of thumb: $C_{\text{act.dec.}} < 6C_{\text{tot}}$

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- Examples

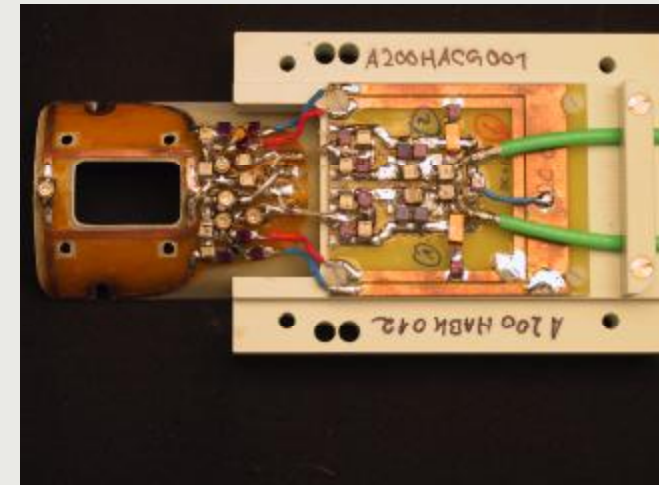
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- Geometry
- Decoupling
- Preamplifier Dec
- Active Dec
- Balancing
- Characterization
- Tips
- Examples

Active Decoupling

Q drop

§ coil diameter 4cm

§ 200MHz



$C_{\text{act.dec.}}$	Q_{unloaded}
none	330
C	150
2C	200
4C	280

Active Decoupling

§ what is important

- _ no Q drop
- _ no additional resonances by chokes
- _ power stability!
- _ blocking efficiency
- _ attention: ground connections in MR system comparable to setup on the bench?

Motivation
Geometry
Decoupling
Preamplifier Dec
Active Dec
Balancing
Characterization
Tips
Examples

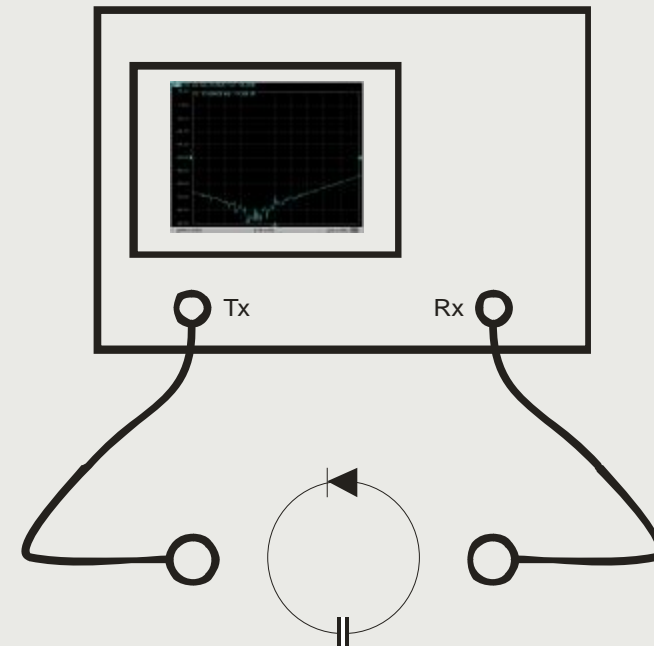
Measure Active Decoupling

Motivation
Geometry
Decoupling
Preamplifier Dec
Active Dec
Balancing
Characterization
Tips
Examples

§ measure S_{12}

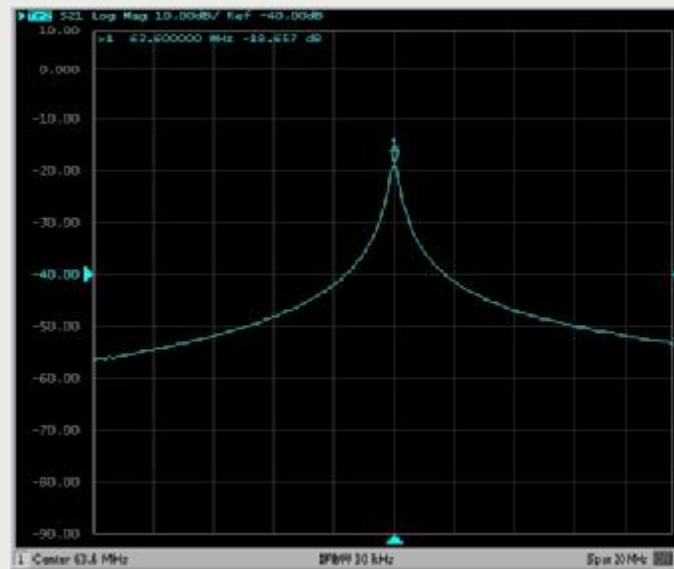
§ difference > 30 dB (usually)

§ no cable waves!



