**Session Title: RF Engineering - Coils**

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**Highlights**

- RF coil is an essential device in MR signal excitation and reception; its performance directly affects the quality of imaging and spectroscopy.
- Surface coils among other coil types provide highest SNR, but inhomogeneous B1 or image intensity.
- Volume coils usually offer homogeneous B1 thus uniform image, but much reduced SNR compared with that provided by surface coils.
- Increased radiation losses and ohmic losses, difficulties in achieving high frequency, and degraded efficiency in double-tuned heteronuclear coils are the main challenges currently encountered in RF coil engineering for high and ultrahigh field MR in humans.

**Title: RF Volume and Surface Coils for MR Imaging**

**Target Audience:** MR researchers and clinicians who want to learn MR RF coil principles and design methods

**Outcome/Objectives:** Attendees will learn the basics design methods of RF surface coils and volume coils used in in-vivo MR imaging and spectroscopy, and the current solutions to technical challenges encountered in human MR imaging at high and ultrahigh fields.

**INTRODUCTION:** RF coil is a radio frequency device which generates radio frequency magnetic fields required in MR experiments for spin excitation and MR signal reception. RF coils are critical for MR imaging and spectroscopy because their performance, e.g. Q-factors, resonance stability, and field distributions, directly affects the quality of MR experiments. At high and ultrahigh magnetic fields which have been advocated due to their intrinsically high sensitivity, the required high frequency leading to increased radiation and ohmic losses makes the design of efficient RF coils even more challenging. Commonly RF coils can be categorized into two different types, surface coils and volume coils (including half volume coils). In the course, we will discuss their functions and applications and the design methods and technical considerations of the surface coils and volume coils, and their recent advances in basic imaging research and clinical practice. We will also discuss the design solutions for ultrahigh field MR applications.

**SURFACE COILS:** Usually surface coils have relatively simple structure, comprising lumped or distributed capacitors (C) and inductors (L). The LC circuit forms a resonator resonating at the desired frequency. Capacitance and inductance of the circuit determine the resonant frequency of the surface coil. A good surface coil design should have high quality factors (Q factors), stable resonance, sufficient frequency tuning range and acceptable impedance matching. Generally the resonant circuits of surface coils for human imaging are designed by using lumped elements. At ultrahigh fields (7T and above), more split capacitors are needed in the coil circuits to help reduce the current phase-variation along the coil conductor and also help to achieve the required high operating frequency. It has been demonstrated that transmission lines with distributed elements, such as microstrip lines, are advantageous in designing high frequency, large size surface coils with improved efficiency for human imaging.

**VOLUME COILS:** In human MR imaging, RF volume coils started with the invention of the "birdcage" coil, a multimodal resonator structure comprising rings and rungs with lumped capacitors. One of its resonant modes has a uniform magnetic field distribution in the area of imaging. This uniform magnetic field can be used to generate uniform MR signal excitation and reception, and consequently achieving homogeneous human MR images. The invention of the birdcage coil is a milestone in the development of MR imaging, making the large volume, homogeneous MR imaging in humans possible, although signal-to-noise ratio (SNR) of the images acquired by using the volume coils is much lower than that provided by surface coils. At ultrahigh fields, the conventional birdcage coil design shows limitations in designing highly efficient large-size volume coils due to the required high operating frequency (300MHz and above). The high frequency results in increased radiation and ohmic losses, and thus, degraded coil Q-factors. For large sized coils in human imaging applications, it is also challenging to achieve the required high frequency. Some design strategies using distributed elements or transmission line circuits are proposed to address these high field RF issues.

**CONCLUSION:** RF surface and volume coils are two types of RF devices for generating the required B1 fields and exciting and receiving MR signals. Surface coils are able to provide high SNR in MR experiments but suffer from field inhomogeneity. Volume coils have homogeneous B1 fields in the imaging area and thus can generate uniform MR images although their SNR is much lower than that of surface coils. At ultrahigh fields, some RF design strategies are proposed to address the technical challenges resulting from the high operating frequency. But truly efficient design techniques for both surface coils and volume coils in ultrahigh field MR in vivo are still needed to be developed so that the high SNR gain of ultrahigh field MR can be fully realized.

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