A method for the measurement of the RF power radiated by 7T transmit coils

Gerd Weidemann[1], Frank Seifert[1], Werner Hoffmann[1], Harald Pfeiffer[1], and Bernd Ittermann[1]
[1]*Physikalisch-Technische Bundesanstalt, Braunschweig und Berlin, Germany*

Target Audience: Basic researchers and scientists interested in safety of RF transmit coil arrays, developers of RF transmit array coils

Purpose: At 7T the portion of RF power radiated by a transmit coil into the far field cannot be neglected a priori. Since it could couple into medical devices it is of interest with respect to RF safety. Knowledge of the RF power radiated by pTx coils is furthermore required to assess the power balance of a pTx coil in dependence of steering conditions. Since the radiation efficiency of a typical 7T transmit MR coil should be low it is not affordable to use standard antenna measurement systems, e.g. in an anechoic chamber. Therefore a method was devised to derive the total radiated power from field measurements inside a wave guide, utilizing the fact that the bore of a 7T magnet also has waveguide properties [1].

Methods: Computed electromagnetic fields inside a waveguide of 280 cm length and 60 cm diameter are used to relate the E-field vector measured at a certain point on the central axis inside the waveguide to the radiated power. The operating frequency (297 MHz) of a 7T pTx coil (Rapid Biomedical) under investigation is close to the cutoff frequency of the wave guide of 60 cm diameter (Fig 1a). Since the waveguide deforms under its own weight (about 1 cm) the horizontal and vertical modes differ slightly in propagation constant which influences the mode propagation such as changing the frequency by 1 to 2 percent. The field distribution at the end of the waveguide, however, is not sensitive to such minor frequency changes.

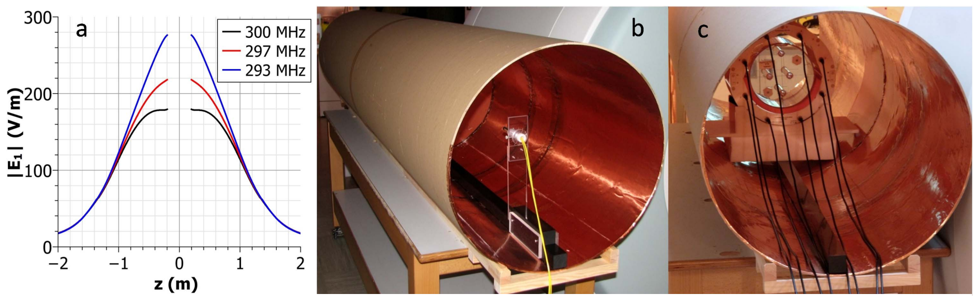

Figure 1: a) calculated transversal E-field for 1 W of total radiated power, b) waveguide end with E-field sensor, c) 7T pTx coil in the centre of the waveguide.

The experimental setup consisted of a cardboard tube with 60 cm inner diameter and 280 cm length clad with 0.1 mm copper foil. The edges of the foil were soldered to generate a continuous copper tube (Fig 1b). A polyethylene (PE) rail and a slider made of PE and PMMA were used to vary the sensor position along the tunnel axis. For the E-field measurement inside the wave guide a time-domain fiber optic E-field sensor (OEFS–S1B, Seikoh Giken) was used. The signal was recorded with a high speed PCIe transient recorder card (M3i.4142, Spektrum) in a Linux host computer. To avoid the pickup of ambient RF noise by OEFS controller or transient recorder card all experiments were performed inside the RF cabin of a 3T scanner. The 8-channel pTx coil was positioned in the center of the waveguide connected to the first 8 ports of a home built 16x16 Butler matrix (Fig 1c). This way the phase increments between channels could easily be incremented in 22.5° steps. An RF signal generator (ESG-1000A, Hewlett Packard) together with an RF amplifier (40WD1000, Amplifier Research) was used to generate 297 MHz signal pulses of 1 ms duration. A TEM cell [2] was used to calibrate the E-field sensor with the signal strength at the input port of the Butler matrix. Signal loss in the Butler matrix and on the cables was measured using a vector network analyzer (ZVB8, Rohde&Schwarz). The average loss for each of the 8 channels was -14.1 dB, i.e. only 31% of the input power at the Butler-matrix arrives at the coil.

Results: The on-axis profile of all E-field components shows that the coil couples to both polarization directions E_x and E_y of the $TE_{1,1}$ waveguide mode (Fig 1a). In the near field of the coil also axial field components (E_z) were observed. All subsequent measurements were therefore performed with the sensor at 1.0 m distance from the waveguide centre (s. Fig. 1b). The highest radiated power was detected when driving the coil in CP-mode, the lowest in the mode with equal phases when most power is reflected by the coil. A radiated E-field of 7.7 V/m is measured in CP-mode corresponding to a radiated power of 3.3 mW. This represents 1.1 % of the forward power at the coil ports (0.31 W).

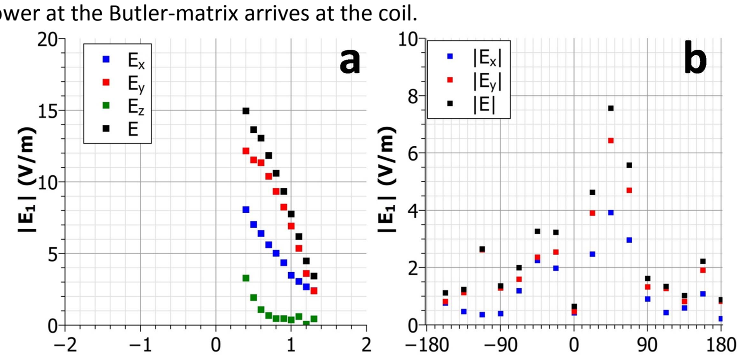

Figure 2 a) axial profiles of the E-field components at 1 W forward power at the Butler matrix (CP-mode), b) horizontal and vertical E-field components at z = 1.0 m as function of the steering conditions.

Discussion: Qualitatively, our data confirm theoretical results for an 8-channel loop array [3] where highest radiation was also found for the CP mode. The low percentage of radiated power in the present case seems to be specific for the locally shielded Rapid coil, however. For other types of coils much higher amounts of radiated power are expected [3]. Our measurements showed that it is possible to derive the power radiated by a 7T pTx coil from E-field measurements inside a simple wave guide ($TE_{1,1}$ mode). For the more complex environment of an MR scanner the radiated power can still be derived from E-field measurements on the scanner axis but a few instead of just one sensor positions may be required.

Conclusion: We devised an experimental method to derive the radiated RF power of 7T transmit coils. Together with the measurement of the S-parameter matrix this allows to assess the power balance of pTx coils in dependence of steering conditions.

Acknowledgements: This work was funded by European Metrology Research Program (EMRP) grant HLT06. The EMRP is jointly funded by the EMRP participating countries within EURAMET and the European Union.

References: [1] Brunner et al. Nature 457, 2009, 994, [2] Klepsch et al. Biomed Tech 2012; 57 (Suppl. 1), DOI: 10.1515/bmt-2012-4428, [3] Kuehne et al. MRM 2014, DOI 10.1002/mrm.25493.