Measure Active Decoupling

- Motivation
- Geometry
- Decoupling
- Preamplifier Dec
- Active Dec
- Balancing
- Characterization
- Tips
- Examples



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Balancing

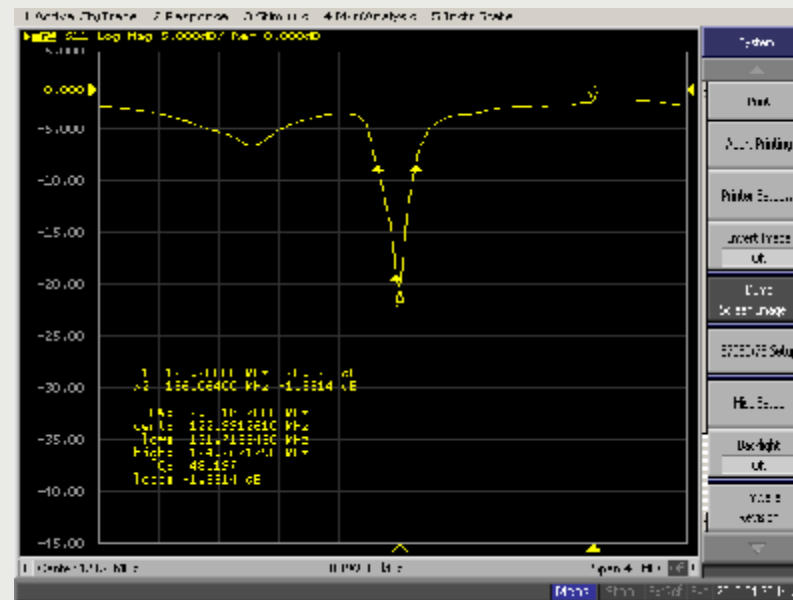
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Balancing

Motivation
Geometry
Decoupling
Preamplifier Dec
Active Dec
Balancing
Characterization
Tips
Examples



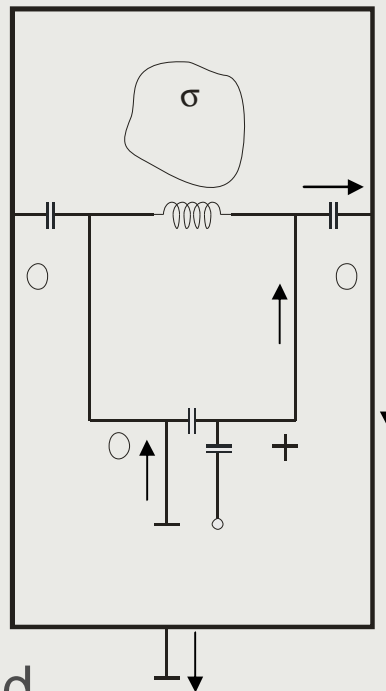
§ mismatch

§ Q drop

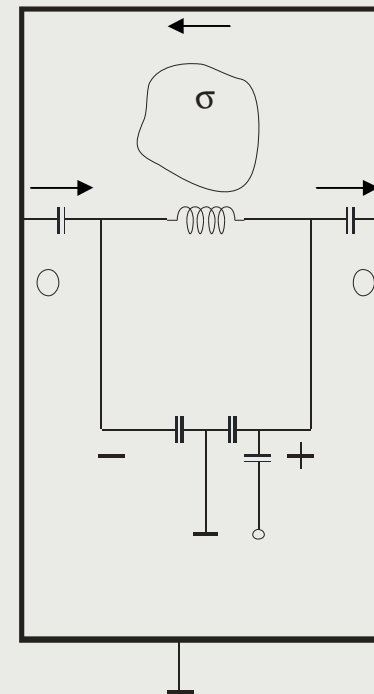
§ safety

Balancing

- Motivation
- Geometry
- Decoupling
- Preamplifier Dec
- Active Dec
- Balancing
- Characterization
- Tips
- Examples



unbalanced
cable waves



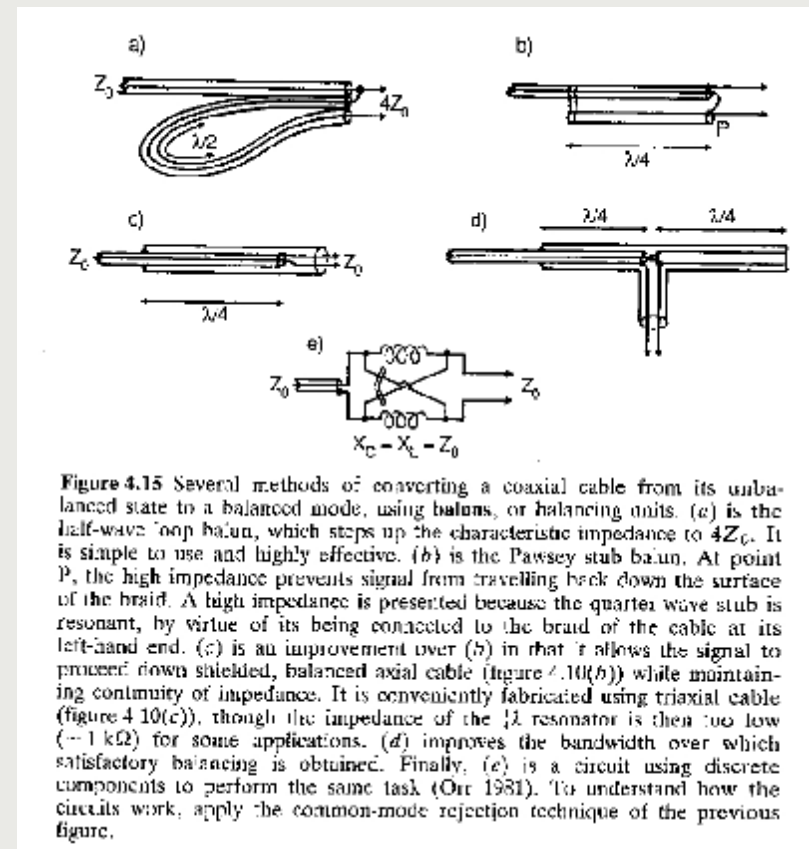
balanced
no cable waves

Balancing

§ electrical symmetry

§ baluns

- Motivation
- Geometry
- Decoupling
- Preamplifier Dec
- Active Dec
- Balancing
- Characterization
- Tips
- Examples



