MR Physics for Physicists: RF Field Generation, Coupling, Standing Wave Transmission

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- Strong, circularly polarized alternating magnetic fields have to be produced to excite spins.
- Losses in the sample and the device have to be kept as low as possible to provide high efficiency.
- Operating in near field this forces the current carrying structure being effectively an inductor.
- To couple high power into an inductor a resonance is established.

Outcomes: Key figures of merits and targets for RF field generating devices will be discussed together with their physical and technical implementations.

Overview: Dipolar spins, as typically observed in NMR and MRI, couple only to the magnetic field as described by the Bloch's equation. Hence coupling power from an external source into the spin system has to be mitigated by the local magnetic field at the spin's location. On-resonant spin nutation is induced by the circularly polarized component perpendicular to the main magnetic field axis having equal sense of rotation as the magnetic moment of the spins widely named as B_1^+ [1]. This time varying field produces inherently losses in conductive samples, which are of particular concern in NMR application with live samples. In that case the total power deposited in the subject as well as the local heating of the sample potentially causing a tissue damaging temperature rise has to be carefully controlled and represents in most cases the limiting factor for the achievable frequency and bandwidth of the final nutation. Hence preventing sample losses and avoiding strong localization of the deposited power while providing high B_1^+ magnitudes are the two key requirements for a device exposing the sample to radio frequency (RF) fields for spin excitation.

Typically the field producing structure has to reside very close to the sample because - at least for clinical routine systems (up to 3 T) - the wavelength is much longer compared to the bore size prohibiting field propagation. An electrical structure that mostly produces an alternating magnetic near field presents an inductance at its terminals and hence to the power delivering driving source. The simplest structure that does exactly this is a loop or a coil, probably the reason why all RF field generating devices are dubbed "coil" in NMR although many current implementations geometrically have hardly anything in common with a coiled wire.

Coupling RF power into an inductor directly is typically very inefficient because the electrical wave emitted by the source with purely resistive inner impedance is just reflected back. In order to make this power transfer efficient, the coil has to be matched to the sources impedance. Adding effective capacitance to the coil and bringing it to resonance is the simplest way of achieving this. The resulting resonance stores electrical energy which is oscillating between the magnetic field of the coil and the electric field in the capacitors and hence the wave stands in the resonant circuit.

Particular implementations of MR coils for transmission are highly dedicated to the application and many topologies are known and further adapted to date optimizing efficiency, uniformity and power handling [2].

References: [1] D. I. Hoult, Conc Magn Reson, 2000 [2] J. Mispelter, NMR Probeheads for Biophysical and Biomedical Applications, Imperial College Press, 2006.