Sponsored by:

Mastering MRI Designs through Component Selection

Mark van Uden
Tesla Dynamic Coils
05-02-2024

MEDISCHE ELEKTRONICA
Ontwikkelingen, normen en toepassingen

6 februari 2024 | Van der Valk Vianen

Sponsored by:

Tesla Dynamic Coils

- Work for about 20 years in the field of MR scanners
  - Philips Healthcare
  - RadboudUMC
  - Tesla Dynamic Coils

- Based in Zaltbommel
- We develop and built RF coils, peripheral electronics, cables, mechanical for MRI scanners
- ISO 13485:2016 certified

Tesla Dynamic Coils

Sponsored by:

Topics

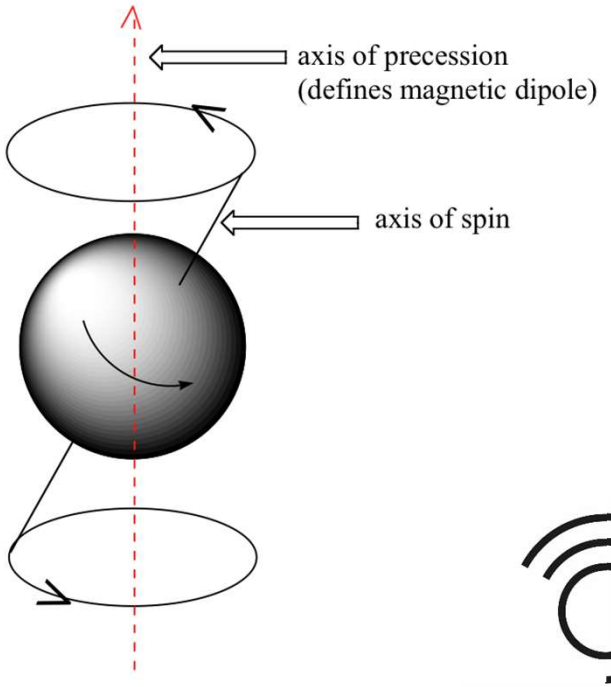
- Nuclear magnetic resonance
- Scanner
- RF coils
- Components and designs
  - Static magnetic field distortion
  - Transmit (receive) coils
  - Receive coils
  - Testing

Tesla Dynamic Coils

Sponsored by:

Nuclear magnetic resonance

- Frequency is determined by:
  - Magnetic field strength
  - Gyromagnetic ratio
  - Nuclei: ^{1}H, ^{31}P, ^{13}C, …
  - Ranges between 30 MHz and 300 MHz
- MRI: Magnetic Resonance Imaging medical application

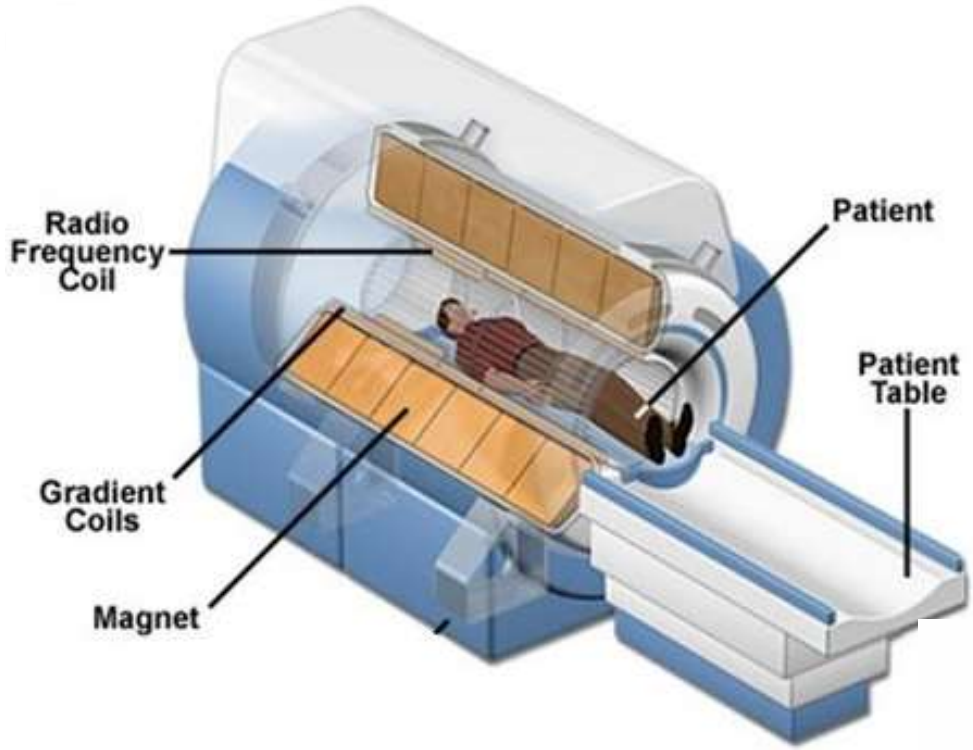


Tesla Dynamic Coils

Sponsored by:

MR Scanner

- Magnet
- RF coils
- Gradient coils
- Patient table
- Patient



Tesla Dynamic Coils

Sponsored by:

MR Scanner

- Magnet
- RF coils
- Gradient coils
- Patient table
- Patient

Tesla Dynamic Coils

Sponsored by:

MR Scanner

- Magnet (B0)
  - 0 Hz
  - 3 – 7 Tesla
- RF coils (B1+)
  - 30 – 300 MHz
  - Max. 50 µT
  - Max. 35 kW peak
  - Max. 250W average
- Gradient coils
  - 1 – 5kHz
  - 200 mT/m
  - 200 T/m/s

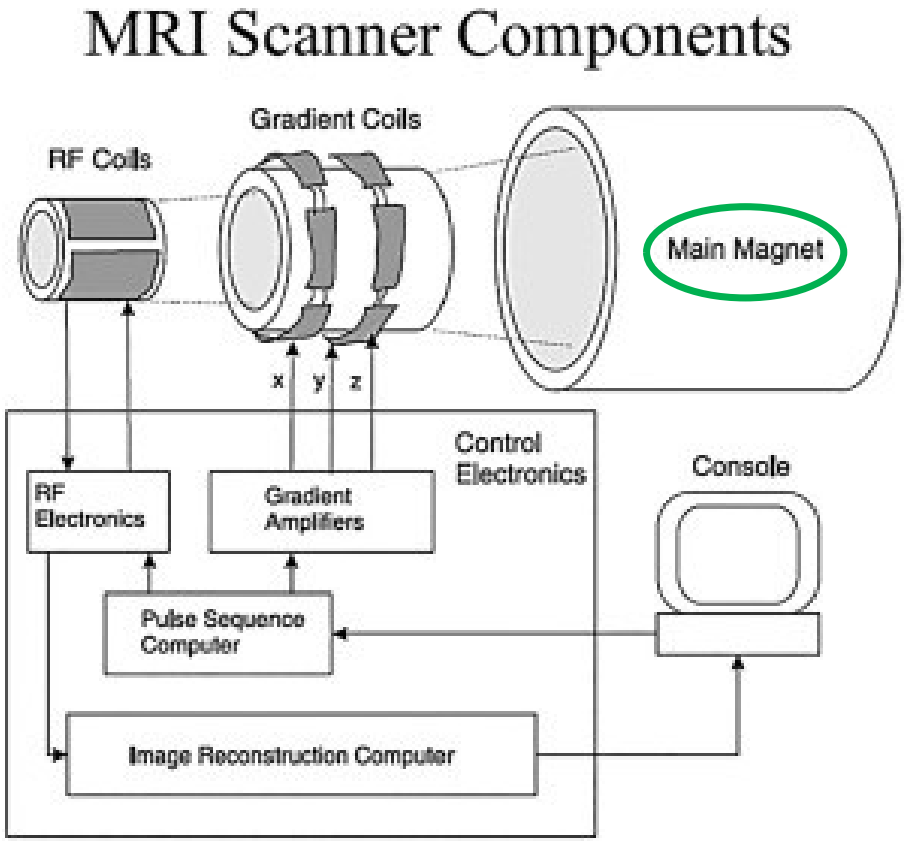


Image from Gruber B, Froeling M, Leiner T, Klomp DWJ. RF coils: A practical guide for nonphysicists. J Magn Reson Imaging. 2018 Jun 13;48(3):590–604. doi: 10.1002/jmri.26187. Epub ahead of print. PMID: 29897651; PMCID: PMC6175221.

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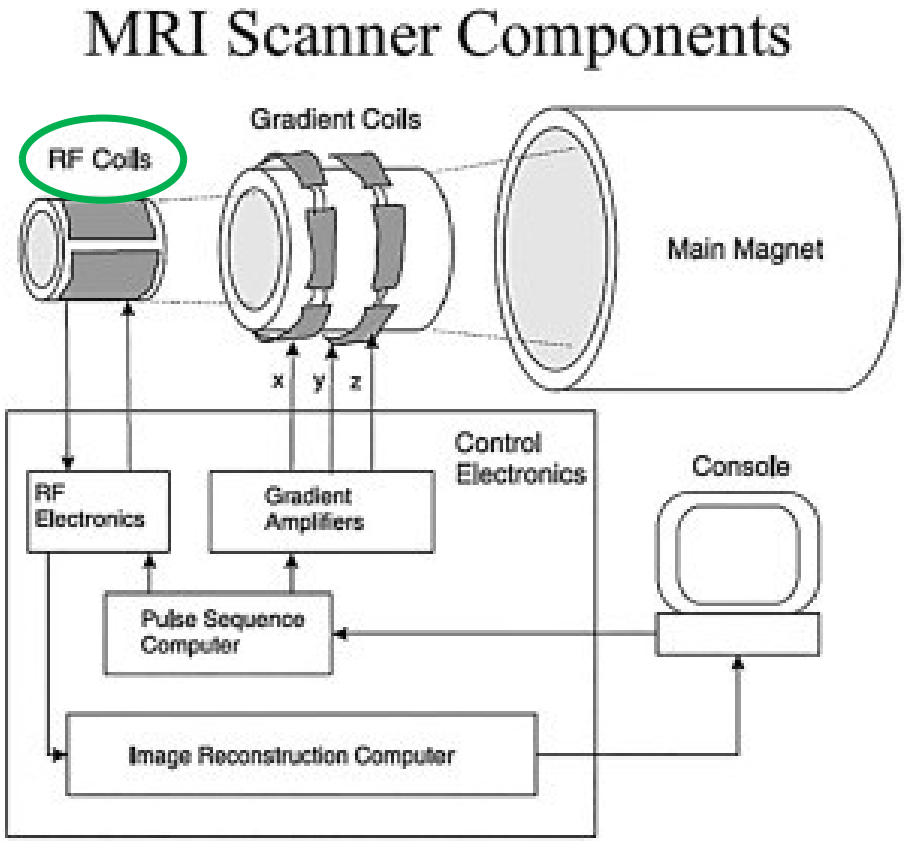

