A system for in situ S-parameter measurements of MR transmit arrays

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

Purpose: The in situ measurement of S-parameter matrices allows to monitor the full network parameters of an RF transmit array coil and thus, to determine the reflected power and the coupling of coil elements depending on loading conditions or coupling to the coil environment. Changes of the transmit phase due to reflections in the transmit path can be identified. Additionally, the monitoring of the S-parameters can be used to detect coupling to the environment or implants. An S-parameter measuring system was designed and built which is compatible with a wide range of scanners, independent of manufacturer or field strength. Except from access to the Tx cables no hardware or software support from the manufacturer is needed. Special purpose sequences and pTx pulses are useful for quick and automated measurements. But since the system does not interfere with the scanner's RF system it can be used with any sequence, including in vivo measurements, for in-situ diagnostics.

Methods: 8 bidirectional couplers were customized by the vendor (EME 7020/30A, EME-HF-Technik) to be completely non magnetic and thus useable in or next to the bore of an MR-Scanner, e.g. at the coil feeder panel of a pTx system (Fig 1a). The bidirectional couplers are have a coupling of about 30 db at 123 MHz and of about 23 dB at 297 MHz; the directivity is better than 25 dB. They tolerate high power (2000 W PEP at 145 MHz and 500 W PEP at 435 MHz) and can be used directly in the transmit path. A setup (Fig 1b) with five cascaded fourfold RF switches (L7104A-T24, Agilent) inside the RF cabinet is used to multiplex the 16 signals (8 forward, 8 reflected) into one channel which is fed to a high speed PCIe transient recorder card (M3i.4142, Spektrum) in a Linux host computer outside the RF cabinet. The same card also triggers the switch controller outside the RF cabinet. The phase reference is taken from one of the eight RF amplifiers of the scanner's pTx system. One column of the S-parameter matrix can be recorded with only two switch positions (forward and reflected signal of one channel) if composite pTx pulses cycling through all channels are used. The whole matrix is measured in 32 s, determined by generous dead times for switching and synchronizing read out. On the bench, switching only the transmit path manually, an S-parameter matrix can still be recorded in less than 5 minutes. The system is calibrated with measurements of the input amplitude of each channel as well as the forward and reflected signals with open contact and terminated with short and load. The S-parameter matrix of an unshielded 8-channel pTx head coil for 3T (Rapid Biomedical) was recorded in situ using the pTx array of the scanner (Verio, Siemens) while the S-parameters for an 8-channel shielded loop pTx head coil for 7T (Rapid Biomedical) was recorded ex situ using an RF signal generator (ESG-1000A, Hewlett Packard) together with an RF amplifier (40WD1000, Amplifier Research).

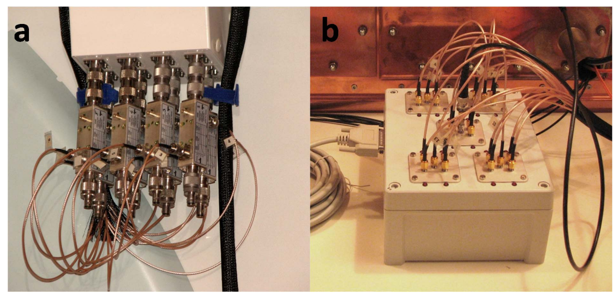

Figure 1: 8 bidirectional coupler directly mounted at the coil feeder panel of the scanner (a) are connected via 10 m cables to a multiplexer box with 5 cascaded RF switches (b) at the filter plate.

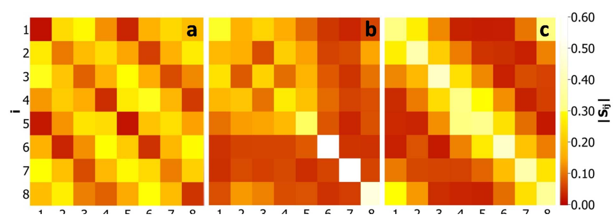

Figure 2: a) magnitude of the S-parameters of a 3T 8 channel birdcage like coil, b) S-parameters of the same coil mounted off center inside a shim insert, c) S-parameters of a 7T 8 channel shielded loop.

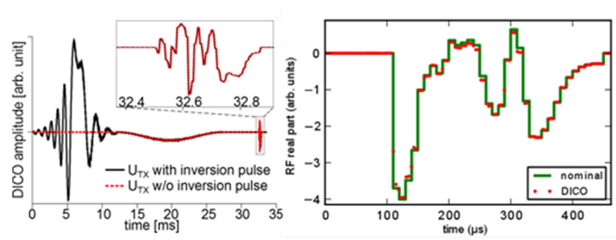

Figure 3: Example application analyzing a segment of a real-life pTx MRS sequence. Left: transmission of a complex pTx pulse (inset) is not affected by the presence (black) or absence (red) of a preceding inversion pulse. Right: the real part of the pTx pulse (red) agrees with the nominal pulse shape. (green).

Results: The S-parameter matrix of the 3T pTx coil (Fig. 2a) shows low direct reflection but strong coupling to the next nearest neighbor (*nnn*) elements. Since the coil is not shielded it is quite sensitive to its surrounding. Placed inside a 38-cm shim insert and a few centimeters off axis, the direct reflection is increased and the coupling to the *nnn* elements is reduced (Fig 2b). The elements closer to the shim insert become more detuned and a reflected amplitude of up to 0.59 (35% reflected power) is measured directly in the transmit channel. The power accepted by the coil is even lower than 65% because of additional losses in cables and Tx/Rx switch. The S-parameter matrix of the shielded 7T array shows a different characteristic (Fig 2c). The direct reflection in the transmit channel is higher but the coupling decreases continuously with the distance of the element. A different application, using the system for an in situ analysis of the transmitted RF pulses in a real-life pTx sequence, is shown in Fig. 3.

Discussion: For RF safety considerations the power balance of pTx coils as a function of steering conditions is a central question is, which can be addressed with the help of S-parameter matrices. We developed a modular and versatile system to measure these quantities. Detuning of coils due to the environment or loading can be detected with little effort. Optional bench use allows to optimize pTx coils during their development without access to the MR scanner. The setup can be used in situ for the monitoring of the S-parameter matrix of pTx coils with up to 8 channels. The system is independent of scanner hardware and does not interfere with a running sequence. It can thus also be used as a versatile tool for monitoring any pTx system in situ, e.g. for the detection of abnormalities like metallic implants.

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.