

Topics of Magnetic Resonance Hardware.

Total hours: 20

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Topic 1. Introduction. Magnetic Resonance Physics and hardware. (2 Hours).

Diversity of MR experiments: MR spectroscopy, MR relaxation, MR imaging. Objects diversity and characteristics. Relationship between the Physics, hardware and object characteristics in MR experiments. General Requirements. General and common characteristics of MR equipment. Field and frequency range. Distinctions. General Block diagram. of Static Magnetic field in MR (B_0). Sensibility. Signal Noise ratio. Spatial and spectral resolution. The influence of the Static Magnetic field in the relaxation process. Larmor frequency as a carrier of the MR information. Correction of the external static magnetic field. General Characteristics Radiofrequency Magnetic field B_1 for the MR experiments. Effective Radio frequency field. Saturation. Physics relationship between the RF field and the electromagnetic and molecular characteristic of the object. Pulse magnetic field for codification, pre polarization, Diffusion measurements, Field cycling experiments and correction of the B_1 and B_0 inhomogeneity. Pulse sequences requirements. Coils and electronics. Geometric symmetry, distribution and its influence on the electromagnetic characteristics.

Topic 2. Static homogeneous external magnetic field. (2 hours)

MR magnet general physics and technological characteristics. Magnet types. Permanent magnets. Air cored Electromagnets. Iron cored resistive magnets. Superconducting magnets. Magnets for High resolution MR spectroscopy experiments. Magnet for Human MRI studies.

Magnets for animal research. Direct and inverse problem of the electromagnetism. Recalling of Maxwell, Laplace and Biot Savart equations. Magnetic field of a current lops. Magnetic field for a set of currents lops. Homogeneity. Spherical harmonics. Zonal and Tesseral Harmonics. Legend polynomials. Calculation of magnetic systems. Different methods for the homogeneity characterization. Magnet shielding. Superconducting Magnet. Wire and material characteristics. Energizing Superconducting magnet. Stress in the magnet. Wiring requirements. Quench damage and protection. Cryostat characteristics. Movement and installation of the Magnet. Safety concerning the magnet. International regulations.

Topic 3. Pulse Magnetic field. (6 hours)

1D, 2D y 3 D Images pulse sequences. General requirements for gradient system. Historical evolution of the gradient systems and calculation methods. Gradient Lobes shape. Gradient for oblique acquisitions. Orthogonality. Concomitant Gradients. Frequency and Phase Encoding Gradients. Common and distinctions characteristics. Slice selection Gradient. Slice rephrasing gradient. Motion sensitizing Gradients: Diffusion, Perfusion, Flow. Correction Gradients. Crusher gradients. Gradient Moment nulling. Spoiler gradients.

Classical and basics gradient coils configurations. Classical Methods for the calculation of Gradient coil. Maxwell coils configuration. Goley configuration. Biot Savart methods. Spherical Harmonics analysis. Zonal and Tesseral harmonics. Improving the Goley Configuration. Bases of the Target field theory. Current density methods. Target Field function. Factor to be included in the Target Field function. Real coils configuration. Efficiency, Homogeneity, linearly, Figure of Merit of gradient coils. Eddy current. Eddy current dependence of the materials. Methods for Eddy current compensation. Forces associated with gradient pulses system. Electrical field generated by gradient pulses. Dependence of the electrical field at the object electromagnetic characteristics. Energy dissipation. Coiling system. Temperature monitoring in Gradient coils system.

Effects of coils inductance. Methods for driving the Rise Time of the gradient pulse. Dependence of the strength and RLC characteristics. Cables, tubes, connector's influences. Gradient coil matching to the Power amplifier. Power amplifier requirements and characteristics. Room characteristics. Filter plate.

System with constant gradient intensity. Single side NMR. Non linear Gradient system. Patloc. Space codification and RF array of coils.

Characterization and quality control of the Gradient system. Different methods to characterize the gradient system in dependence on the step of the design and Pulse shape and parameters. Fourier analysis. Linearity and orthogonality analysis. Electronics and Hardware methods. Imaging methods.

Safety and protection in the Gradient system. International regulations.

Topic 4. Shimming technology. (2 hours.)

Causes of the magnetic field inhomogeneity. Spherical harmonic analysis. Characterization and correction actions. Passive and active shimming. Possibilities and restrictions. Magnetic field susceptibility inhomogeneity. Dependence on the geometry, Temperature, time, Pulse sequence, NMR mapping. Imaging methods. Shimming efficiency. Dynamic shimming. Eddy current compensation.

Interaction between the gradient coils the shim coils and main magnet. Methods to decrease the interaction.

Topic 5. Radiofrequency Magnetic field (6 hours)

Radiofrequencies pulse shape. Time and frequency domains. Rectangular pulses. SINC pulses. SLR pulses. Variable rate pulses. Excitation and refocusing pulses. Inversion pulses. Composite RF pulses. Magnetization Transfer pulses. Multidimensional pulses (2D and 3D). Ramp pulses. Spatial saturation Pulses. Spatial spectral pulses. Tagging pulses. SPANMM and DANTE. Adiabatic RF pulses. Excitation, Refocusing and inversion pulses. Modulation functions.

RF magnetic field characteristics and function in MR experiments. General goals in RF coil design quasi static electromagnetic condition. RF magnetic and electric field produced by one loop. Principle of Reciprocity. Phase in RF magnetic field. Linear and circular polarizing RF field. Quadrature in transmission and reception. Coils generation homogeneous RF field: Birdcage, Open configuration and Surface configurations.