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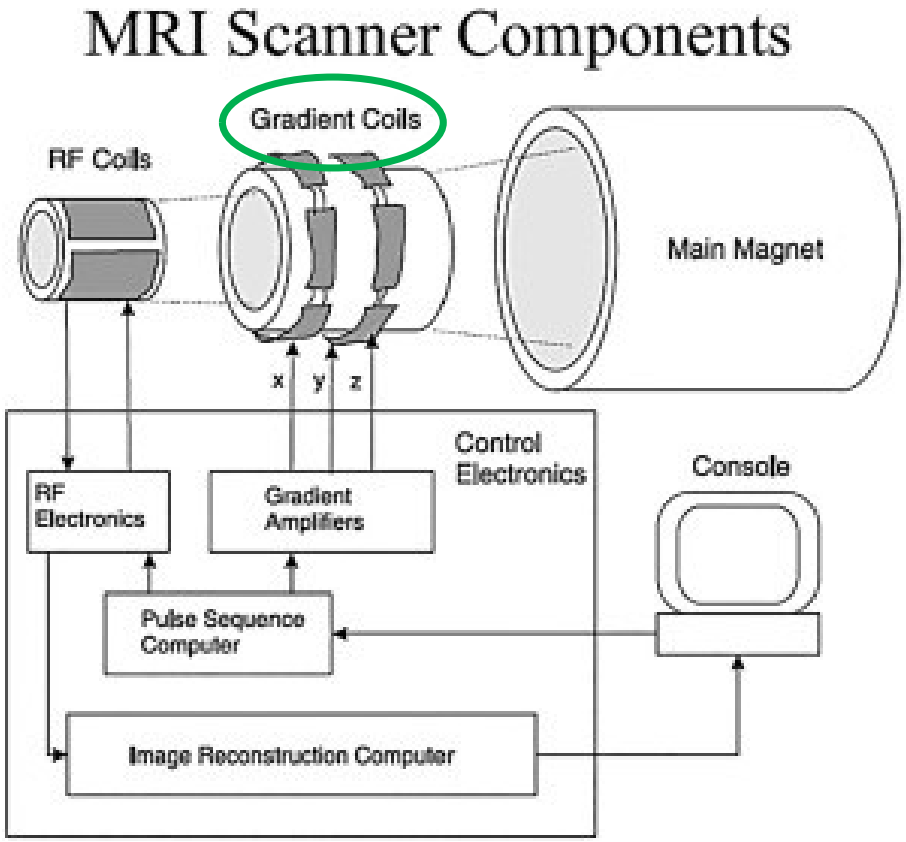

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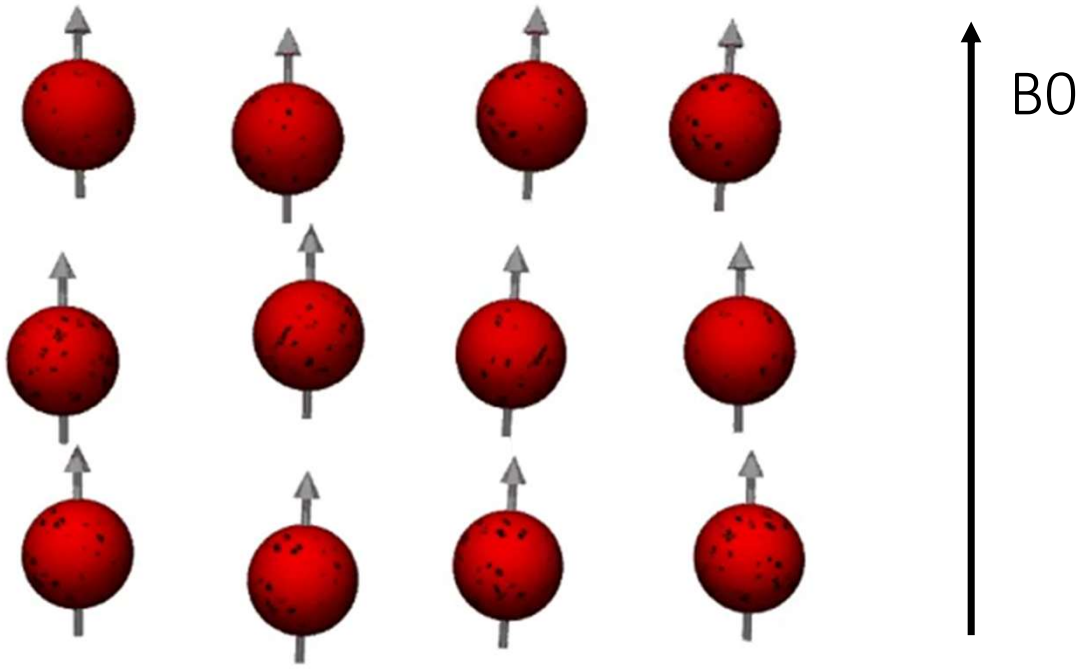
Tesla Dynamic Coils

Nuclear magnetic resonance

- Transmit and/or receive on frequency of interest



https://www.youtube.com/watch?v=0YBUSOrH0lw

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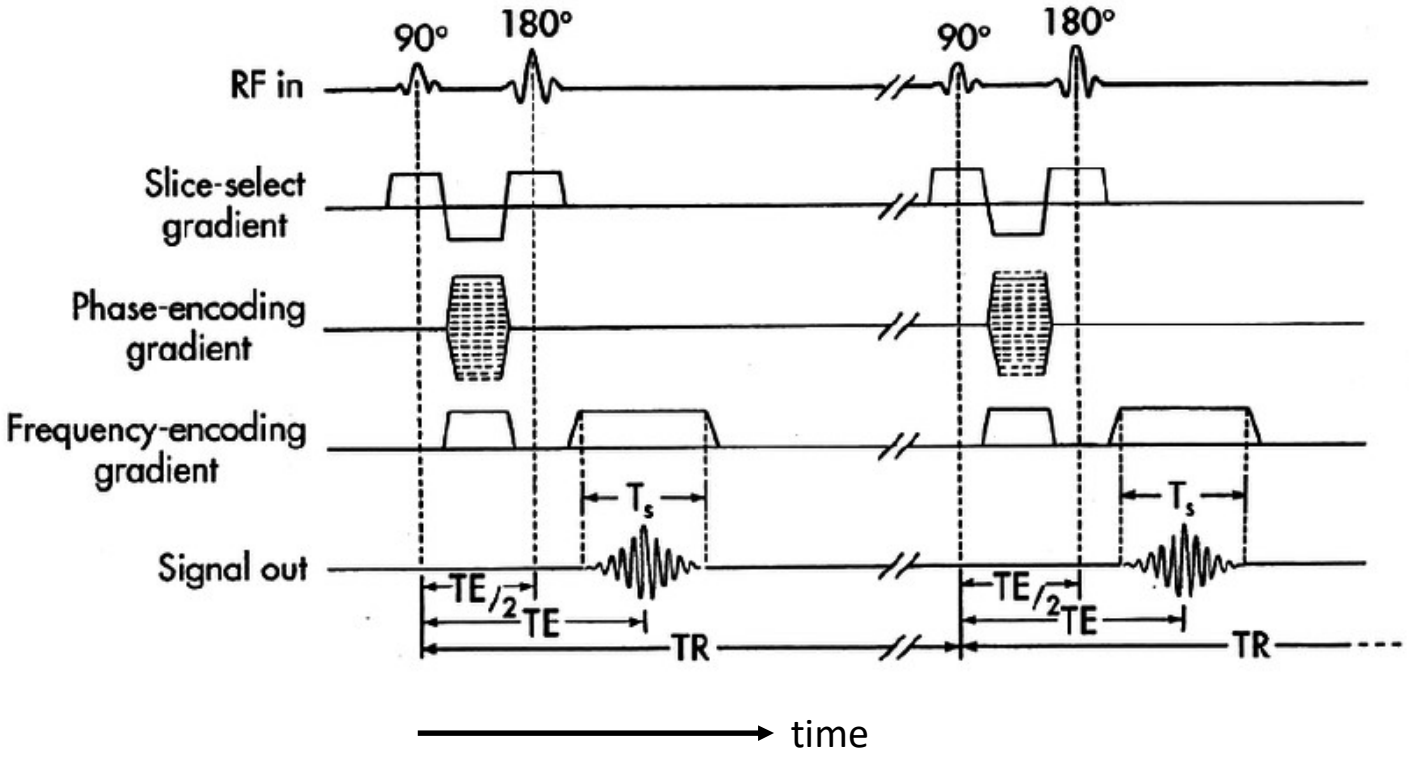
MR Scanner

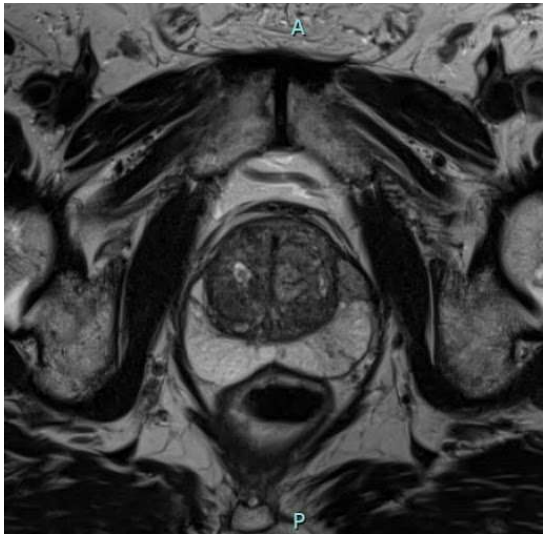
- Combine RF pulses and gradient fields
- Right timing
- Image/spectrum



Sponsored by:

