NEAR- AND FAR-FIELD MEASUREMENTS OF STRIP CONDUCTOR-TYPE COILS FOR 7-TESLA MRI

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Introduction: We have realized strip conductor-type coils for 7-Tesla MRI based on two design concepts, the dipole- and the loop-configuration. However, both types have shown unconventional characteristics, in particular the figure-of-merit of "unloaded" Q-factor over "loaded" Q-factor and its dependence on the distance from a phantom, see our companion abstract/1/. In order to learn more about the inherent properties of the coil designs, we performed measurements of the magnetic and electric near-field in free space around the coils as well as far-field radiation measurements.

Methods: Our dipole-type, Fig.1(above), has been used successfully in an 8-element circular array configuration /2/. This design is a true half-wavelength dipole with 60% of the length of each arm folded in a meander to reduce the total length to 25 cm. The dipole is fed symmetrically at the centre and is elevated above a 10 cm wide reflector plate by 20 mm. The currents in the reflector plate are excited by (parasitic) electromagnetic coupling, contrary to the ground plane current in the loop-type coil of Fig.1(below), an off-center feed adaptation of /3/with about 30 cm length by 10 cm width, where the current flows continuously through the end capacitors into the ground plane (hence "loop"-type coil).

Fig. 1

Near-field measurements were performed in our anechoic chamber with the coil fixed on a table which can be moved horizontally on a rail and with a field probe fixed to a precision vertical slide, Fig.2. By setting-up the coil with the strip conductor in vertical direction we did longitudinal cuts while transverse cuts were done by rotating the coil and the probe (polarization!) by 90°. Cuts in different levels (distances) above the coil were produced by moving the table along the rail. Any absorbing or dense material was placed far away from the coil in order not to load or distort the coil fields, yet it was found necessary to have an absorbing environment in order to achieve repeatable measurements with a low level of measurement range artifacts (caused by radiation). The probe for B_1 magnetic flux, Fig.3, is based on the conventional loop design with slotted electric shield – improved by a compensation of the loop E-field pick-up sensitivity. The probe for the electric field was a short dipole fed symmetrically by a coaxial half-wave balun. By measuring the complex coupling coefficients between the coils and the probes as a function of position using a Vector Network Analyzer, we were able to compare field distributions of different coils without the need for absolute probe calibration. The far-field measurements were done in our microwave anechoic chamber using a transmitting antenna at the end of the chamber and the coil as receiving antenna positioned on a rotating table 5 meters apart at the other end. Since the absorber lining of the chamber walls is not well suited for frequencies much below 1 GHz, artifacts have been observed in the measured patterns; therefore, we also did verification measurements in free space on the roof of our building, Fig.4 which gave reasonable agreement in gain and pattern measurements.

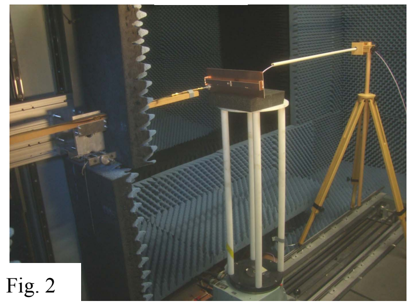

Fig. 2

Fig. 3

Fig. 4

Results: The far-field patterns of the two coil types are shown in Fig.5: The dipole exhibits deep minima in axial direction, as required due to the lack of transverse current flow. Contrary to that, the loop exhibits strong fields in axial direction which can be attributed to the transverse currents through the capacitors at the strip conductor ends. We also see that the dipole has its maximum radiation into the backward direction which proves that the reflector plate acts as a "director" of a Yagi-Uda array, while the coil produces its main beam in forward direction (the ground plane is a true "reflector"). However, both coils exhibit only a small forward-to-backward ratio which is a clear indicator that the size of reflector plane or ground plane is electrically small (only lambda/4). The absolute gain was measured by the comparison method using a reference standard dipole antenna and was found around 0 dB_i for the dipole and about 2 dB_i for the loop which is only a few dB below the gain expected from a conventional quarter-wave antenna.The longitudinal cut measurements of magnetic flux at close distance of 20 mm above the conductor strip, Fig.6(upper), show that the current magnitudes are 3 dB apart with similar distributions along the strip conductor (both types with two mild current maxima offset from the centre). However, as shown in Fig.6(middle), at a larger distance of 100 mm, the resulting magnetic flux of the dipole is 6 dB larger compared to the loop-type. However, the loop spreads the magnetic flux over a wider area which can also be observed in the transversal cut patterns, Fig.6(lowest). In dead, further measurements of fields at the sides of the coils prove that the main flux of the loop-type coil is close to the plane normal to the loop-plane and containing the strip conductor; this seems to be the reason for the observed strong mutual coupling of two loop-type coils side by side of about -4 to -5 dB while we measure only -13 dB for two dipole-type coils. A comparison of electric field strength of the two coil types shows quite non-uniform field distributions close to the conductor strips, but at larger distance of 100 mm, Fig.7, we observe very low levels of E-field directly above the dipole with higher levels close to the dipole open ends; the loop-type coil shows an opposite behavior with high peak field directly above the conductor strip and lower field strength off the center.

Discussion: The strip conductor –type coils investigated in this study have shown strong far-field radiation. It is not a surprise that we see this in 7-T coils (and probably not in 1.5-T and 3-T coils) as the linear dimensions of the conductors are about a quarter-wavelength and in a first approximation the radiation resistance increases with the square of the "electrical" length. These coils, therefore, may also be termed true "antennas" and consequences for Q-factor characterization are demonstrated in /1/. The comparison of the dipole- and loop-type coil near-fields has shown higher B_1- flux levels and more concentrated spatial distribution as well as lower E-field levels in the dipole-type. This, together with the much lower mutual coupling levels make the dipole the superior coil for array applications.

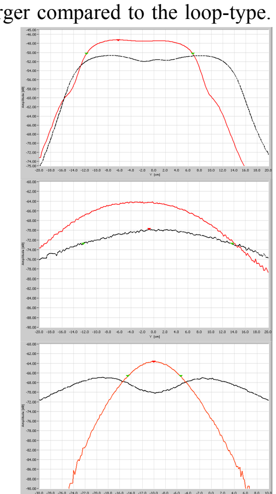

Fig.6: B_1- distributions of dipole (red) and loop (black). Longitudinal cuts in 20 mm, 100mm and transversal cut in 100 mm (lowest)

References: [1] K.Solbach et al., "Measurement of Q-factors…", abstract submitted, ISMRM2010. [2] S. Orzada et al., Proc. Intl. Soc. MRM 16 (2008), 2979. [3] J. Fröhlich et al., "Computational Analysis and Validation …",IEEE MTT-S Int. Microwave Symposium. pp.2217 - 2220, June 2007.

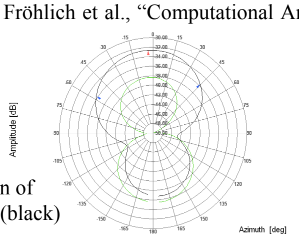

Fig.5: Far-field pattern of dipole (red) and loop (black)

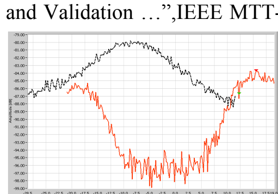

Fig.7: Longitudinal E-field distribution