Chen & Hoult 1989: Biomedical Magnetic Resonance Technology

Balancing

§ electrical symmetry

§ baluns

§ cable traps

Motivation
Geometry
Decoupling
Preamplifier Dec
Active Dec
Balancing
Characterization
Tips
Examples

resonant trap on
outside of coax



Literature

§ Chen & Hoult 1989: Biomedical Magnetic Resonance Technology

§ The ARRL Handbook

§ Peterson et al Conc in Magn Reson B, Vol 19B(1) 1-8 (2003)

Motivation
Geometry
Decoupling
Preamplifier Dec
Active Dec
Balancing
Characterization
Tips
Examples

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Characterization in the MR System

Characterization in the MR

Motivation
Geometry
Decoupling
Preamplifier Dec
Active Dec
Balancing
Characterization
Tips
Examples

- § all channels active
- § compare signal level of channels
- § compare noise of channels
- § active decoupling
- § g factors
- § compare to other coils
- § signal of housing
- § B0 distortions
- § power stability...

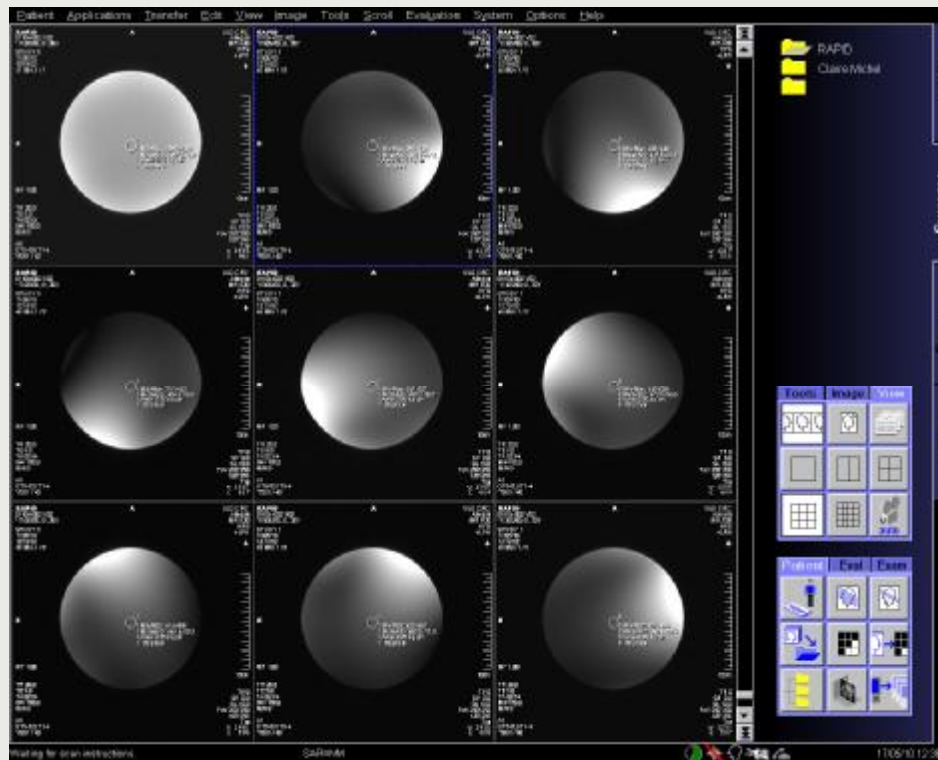
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Signal Levels of Individual Channels

- Motivation
- Geometry
- Decoupling
- Preamplifier Dec
- Active Dec
- Balancing
- Characterization
- Tips
- Examples