heynen

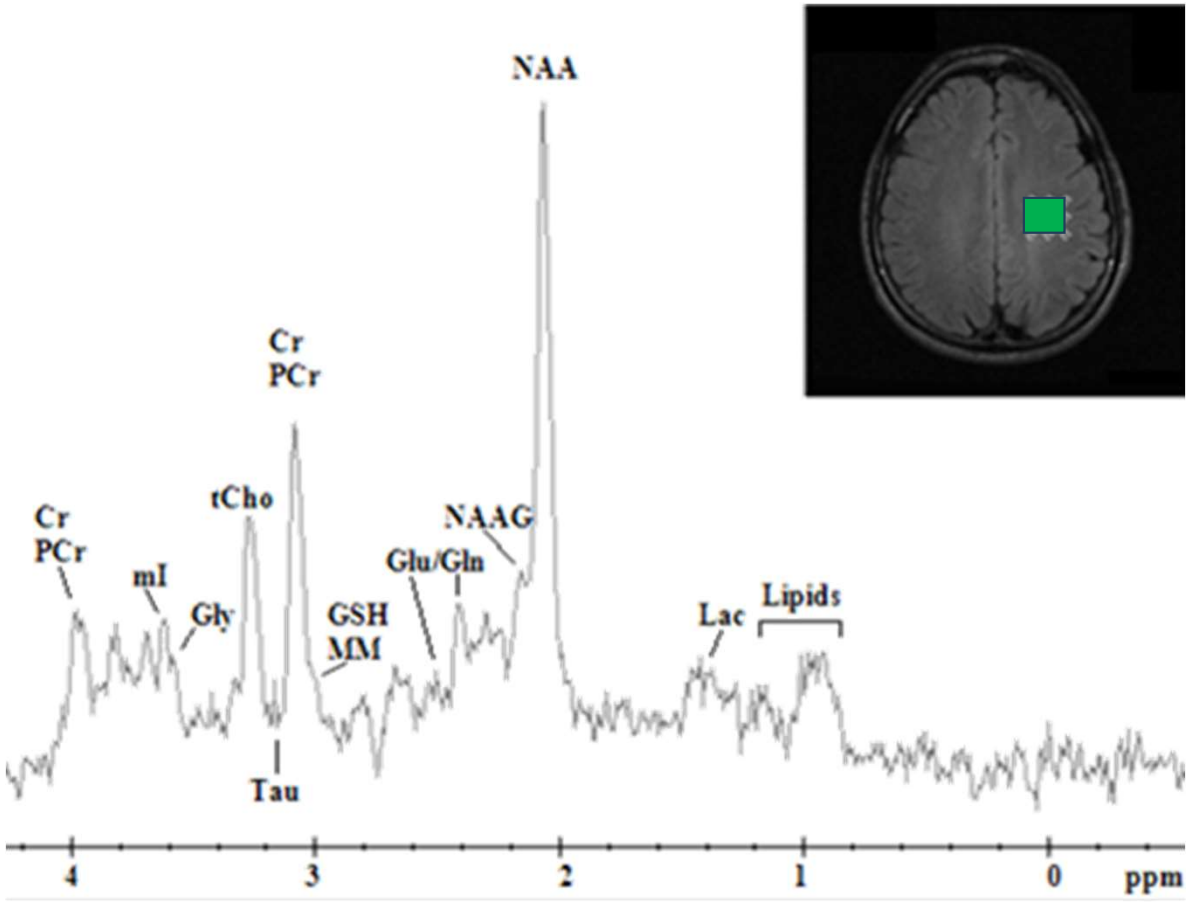
MR Scanner



Tesla Dynamic Coils

Sponsored by:

MR Scanner



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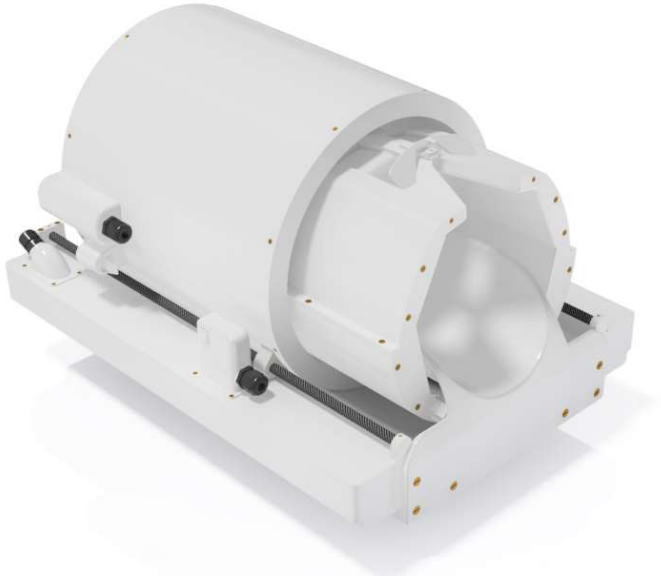
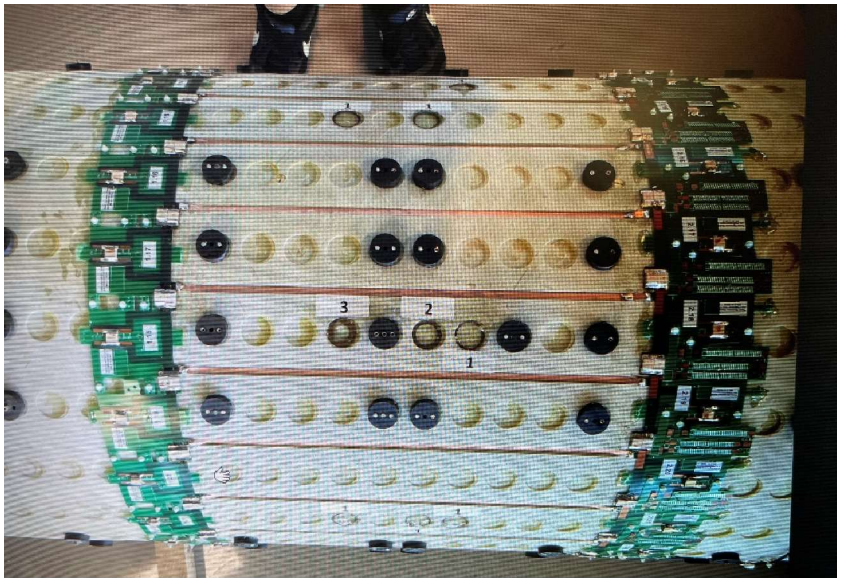
RF coils

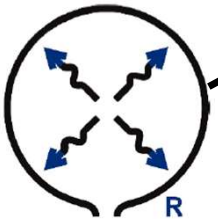




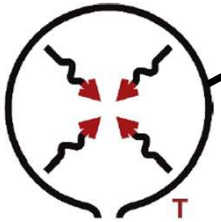
Tesla Dynamic Coils

RF coils

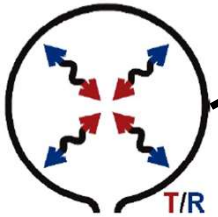
Receive coil



Transmit coil



Transmit-receive coil



Interfacing:
- Filters
- Phase shifters
- PIN diode control

Interfacing:
- T switches
- Filters
- PIN diode control

Interfacing:
- TR switches
- Filters
- Low noise amplifiers
- PIN diode control

Scanner back-end

Sponsored by:

Components and designs

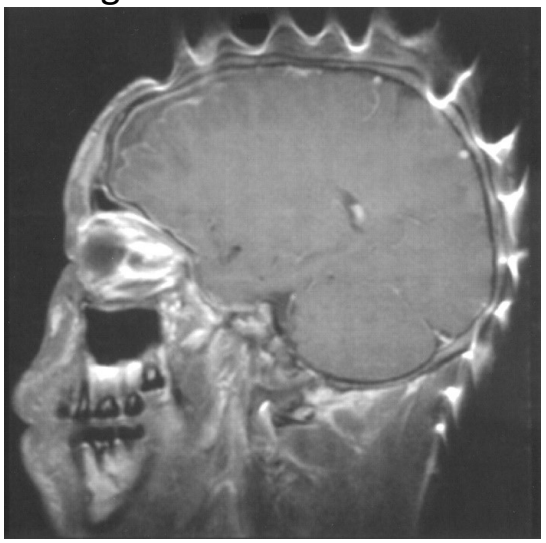
- Capacitors
- Inductors
  - RF
  - DC/chokes
  - Traces
- Resistors
- Low Noise Amplifiers
- Fuses
- Diodes
  - PIN diodes
  - Fast diodes
  - ESD suppression
- RF connectors
  - BNC
  - SMA
  - SMB
  - N

Tesla Dynamic Coils

Components and designs: B0 distortion

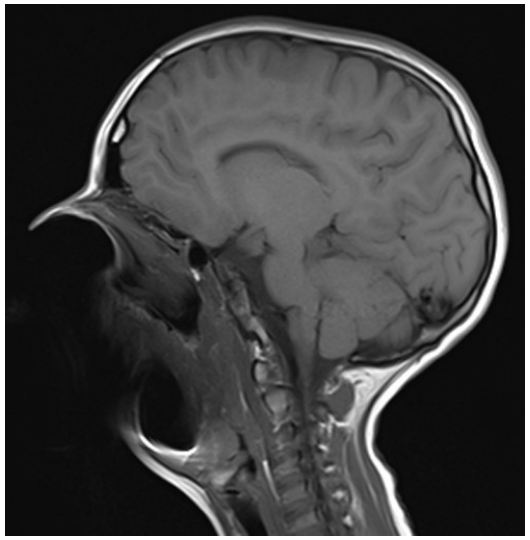
- Distortion of main magnetic field in imaging Field Of View (FOV)

Hair gel



https://www.ajronline.org/doi/10.2214/ajr.182.2.1820532

Braces

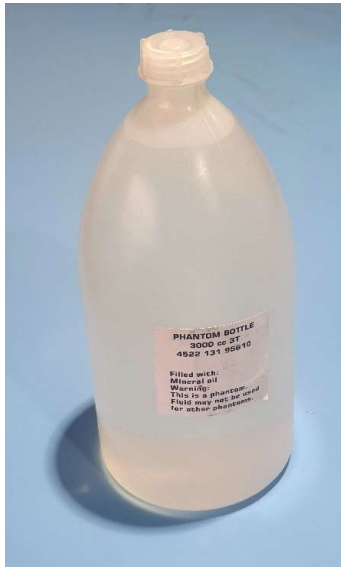


https://mriquestions.com/susceptibility-artifact.html

Sponsored by:

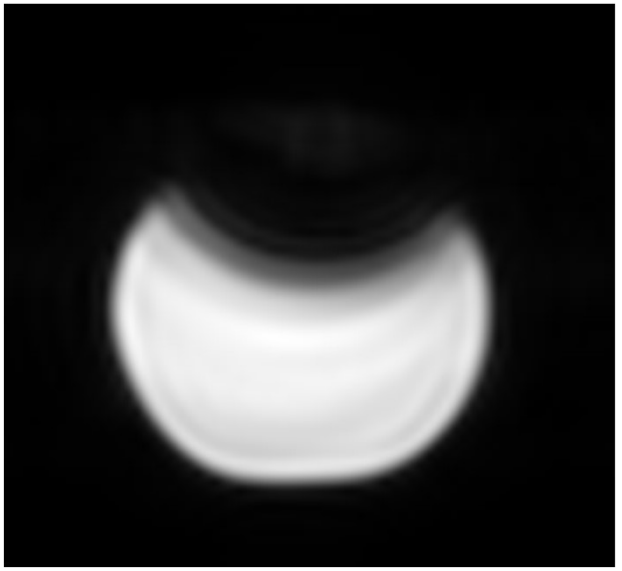
Components and designs: B0 distortion

- Test protocol on MR scanner



M4 screw

N connector



Tesla Dynamic Coils

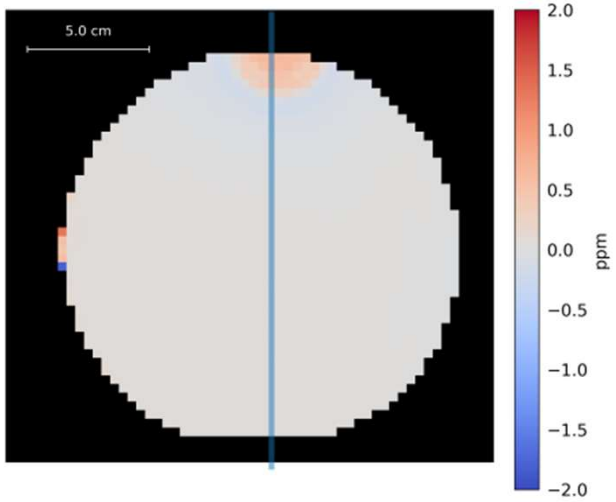
Sponsored by:

