RF Engineering: Coils

Mark E. Ladd, mark.ladd@dkfz-heidelberg.de
Medical Physics in Radiology, German Cancer Research Center and Heidelberg University, Heidelberg, Germany

Highlights:

- Transmit (Tx) arrays enable finer control over the RF field distribution than conventional volume resonators.
- Prerequisites include knowledge of the element field distributions (magnetic and electric) and the complete scattering matrix (matching/tuning/coupling).
- Potential applications include enhanced uniformity of the excitation field, sub-volume excitation, and SAR management.

Transmit Arrays & Circuitry

Target audience: MR technicians, scientists, and engineers with an interest in understanding the physical principles of Tx RF coil arrays.

Objective: Illustrate the principles of operation and basic applications of Tx RF coil arrays.

Principles: The primary goal of the excitation coil in MRI is to generate a transverse magnetic field (B_1^+) which is homogeneous across the imaging FOV. This goal is traditionally realized at lower field strengths by a volume resonator with a birdcage geometry [1]. As the field strength is increased, the Larmor resonant frequency linearly increases and the wavelength in the body tissue decreases (roughly 14 cm at 7T), implying that the quasistatic state can no longer be assumed and that the phase of the waves must be considered. Also, RF absorption in the tissue becomes more prominent. To provide more control over the fields, arrays of Tx elements have been introduced that allow independent driving of each element. One of the most basic geometries is the degenerate birdcage [2], which basically decouples all of the circular subunits formed by the legs and end-rings from one another. Many of the Tx arrays currently under investigation are, however, based on the combination of multiple, individual transmission line elements, each of which supports a transverse electromagnetic (TEM) field pattern [3].

Several issues need to be considered in the design of a Tx array. An important point is knowledge of the matching and tuning of the individual elements and a clear characterization of the interactions between elements (coupling), all of which are in general load-dependent. Also, the Tx pattern of each element should be known; this knowledge is often obtained in vivo with B_1^+ mapping techniques, but unfortunately these techniques still do not provide sufficient accuracy for all applications.

Another point is the SAR distribution of the array. Unlike a volume coil which usually has a fixed Tx mode, Tx arrays are routinely driven with variable phase and/or magnitude relations between the elements. For a set of eight elements equally distributed circumferentially around the target anatomy, the phase difference between elements to achieve the circularly polarized (CP) mode would be 45°. Especially at higher magnetic fields (body imaging at 3T, head and body imaging at 7T), this mode may not lead to the desired circular polarization inside the tissue. By adjusting the phase differences and element magnitudes (so-called B_1 shimming), the B_1^+ field uniformity can be greatly improved; however, the electrical field distribution and hence the SAR distribution varies as well. To fully describe a Tx array and assess the RF exposure (in particular local SAR) of the subject, the field distributions of the individual elements must be known for a suitable inhomogeneous body model, and these field distributions must be superposed for each applied shim. Concerning RF safety, this makes the use of Tx arrays more complicated compared to Tx coils/arrays with fixed excitation vectors.

The potential applications of Tx array technology go well beyond achieving a uniform excitation field. Such arrays can be used to apply unique RF pulses on each element as required in Transmit SENSE [4]. Degrees of freedom include RF frequency, phase, and magnitude on each element, as well as the design and spatial placement of the individual elements. Transmit SENSE can facilitate the use of multi-dimensional RF pulses by shortening them to practical durations. Such pulses can be used to excite arbitrary sub-volumes, correct for artifacts due to non-uniformities in both the B_0 and B_1 fields, and manipulate the electric field. The latter capability is important for limiting local SAR and resultant tissue heating, and one application of Tx arrays may be the reduction of heating around electrically conducting implants.

Conclusion: Due to wave effects at higher static magnetic field strengths (> 3T), Tx arrays are likely a necessity to perform even basic imaging in anatomy with large cross-section. But even at the conventional clinical field strengths of 1.5T and 3T, Tx arrays open up many opportunities to take advantage of complex RF field manipulation. Due to these multifaceted uses, Tx arrays can be expected to play an increasing role in MRI in the coming years and replace conventional volume resonators, helping to improve image quality, promote safety, and increase application versatility.

References:

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