Surface coil's field distribution. Quadrature surface coils. Capacitors functions. Mutual inductance and critical overlapping. Arrays of surface coils. Criterion of coils design. Signal Noise Ratio, Resolution, Field of View (FOV), B1 homogeneity. SNR and resolution versus FOV. Phase and weighting compensation of the voxel contribution in the SNR. Coils efficiency. Double tuned surface coils. RF surface coils circuits. Resonance circuits. Tuning and detuning circuits. Matching, coupling and decoupling in reception and transmission regimes. Capacitance

and Inductive matching. Impedance matching by transmission lines. Surface coils characterization. Real surface coils in MRI machine. Connection of surface array coils. Experimental proof.

Volume coils configuration. Current density methods. Target field approach. Birdcage configuration. Hybrid, Low pass and high pass birdcage configuration. Equivalent circuits. Tuning and matching. Double tuning coils. Spectrum analysis. Birdcage coil length. Number of loops characteristics. Ends rings effect. B1 RF homogeneity. Effect of the capacitors. RF coils interaction with Electromagnetic the surrounding. Birdcage shielding. Effect of the shielding in the B1 homogeneity, intensity and the coil efficiency. Method of images to improve the homogeneity. Mesh method. B1 map. Calculation of the B1 density. Open coils case. Double tuning birdcage coil. Requirements and possibilities. Different options. Criteria for the topology selection of the Birdcage coil configurations. Birdcage coils limitations.

Transverse Electromagnetic coils (TEM). Some configurations. Advantages. Shimming of RF coils in the TEM configurations. Target field and stream function. Surfaces TEM. Electronic Block diagram of the TEM and multi tuning coils. B1 map of TEM coils. B1 Map Birdcage versus TEM coils load and unload. TEM arrays design and implementation. TEM coils for extremities.

Dielectric resonators characteristics. Advantage and disadvantages. Hybrid electromagnetic modes (HEM).

Some special coils. RF coils for animal's model. RF coils for NMR solid state. Catheter RF coils. Micro coils.

Specific Absorption Rate (SAR). Tissue electrical properties. Common calculation and simulation methods. Comparison between different configurations. MRI protocols to decrease the SAR. RF safety International regulations.

RF power amplifier and Receiver design for MR. General characteristics.

Some references.

- 1) R.W. Brown, Yu-Chung N. Cheng, E. Mark Haacke, M. R. Thomson, R. Venkatesan, *"Magnetic Resonance Imaging Physical Principles and Sequence Design"* Second edition, Willey Blackwell, 2014.
- 2) Z.P. Liang, P. Lauterburg "Principles of Magnetic Resonance Imaging. A signal Processing Perspective" IEEE Press, 2000.

- 3) C.N Chen and D.I. Hoult "*Biomedical Magnetic Resonance Technology*". Adam Hilger, NY, 1989.
- 4) M. A. Bernstein, K.F. King X.J. Zhou, "*Handbook of MRI Pulse sequences*". Elsevier, Academic Press, 2004.
- 5) D. I. Hoult, "The NMR Receiver: A Description and Analysis design" *Progress in NMR Spectroscopy*, 1978. Vol. 12 PP. 41-77.
- 6) J. T. Vaughan, J. R. Griffiths "RF Coils for MRI" John Willey and Sons, 2012.
- 7) T. S. Ibrahim "Design of Radiofrequency Coils for MRI Applications: A computational Electromagnetic Approach "Dissertation; The Ohio University, 2003.
- 8) J. Mispelier, M. Lapu, A. Briguet "NMR Probeheads for Biophysical and Biomedical Experiments. Theoretical Principles and Practical Guidelines" Imperial Collage Press, 2009.
9. H. Sánchez López "*Développement de méthodes de calcul des systèmes magnétiques en Imagerie par Résonance Magnétique*», THESE, University Oriente and l'Université Claude Bernard- Lyon 1 , 2003.
10. A. G. Webb «*Magnetic Resonance Technology*» Hardware and System component design» The Royal Society of Chemistry , 2016.
11. J. Jin, « *Electromagnetic Analysis and Design in MRI*» CRC Press, 1999.
12. A. Kangarlu, P.M L. Robitaille, "*Biological Effects and Health implications in Magnetic Resonance Imaging*" *Concepts in Magnetic Resonance*, 2000, Vol. 12(5) p.321-359.

Final Test. Questions.

Part 1 Write test with the fallow questions:

1. Mention and describe the parameters and its units which characterize the B_0 field.
2. Discuss the principal causes of the B_0 inhomogeneities and how works the Shimming process.
3. Discuss the relationship between physics parameters and technological parameters to be taking account in the Gradient coil design.

4. Mention each of the Gradient pulse function and describe 3 of those function. Discuss the action of the Gradient over the spin system.

5. Discuss the interaction between B_0 , Gradient Pulse and RF fields. How these interactions can be compensating or avoid?

Part 2 Presentation and discussion of a scientific paper related to one of the fallow thematic:

- Design of the main magnetic field B_0 .
- Calculation of the main magnetic field B_0 .
- B_0 characterization and correction.
- Gradient coil calculation.
- Gradient coil design.
- Gradient Characterization.
- Interaction between B_0 , Gradient Pulse and RF fields.
- Shimming Technology, procedure.