Components and designs: B0 distortion

- Test protocol on MR scanner

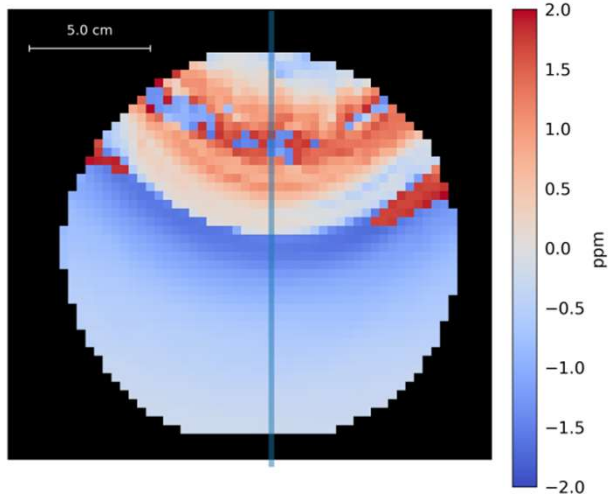
M4 screw

Half ppm distance: 7 mm



N connector

Half ppm distance: 126 mm

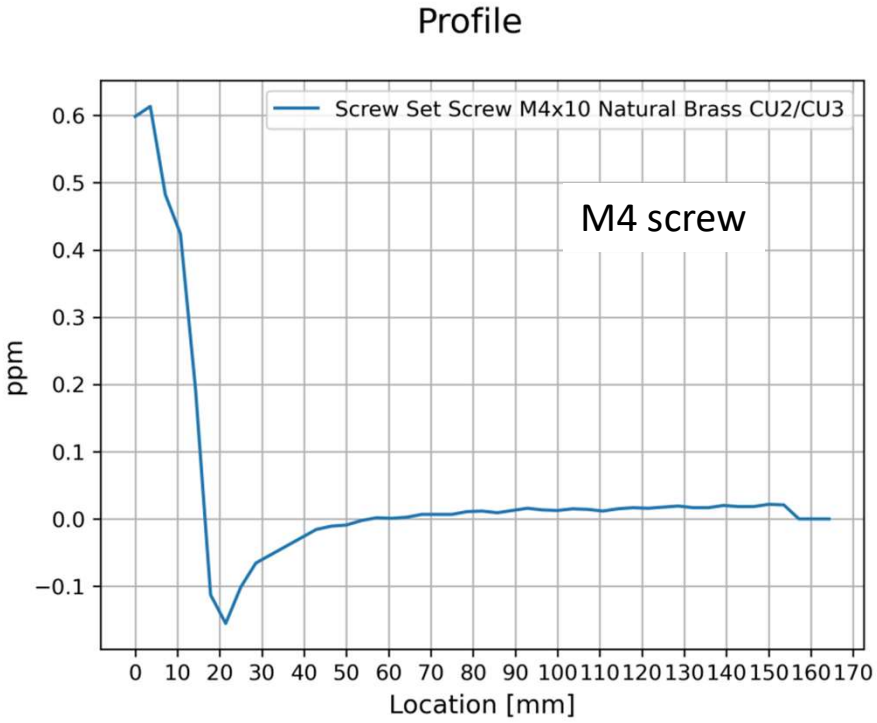


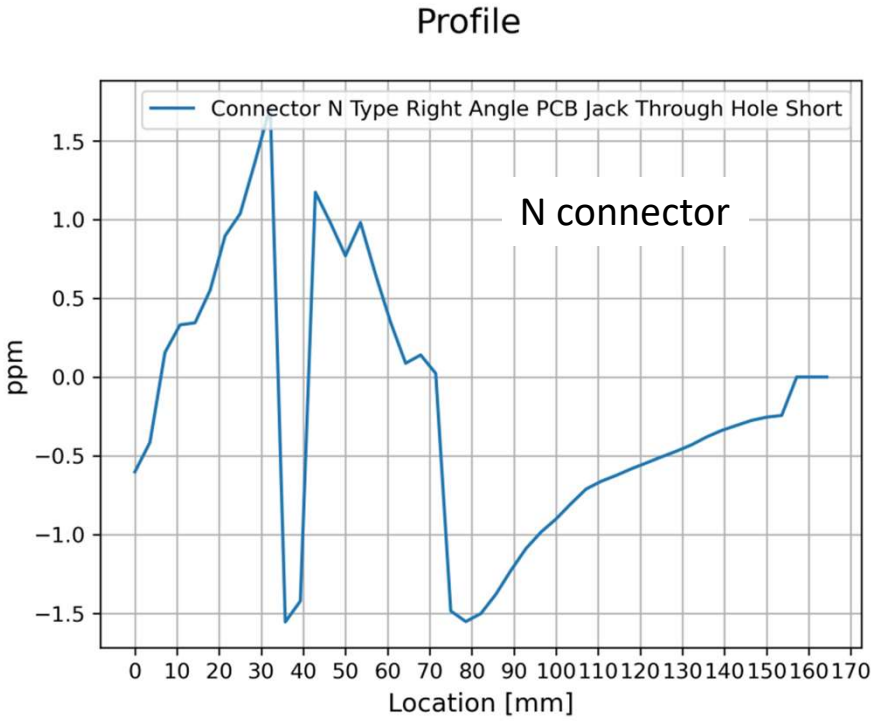
Tesla Dynamic Coils

Sponsored by:

Components and designs: B0 distortion

- Test protocol on MR scanner

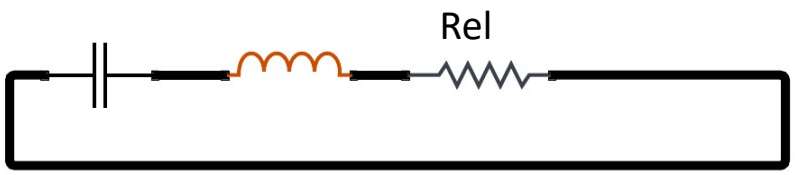


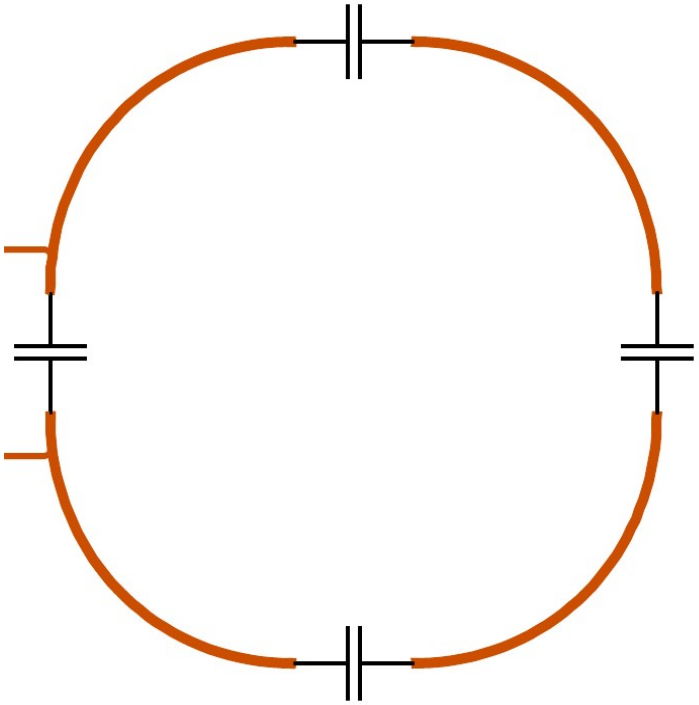


Tesla Dynamic Coils

Components and designs: Tx(Rx) coils

- Loading of RF coil
- EM fields couples to conducting substance





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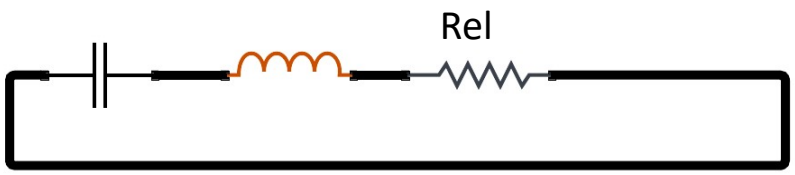
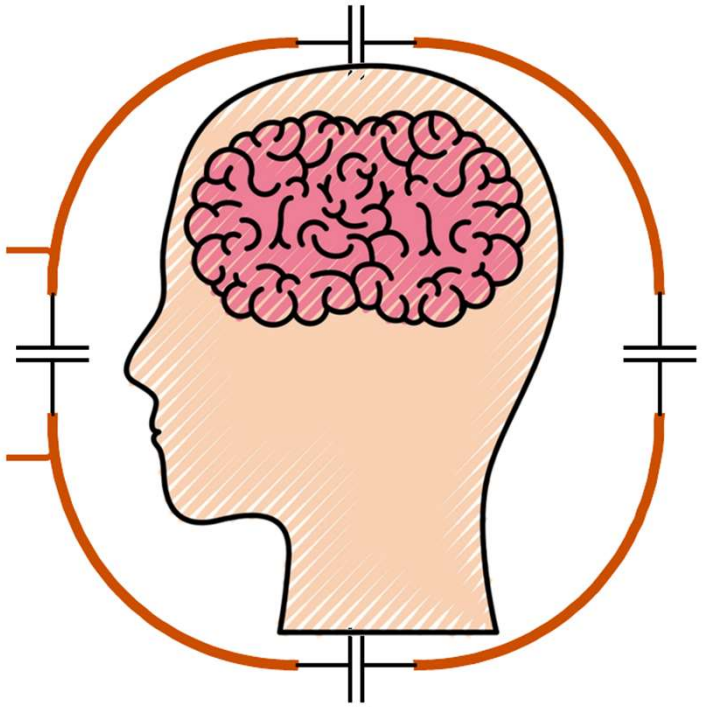
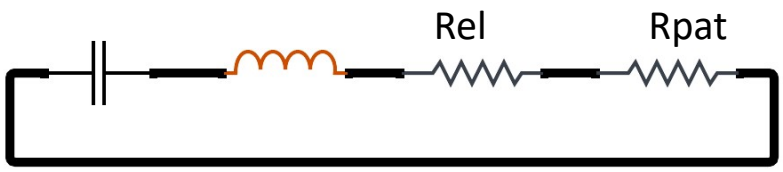
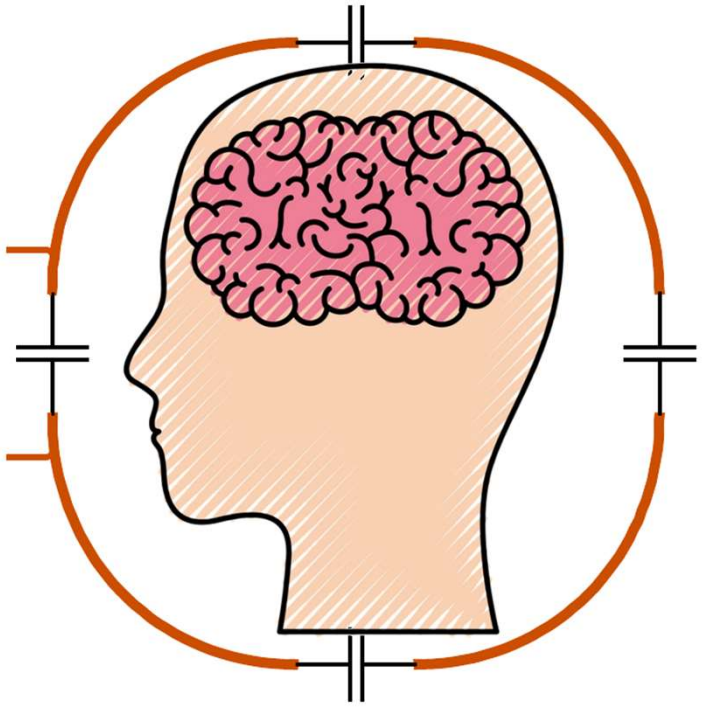




