Why do dipole antennas work? A comparison to loop coils as a function of element size

Alexander Raaijmakers[1], Peter R. Luijten[1], and Cornelis A.T. van den Berg[2]
[1]*Radiology, UMC Utrecht, Utrecht, Utrecht, Netherlands,* [2]*Radiotherapy, UMC Utrecht, Utrecht, Netherlands*

Dipole antennas were first used in MRI [1] in 2010, but since then, gradually, more and more institutes are beginning to recognize their potential [2]. However, many coil engineers are reluctant to adopt this new technology, mostly because well understood design concepts (Q-factor, decoupling circuits) are meaningless. This abstract will provide a meaningful insight into why dipoles can outperform more conventional coil array elements at ultra-high fields.

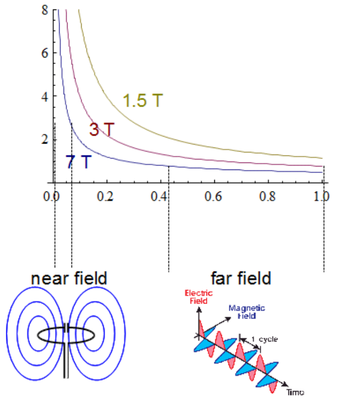

Figure 1: Near field and far field

Conventionally, coils are designed as resonant structures that sweep up the currents in the coil conductors. The B_1 magnitude in the region close to the coil is boosted by the resonance so the design is efficient if the imaging target is located in this nearby region. If the imaging target is located deep inside the body, a different perspective is needed: RF coils in MRI are effectively antennas. In antenna theory, the nearby region, where resonant fields exist, is called the near-field region. In addition, antennas have a so-called far-field region where electric and magnetic fields co-exist to form a propagating wave. B_1 field in this region needs to be generated by emitting a propagating electromagnetic wave. At ultra-high fields (>7 T), typical body imaging targets such as prostate and heart are located in this region. Thus, design criteria for RF coils become entirely different: resonance should be avoided and the coil should preferably generate both magnetic and electric fields in order to setup a Poynting vector oriented towards the imaging target. Such a coil we call a 'radiative antenna'.

Although loop coils are commonly used as resonant elements, they are also quite good radiative antennas [3]. But a somewhat more attractive candidate is the dipole antenna. The dipole antenna has one linearly oriented current pattern instead of a circular current such as a loop coil has. This results in a symmetrical, homogeneous propagating plane wave being emitted from the dipole (figure 2a). The polarization of the field is linear almost everywhere. Loop coils emit a more inhomogeneous wave front (figure 2b) with regions of right-circular polarization (high B_1^+) and left-circular polarization (high B_1^-). These circular polarization patterns result in a less efficient transportation of energy towards the target region.

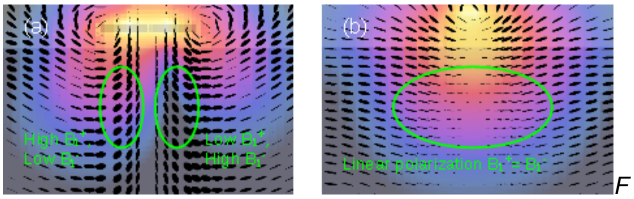

Figure 2: Polarization patterns for (a) loop coil and (b) dipole antenna. Circular disks indicate circular polarization; disks that are stretched and flat indicate linear polarization

The higher efficiency of dipoles in comparison to loop coils (for deeply located targets at ultra-high field strengths) has been demonstrated by a basisfunction analysis [4]. Here, we make this prediction concrete by simulating loop coils with various diameters and dipoles with various lengths and comparing their performance in B_1 per unit power at 7T. Simulations are performed with SEMCAD X (Speag, Zurich, CH) with a cubic 0.5 m phantom (ε_r = 34, σ=0.4). Elements are positioned 2 cm above the phantom. Results are presented in figure 3 for a selection of the investigated dimensions. Each B_1^- distribution is shown from two sides as indicated in the figure. Results clearly show the asymmetrical and inhomogeneous loop coil pattern for any diameter while the patterns for the dipole antennas are (almost) symmetrical and generally show a much more homogeneous field distribution. For both loops and dipoles, the optimal size depends on the imaging target depth (as predicted for loop coils [5-6]). This is also clearly depicted in figure 4, where the in-depth B_1^- profile is presented in sections corresponding to the best performing element size for that depth. From a depth of 6 cm the dipole antenna performs better.

Dipole antennas form a promising candidate to replace or strengthen existing coil arrays. Next to plain dipoles, design variations have been presented to enhance the performance [1-2]. Given these fundamental advantages, we expect dipole antennas will be used for an increasing amount of ultra-high field applications in the next couple of years.

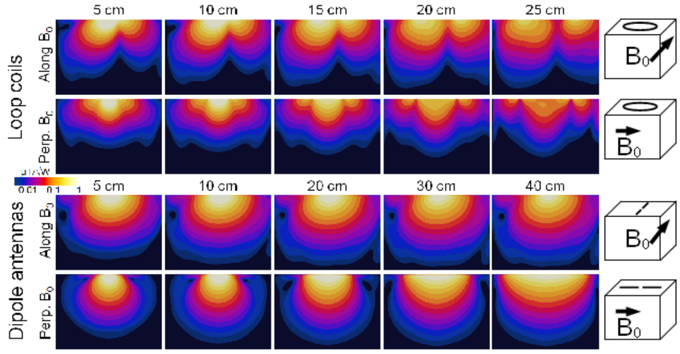

Figure 3: B_1^- field distributions for loop coil and dipole antenna as a function of element size.

References: [1] Raaijmakers et al. ISMRM 2010 [2] Winter et al., Wiggins et al., Eryaman et al. ISMRM 2013 [3] Raaijmakers et al. MRM 2011 [4] Lattanzi et al. MRM 2012 [5] Roemer et al. SMRM 1987 [6] Chen and Hoult 1989

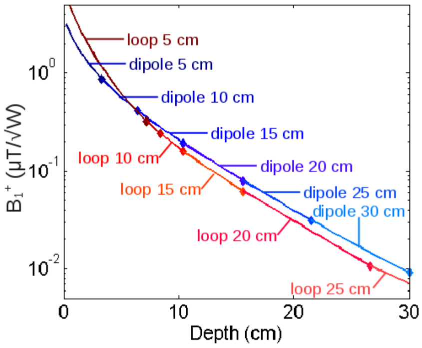

Figure 4: In-depth B_1^- profiles (maximum intensity projection) for loop coils and dipole antennas. Each graph consists of sections corresponding to the best performing element size for that depth range.