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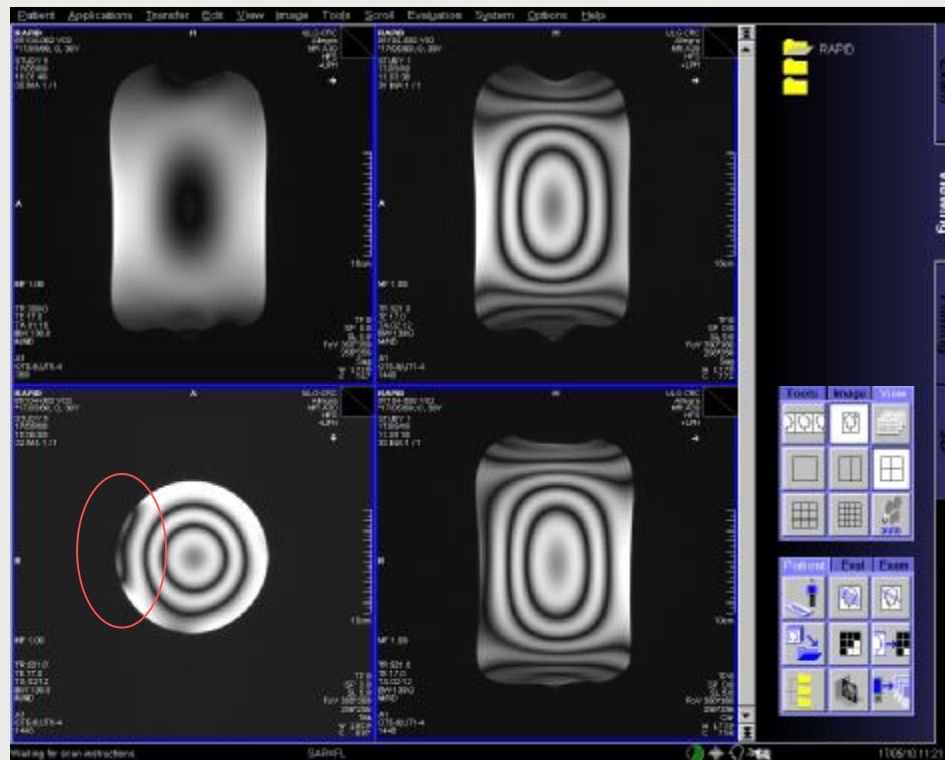
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RF Field distortions During Excitation

- Motivation
- Geometry
- Decoupling
- Preamplifier Dec
- Active Dec
- Balancing
- Characterization
- Tips
- Examples

coupling of
Rx coil
during Tx



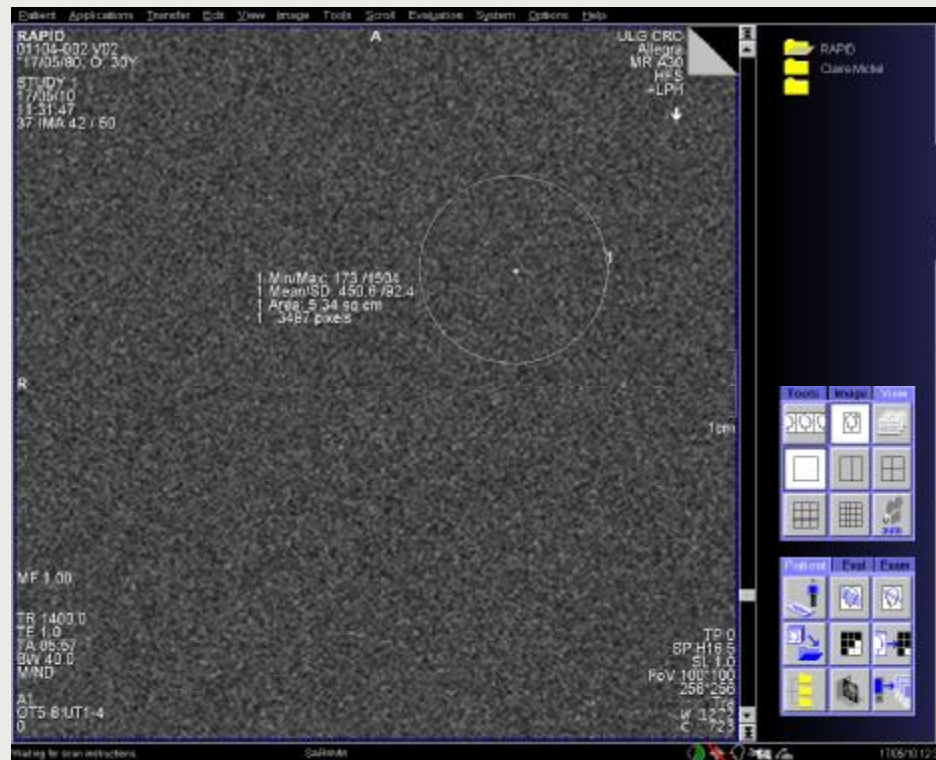
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Noise

- Motivation
- Geometry
- Decoupling
- Preamplifier Dec
- Active Dec
- Balancing
- Characterization
- Tips
- Examples