Components and designs: Tx(Rx) coils

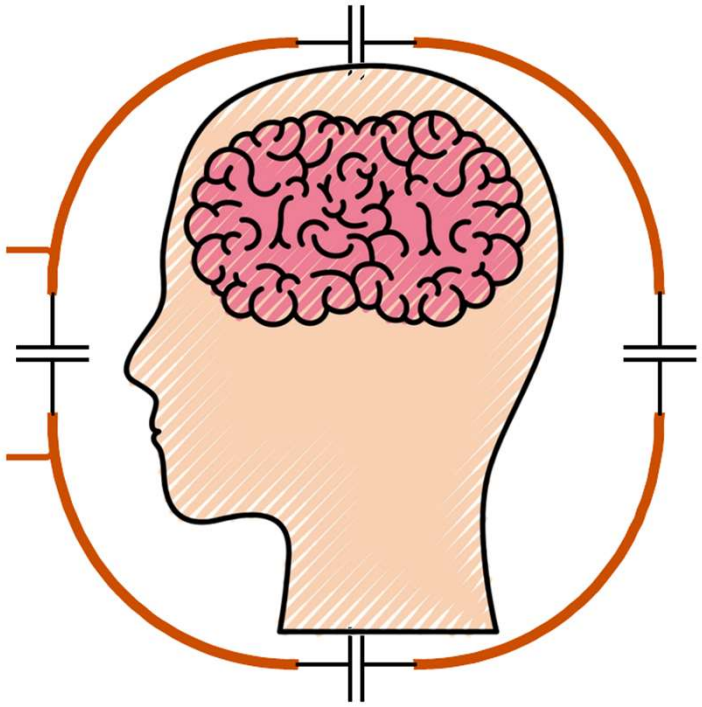
- Loading of RF coil
- EM fields couples to conducting substance
- Quality factor drops





Components and designs: Tx(Rx) coils

- Specific absorption rate (SAR)
- E-field
- Great effort put in prediction



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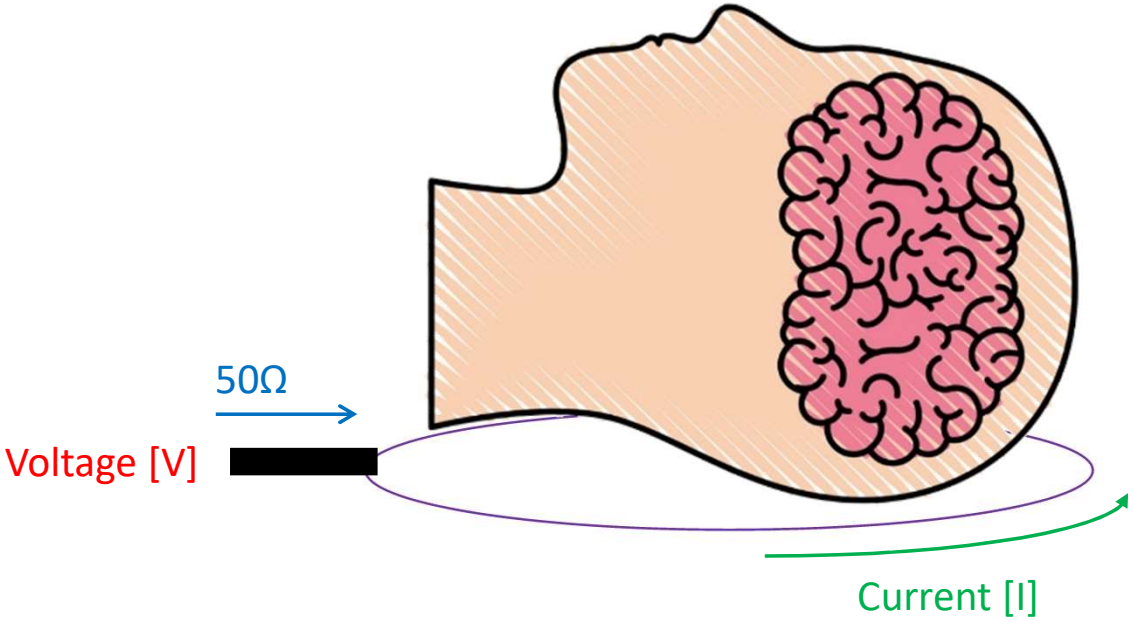

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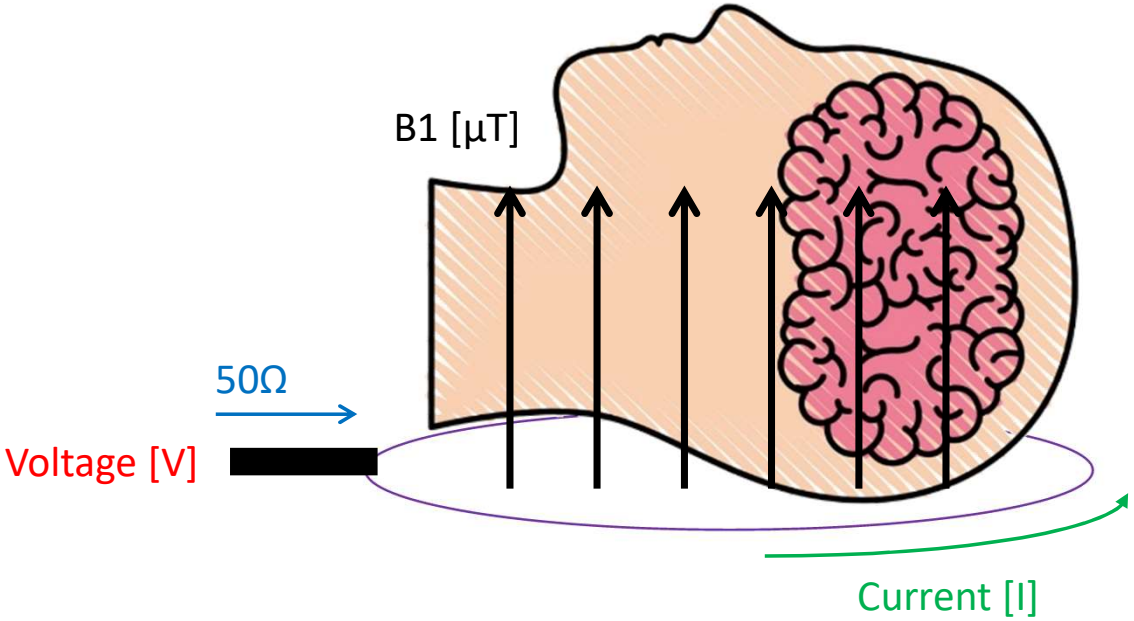
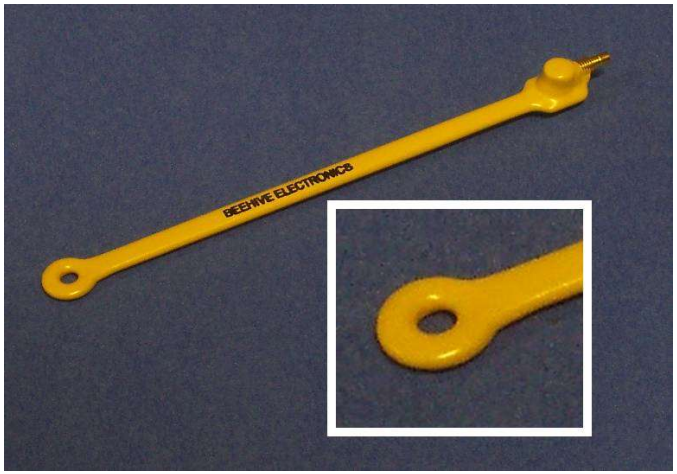


Sponsored by:

Components and designs: Tx(Rx) coils

- How much B1+/V is generated by a coil
  - Measure pick up probe

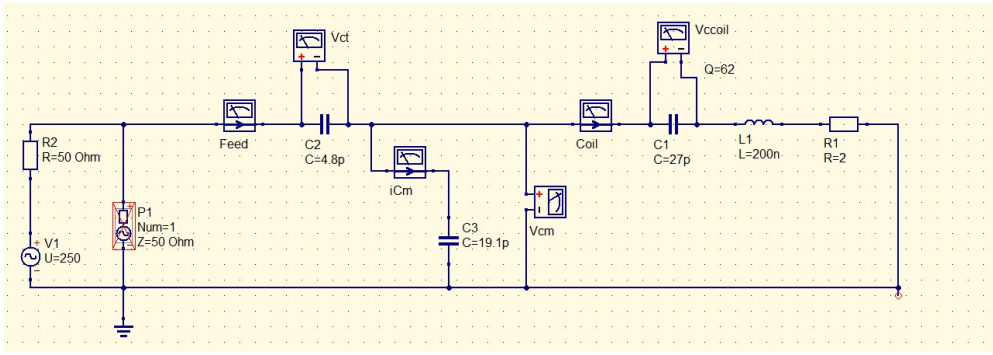


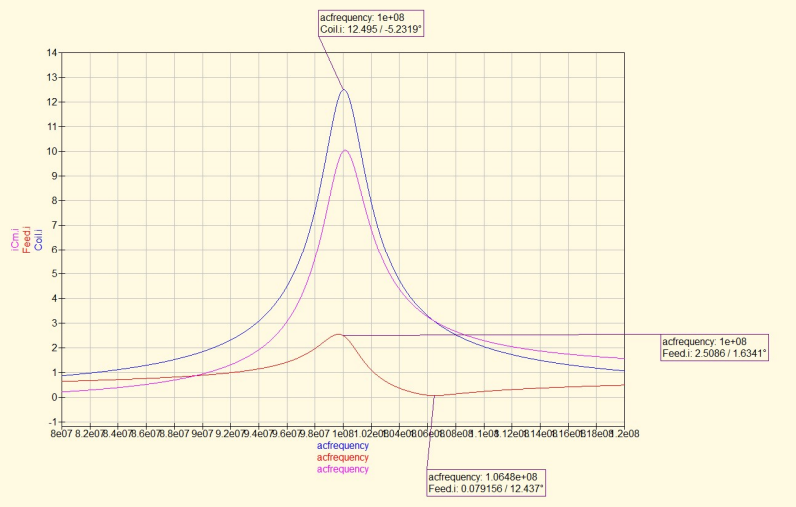
Tesla Dynamic Coils

Sponsored by:

Components and designs: Tx(Rx) coils

- How much B1+/V is generated by a coil
  - Measure pick up probe
  - Circuit simulation





Tesla Dynamic Coils

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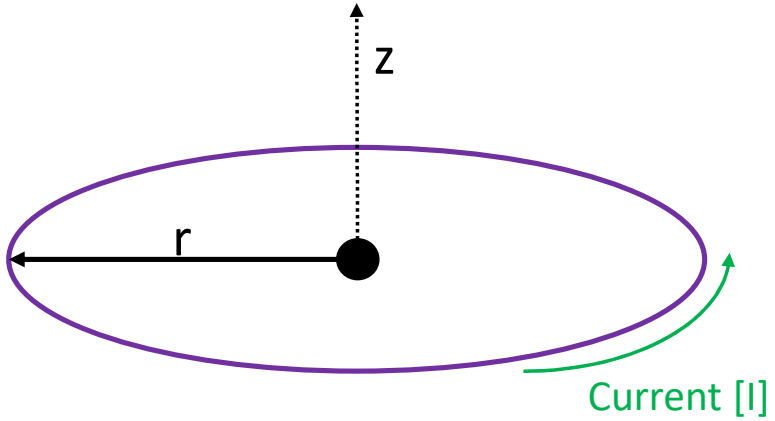
Components and designs: Tx(Rx) coils

- How much B1+/V is generated by a coil
  - Measure pick up probe
  - Circuit simulation
- Tissue does change the EM field

$$B_Z = \frac{\mu_0}{4\pi} * \frac{2\pi r^2 I}{(z^2 + r^2)^{3/2}}$$



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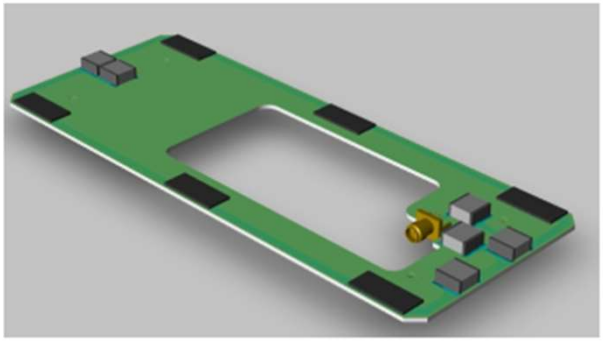

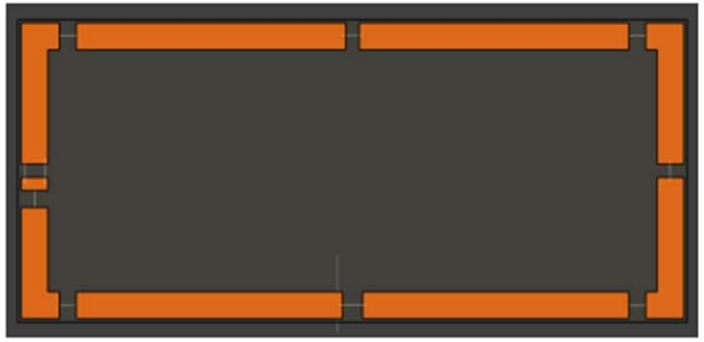

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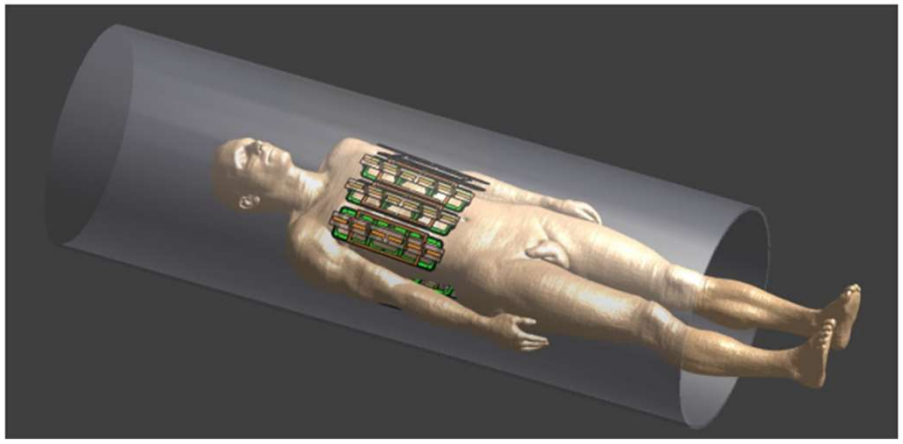

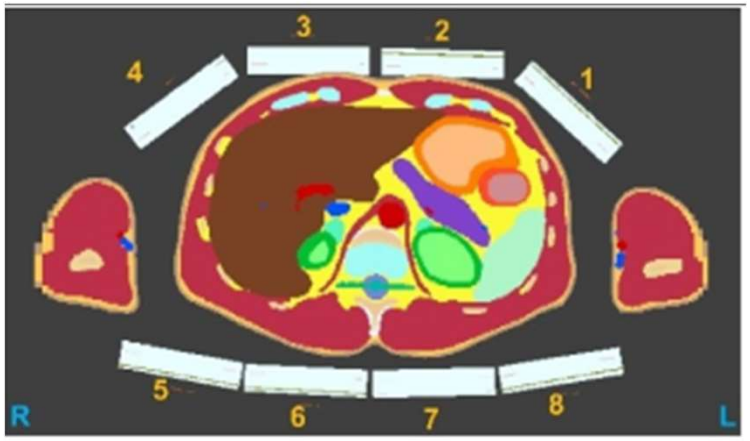

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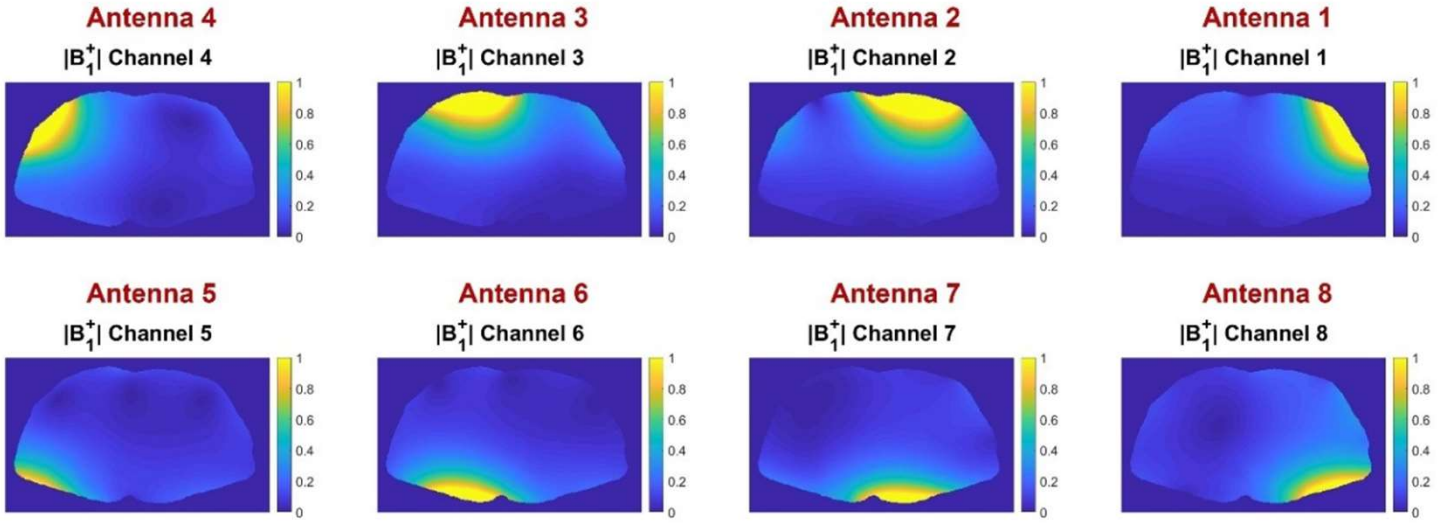

Tesla Dynamic Coils

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Sponsored by:

Components and designs: Tx(Rx) coils

- How much B1+/V is generated by a coil
  - Measure pick up probe
  - Circuit simulation
  - EM field simulation
  - Measure on MR scanner
    - B1+ map
    - Flip angle train

Tesla Dynamic Coils

Sponsored by:

Components and designs: Tx(Rx) coils

- Scale voltage and currents to desired B1+ field
- Or maximum output of the RF power amplifier of the scanner
- Compare scaled values to datasheet

Tesla Dynamic Coils

Sponsored by:

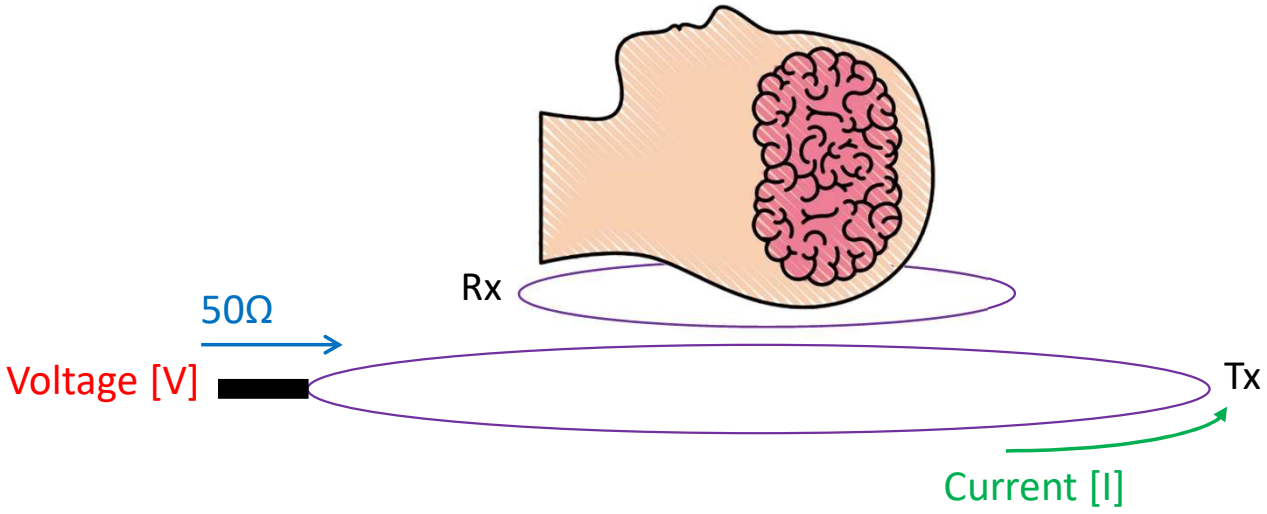
Components and designs: Rx coils

- Pick up the tiny RF signals
- Positioned close to the patient
- Losses (resistance) result in lower SNR
- Rx coils must be combined with a Tx coil
- They are exposed to high B1 fields

Tesla Dynamic Coils

Components and designs: Rx coils

- During transmit voltage induced
- Induced voltage creates a current
- Current generates own magnetic field
- Disturb original B1 field