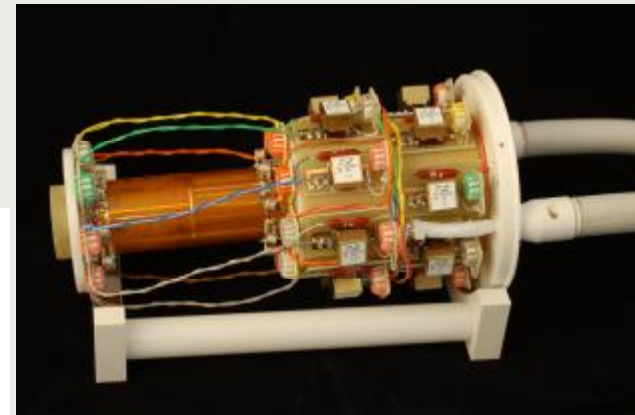
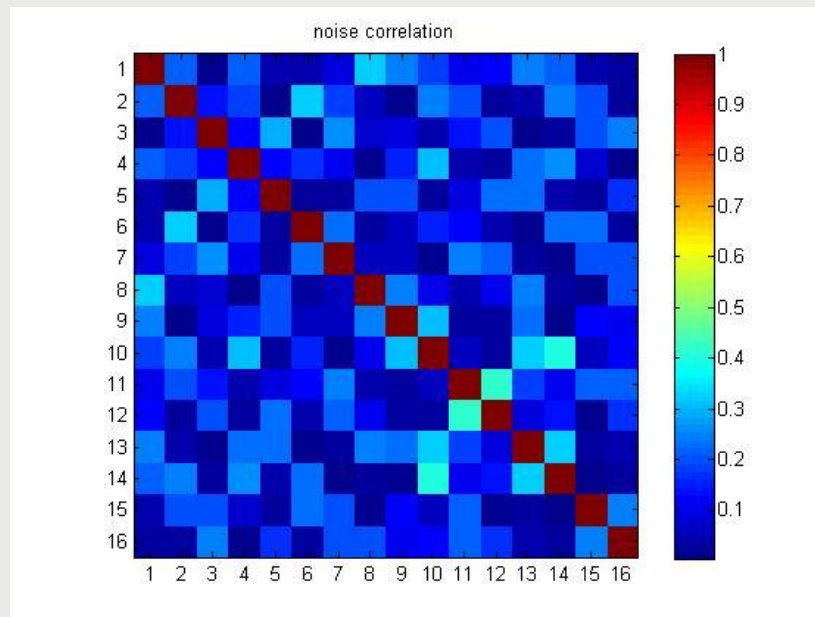
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Noise Correlation

- Motivation
- Geometry
- Decoupling
- Preamplifier Dec
- Active Dec
- Balancing
- Characterization
- Tips
- Examples



SNR

§ attention: don't draw circles!

§ SOS reconstruction changes noise in background

§ Olaf Dietrich et al. JMRI 26:375 (2007) (inkl. letter to the editor und response)

§ Peter Kellman et al. MRM 54:1439 (2005) (inkl. Erratum)

§ Philip Robson et al. MRM 60:895 (2008)

§ Matthew Riffe et al. Proc ISMRM 15, Berlin: #1879 (2007)

- Motivation
- Geometry
- Decoupling
- Preamplifier Dec
- Active Dec
- Balancing
- Characterization
- Tips
- Examples

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Tips

Components

Motivation
Geometry
Decoupling
Preamplifier Dec
Active Dec
Balancing
Characterization
Tips
Examples

§ preamplifiers:

- _ MWT (USA)
- _ Advanced Receiver Research (USA)
- _ your MR system vendor

§ chip capacitors

- _ Temex
- _ ATC
- _ Passive Plus
- _ DLI

Components

Motivation
Geometry
Decoupling
Preamplifier Dec
Active Dec
Balancing
Characterization
Tips
Examples

§ inductors

- Jahre GmbH (Germany)
- Miller
- etc...

§ PIN diodes

- Chelton
- Microsemi
- ...

§ Resistors

- Vishay Dale
- SRT Resistor Technology
- ...

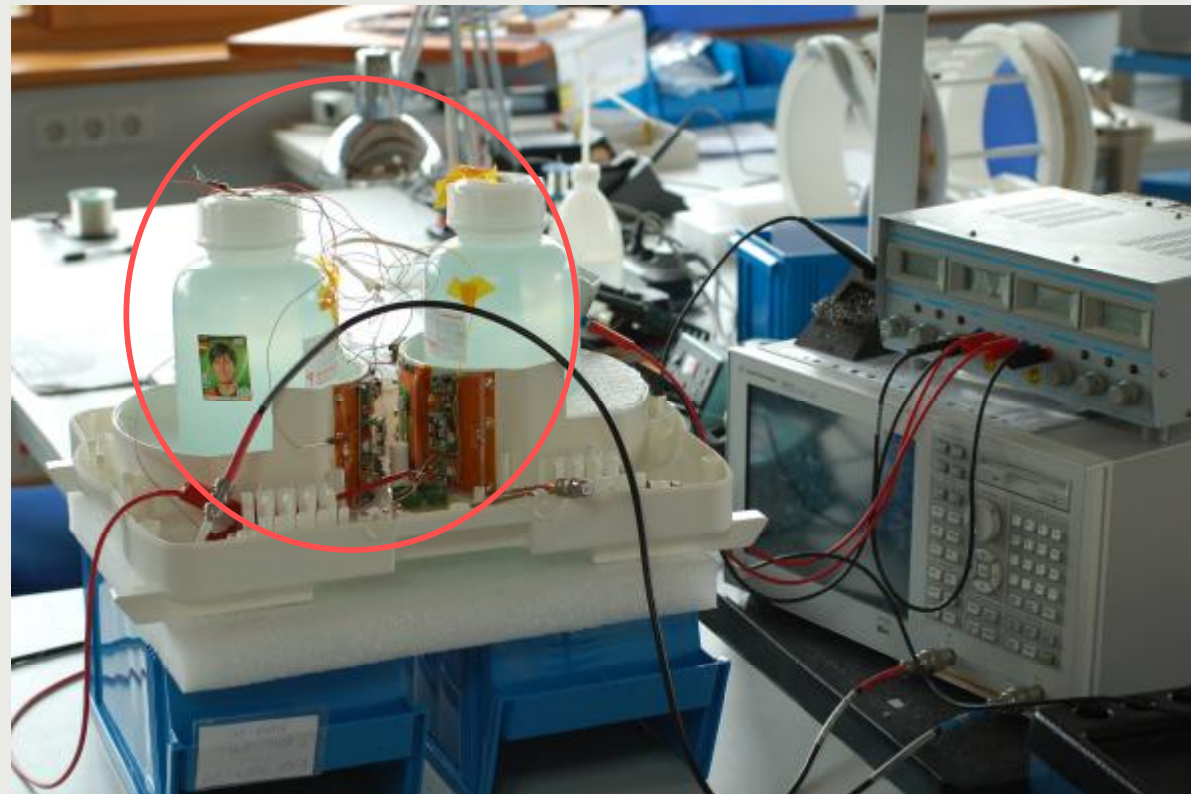
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Stable Setup

Motivation
Geometry
Decoupling
Preamplifier Dec
Active Dec
Balancing
Characterization
Tips
Examples



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Stable Setup

Motivation
Geometry
Decoupling
Preamplifier Dec
Active Dec
Balancing
Characterization
Tips
Examples



Design Rules Small Coils

Motivation
Geometry
Decoupling
Preamplifier Dec
Active Dec
Balancing
Characterization
Tips
Examples

§ coil losses dominant

- _ highest Q_u
- _ coupling network losses!

§ high filling factor geometrically difficult

§ (conservative) electrical field neglectable

- _ $E = E(\omega^2)$, $B = B(\omega)$

§ cable waves easier to address

§ not many C for high Q, real coils

Design Rules Large Coils

§ sample losses dominant

_ too much Q drop (tuning range)

§ avoid sample coverage which does not contribute to signal

§ radiation of coil (shield!)

§ (conservative) electrical fields become severe

_ $E = E(\omega^2)$, $B = B(\omega)$

§ don't use C with too small values (stray capacitances)

§ cable waves!

§ phase changes, resonators

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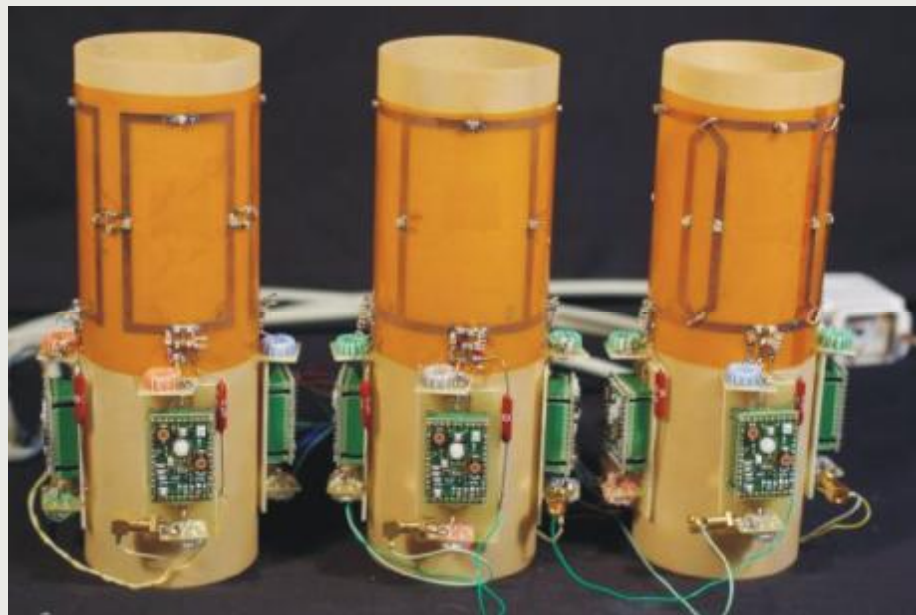
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Some Examples

Rat Volume Array @ 1.5T

- Motivation
- Geometry
- Decoupling
- Preamplifier Dec
- Active Dec
- Balancing
- Characterization
- Tips
- Examples

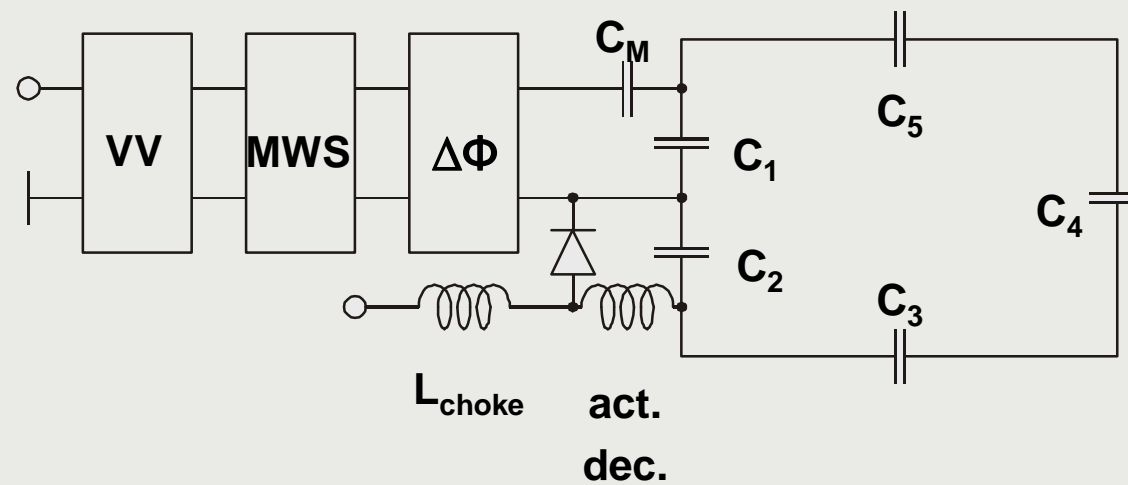


§ identical size

§ different decoupling

Rat Volume Array @ 1.5T

- Motivation
- Geometry
- Decoupling
- Preamplifier Dec
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- Balancing
- Characterization
- Tips
- Examples