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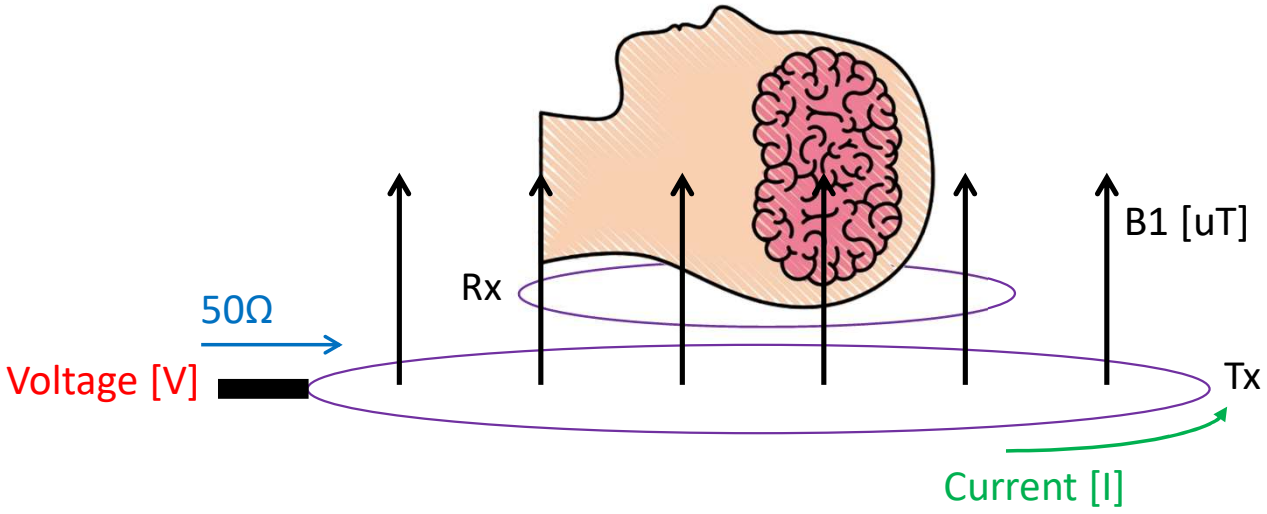

Tesla Dynamic Coils

Sponsored by:

Components and designs: Rx coils

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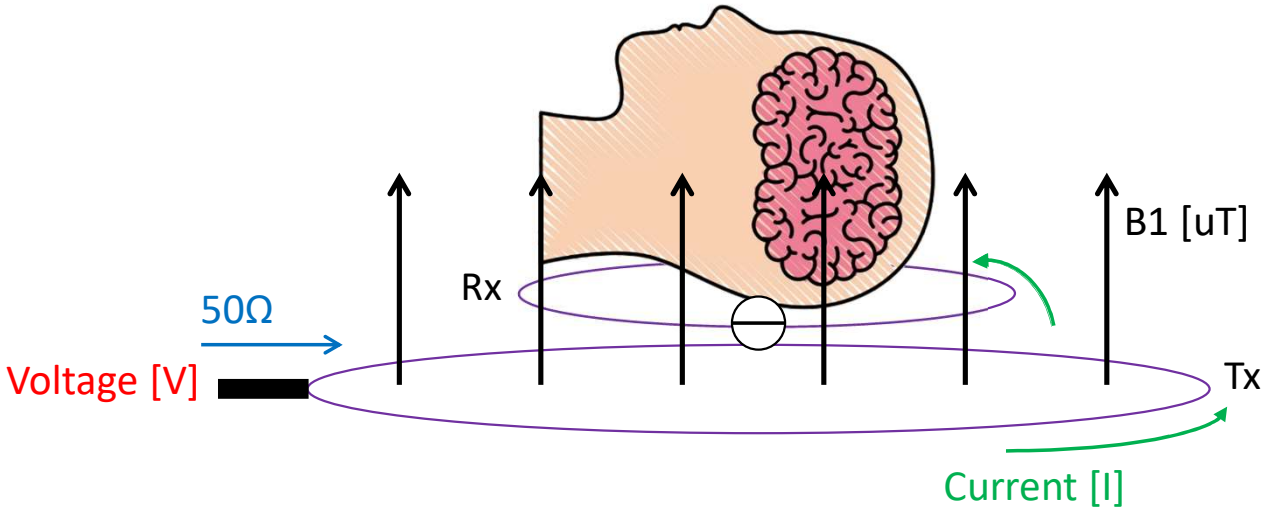
$$Vind = 2 * \pi * f * A * B_1$$

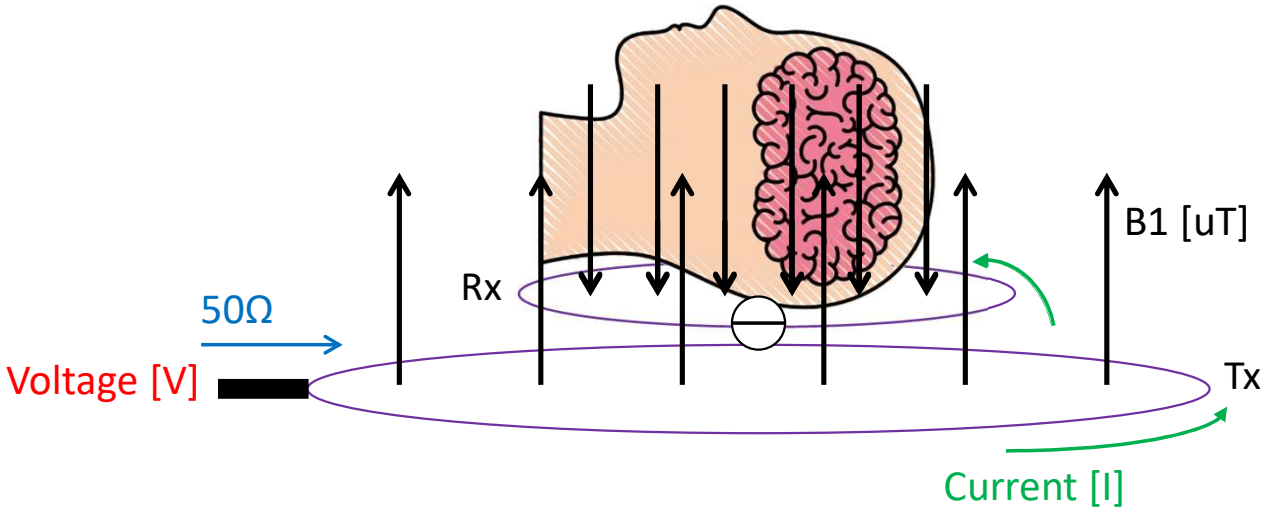


Tesla Dynamic Coils

Components and designs: Rx coils

- During transmit voltage induced
- Induced voltage creates a current
- Current generates own magnetic field
- Disturb original B1 field

$$Vind = 2 * \pi * f * A * B_1$$



Components and designs: Rx coils

- During transmit voltage induced
- Induced voltage creates a current
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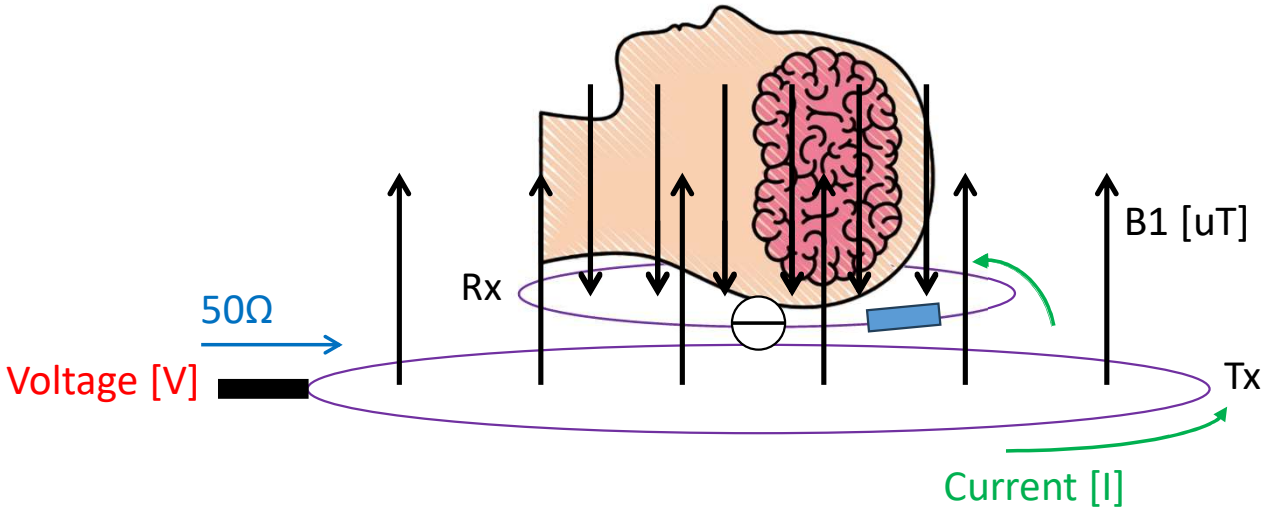
$$Vind = 2 * \pi * f * A * B_1$$

$$I_{coil} = \frac{V_{ind}}{Z_{coil}}$$

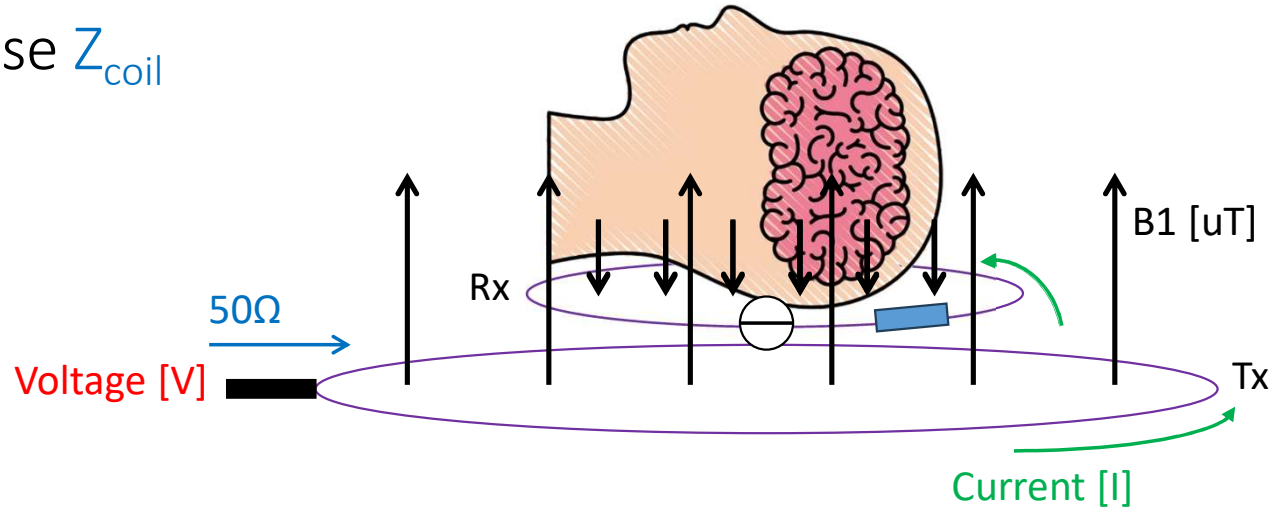


Components and designs: Rx coils

- During transmit voltage induced
- Induced voltage creates a current
- Current generates own magnetic field
- Disturb original B1 field
- Increase Z_{coil}