Rat Volume Array @ 1.5T

- Motivation
- Geometry
- Decoupling
- Preamplifier Dec
- Active Dec
- Balancing
- Characterization
- Tips
- Examples

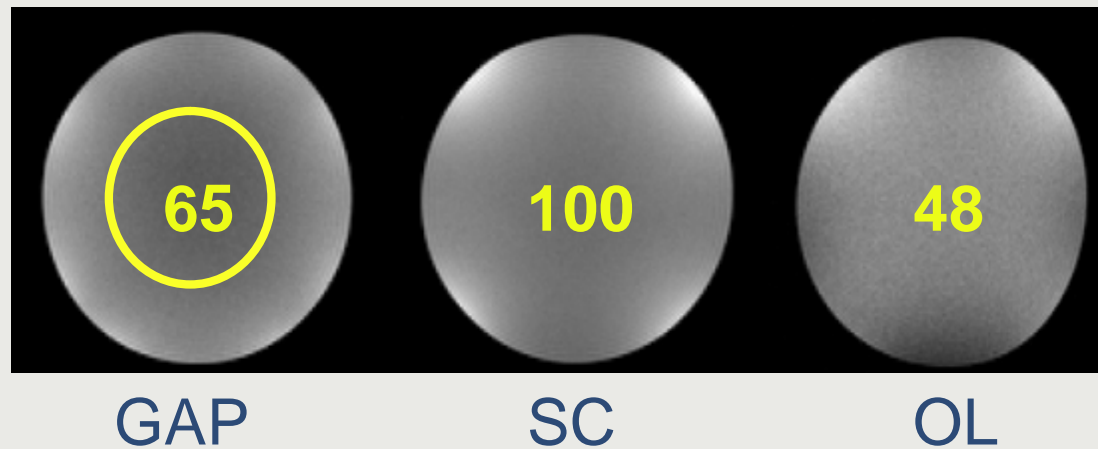
	GAP	SC	OL
Q_u/Q_l	2.1	2.5	2.2
S_{12} (next neighbours) / dB	-31	-20	-23
D_n / n_0 (opposit)	0.03	0.01	0.07

Rat Volume Array @ 1.5T

§ SNR maps

§ 100 measurements

§ SNR pixel by pixel

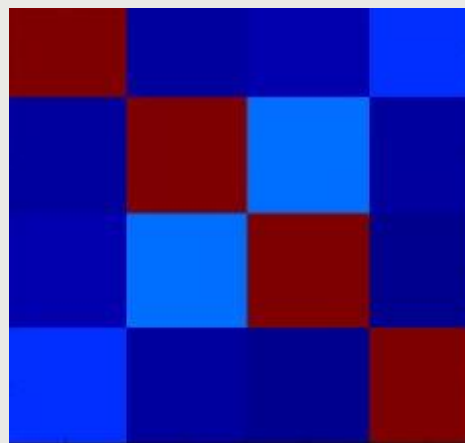


Motivation
Geometry
Decoupling
Preamplifier Dec
Active Dec
Balancing
Characterization
Tips
Examples

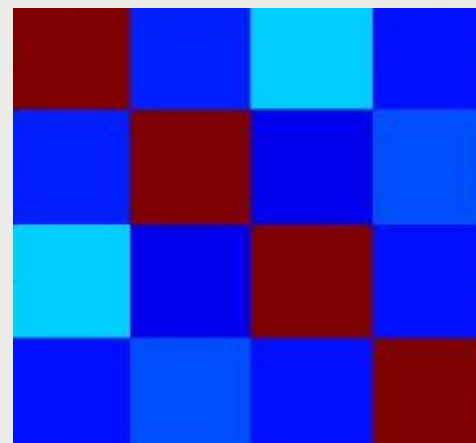
Rat Volume Array @ 1.5T

§ noise correlation

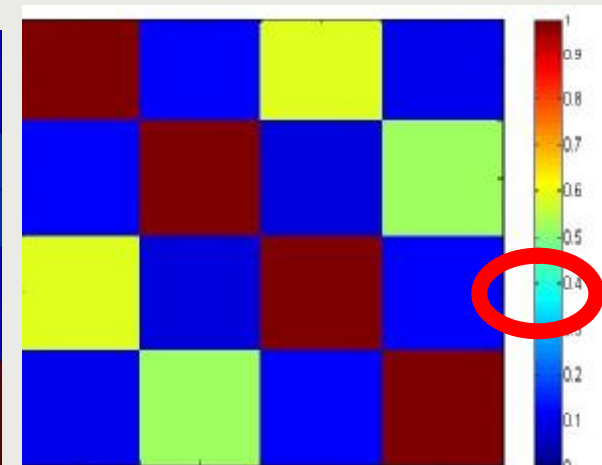
- Motivation
- Geometry
- Decoupling
- Preamplifier Dec
- Active Dec
- Balancing
- Characterization
- Tips
- Examples



GAP



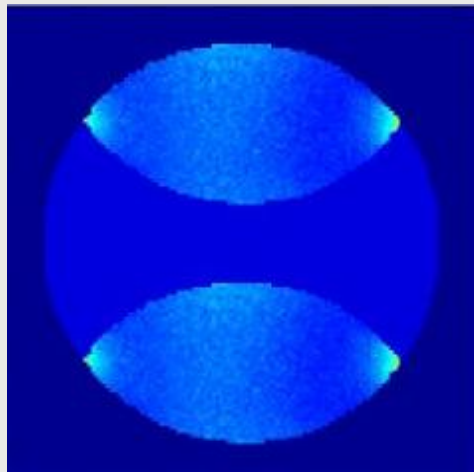
SC



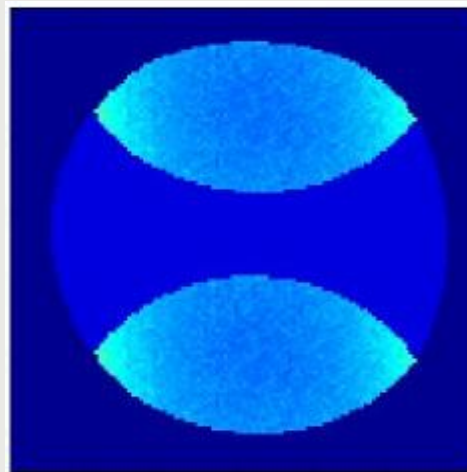
OL

Rat Volume Array @ 1.5T

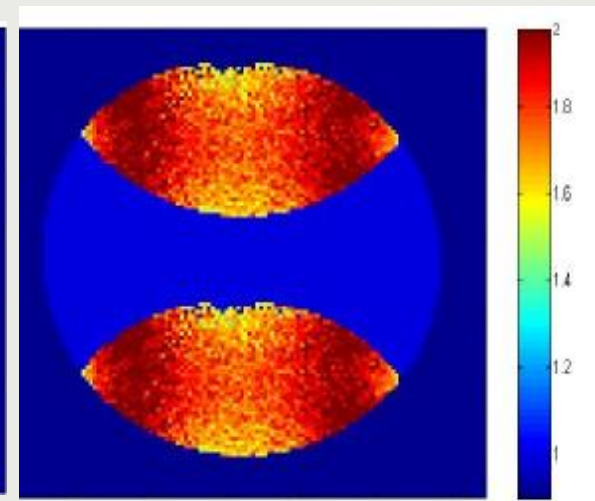
§ g factors, R=2



GAP



SC



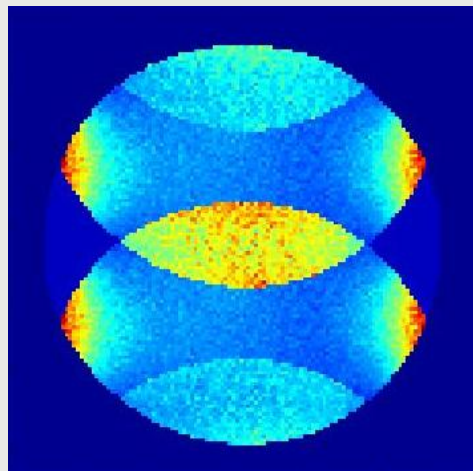
OL

- Motivation
- Geometry
- Decoupling
- Preamplifier Dec
- Active Dec
- Balancing
- Characterization
- Tips
- Examples

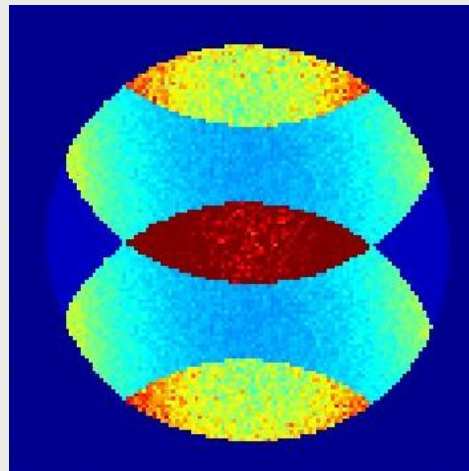
Rat Volume Array @ 1.5T

§ g factors, R=3

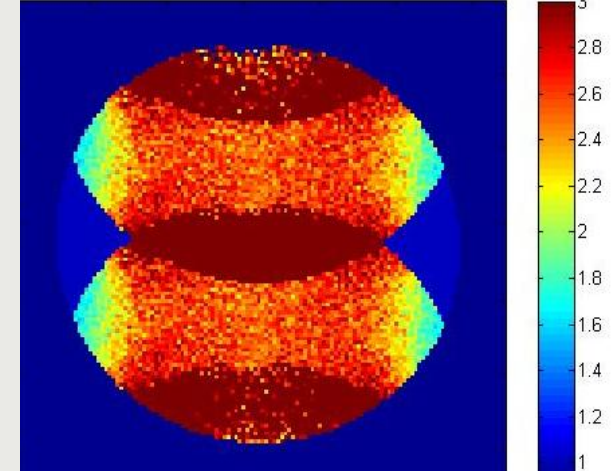
Motivation
Geometry
Decoupling
Preamplifier Dec
Active Dec
Balancing
Characterization
Tips
Examples



GAP



SC



OL

Thanks!

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