$$Vind = 2 * \pi * f * A * B_1$$

$$I_{coil} = \frac{V_{ind}}{Z_{coil}}$$

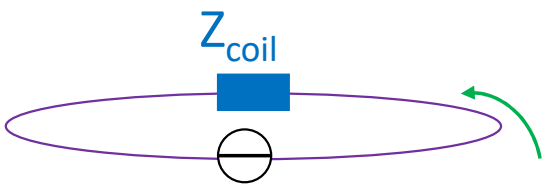


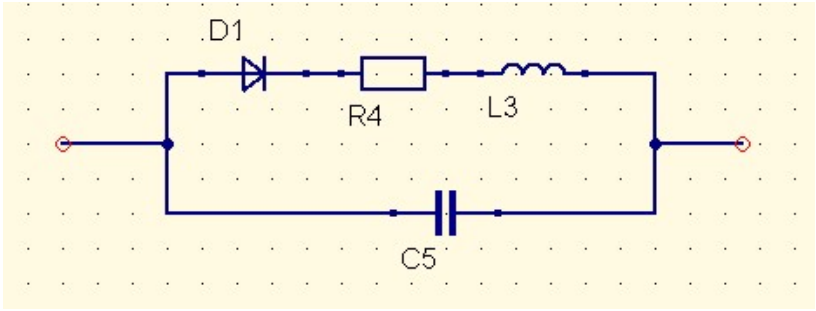
Tesla Dynamic Coils

Sponsored by:

Components and designs: Rx coils

- High Zcoil means low SNR
- Switch the high impedance on and off: detune circuits
- PIN diode biasing





Tesla Dynamic Coils

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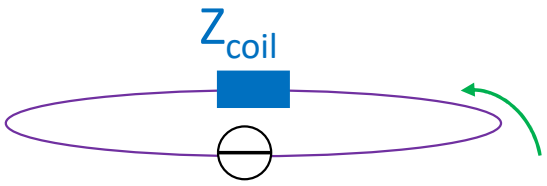

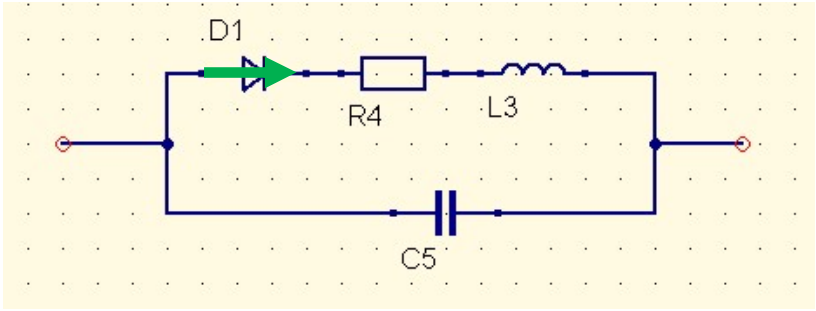

Tesla Dynamic Coils

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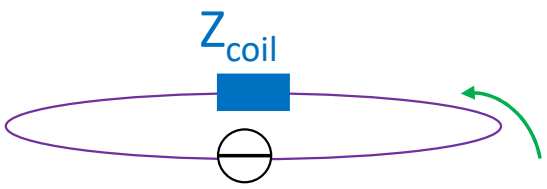
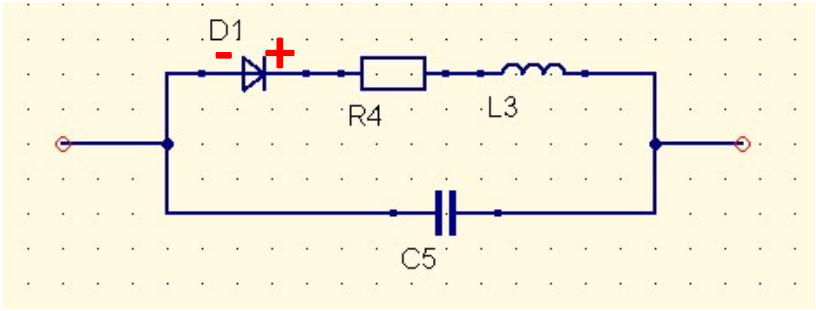




Tesla Dynamic Coils

Sponsored by:

Components and designs: Rx coils

- Missing specifications
- Experience and common practice
- +60dBm CW ≠ 8kW puls

Absolute Maximum Ratings[1] @ 25°C

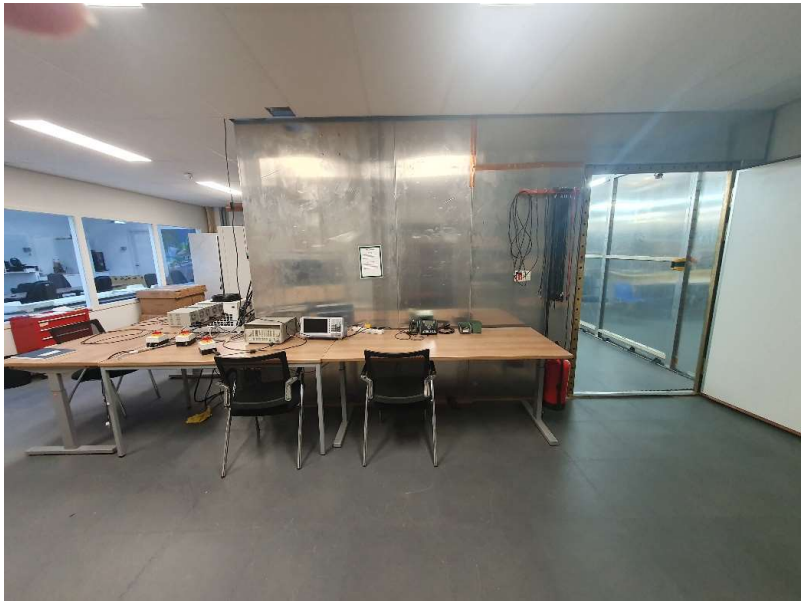
Parameter	Absolute Maximum
Operating Temperature	-65°C to +125°C
Storage Temperature	-65°C to +150°C
Diode Junction Temperature	+175°C Continuous
Diode Mounting Temperature	+265°C for 10 seconds
RF C.W. Incident Power	+ 60 dBm C.W.
Forward D.C. Current	+500mA
Reverse D.C. Voltage @ -10µA	-1100V

1. Exceeding these limits may cause permanent damage.

Tesla Dynamic Coils

Sponsored by:

Components and designs: Testing

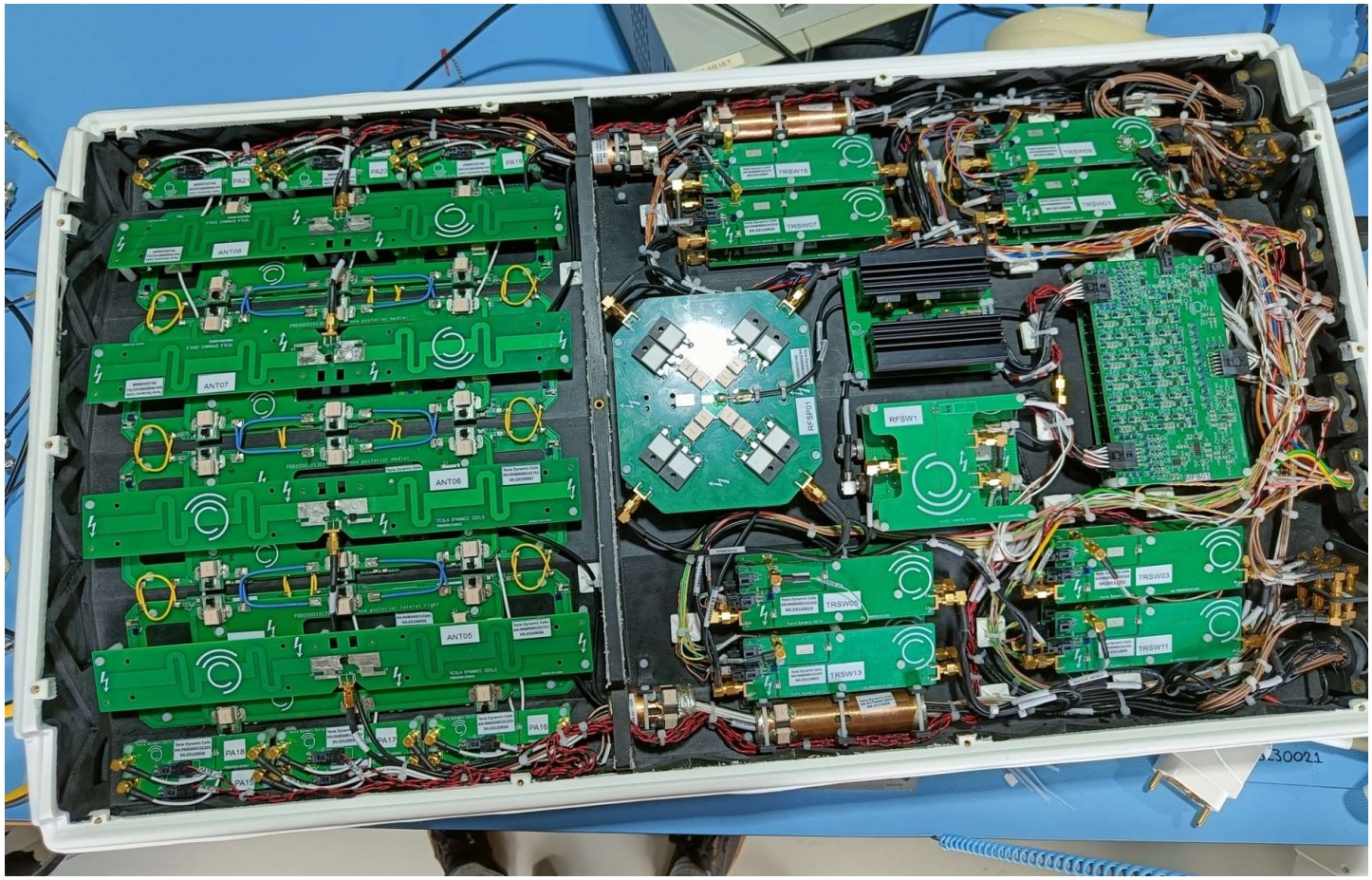


Tesla Dynamic Coils

Sponsored by:

heynen

Cables



Tesla Dynamic Coils

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6 februari 2024 | Van der Valk Vianen

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Summary

- Showed the electromagnetic field environment and application
- Component selection
  - Distortion of static magnetic field
  - SAR
  - High pulse power
  - Missing specifications
- Testing

Tesla Dynamic Coils

Sponsored by:

Tesla Dynamic Coils

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Stand #10

Tesla Dynamic Coils

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