A 3-Port Traveling-Wave Antenna in Combination with TIAMO for the Acquisition of Void-Free Brain Images at 9.4 Tesla

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Background: The original traveling-wave approach uses a remotely placed antenna to stimulate the propagation of two TE_{11} waveguide modes in circular polarization (CP) within a human 7 T scanner[1]. While this approach enables large field-of-view imaging and provides free space around the subject, one major drawback is the small number of transmit/receive sensitivities (i.e. the two TE_{11} modes), which limits the B_1^+ management and parallel receive capabilities and therefore the practicability of this setup.

At 9.4 T, a third waveguide mode (TM_{01}) can be excited whose $|B_1^+|$ pattern shows complementary features compared to the TE_{11} modes (Fig.1 A1&A2). While three antenna-channels are still insufficient to homogenize the B_1^+ field across larger volumes[2], two time-interleaved acquisitions using complementary RF shims (TIAMO[3]) and the subsequent rooted sum-of-squares (RSS) combination of the single images may facilitate 9.4 T traveling-wave MRI of the entire brain without signal dropouts.

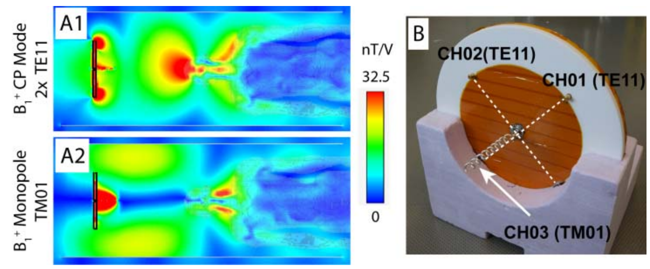

Fig.1: B_1^+ field of the TE_{11} modes in CP (A1) and the TM_{01} mode (A2); coronal view. B: 3-port antenna for excitation of the three modes: TE_{11} (patch: CH1&CH2) and TM_{02} (monopole: CH3).

Methods: Experiments were conducted on a Siemens 9.4 T scanner equipped with SC72 gradients. A 3-port antenna (Fig.1B) was constructed by integrating a helix monopole into a tunable patch antenna[2,4]. For simultaneous phase/amplitude control over the waveguide modes, the antenna was connected to three channels of an 8-channel pTx system (Siemens Tx-Array Step2). Numerical simulations were performed with CST Studio Suite 2012 (CST, Germany) and RF power limits were derived for the worst-case local SAR scenario.

For TIAMO, two time-interleaved acquisitions were performed, each with a different RF shim, i.e. $B_{1,a}^+$ and $B_{1,b}^+$. The final image is reconstructed as RSS of all six single-channel images. The RSS addition of both B_1^+ fields is a measure of excitation homogeneity, as it largely determines image contrast[5]:

$$B_{1,RSS}^+ = \sqrt{\left|B_{1,a}^+\right|^2 + \left|B_{1,b}^+\right|^2}$$

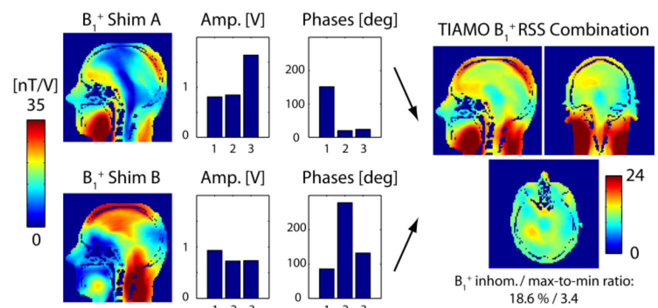

Fig.2: Two different linear combinations of the three waveguide modes (RF shims, left) optimized to yield a homogeneous RSS combination across the whole brain (right).

Based on single-channel B_1^+ maps, an optimization algorithm searched for two complementary RF shims that result in a homogeneous $B_{1,RSS}^+$ across the brain. For volunteer scanning, a 2D FLASH sequence with TR/TE=40/4.5 ms, TA=1:17 min, voxel=1.2x1.2x2.5 mm was modified to acquire each line in k-space twice, once with each of the two optimized RF shims.

Results: In the final position inside the bore (~40 cm antenna-to-head distance), all channels could be matched and decoupled to better than -20 dB, except for the isolation between the two patch channels (-12 dB). Fig. 2 shows two simulated RF shims optimized for a homogeneous $B_{1,RSS}^+$ combination across the whole brain. For $B_{1,RSS}^+$, a standard deviation (max-to-min ratio) of 18.6 % (3.4) could be achieved compared to 36.7 % (13.7) for the B_1^+ field in CP mode; i.e. inhomogeneity and max-to-min ratio were reduced by a factor of 2 and 4, respectively. Fig. 3 shows *in vivo* data acquired with the 3-port antenna: One TIAMO solution optimized for the entire brain (3A) and one solution optimized for a single slice (3B, TR=80 ms, TA=2:03 min). The images were not corrected for non-uniform receive sensitivities.

Discussion/Conclusion: Despite the limited number of channels, the 3-port antenna together with TIAMO facilitates void-free images of the entire brain at 9.4 T without spoiling the simplicity of the traveling-wave setup. This is possible since the $|B_1^+|$ patterns of the waveguide modes complement each other. Compared to B_1^+ shimming, using two separate RF shims increases the degrees of freedom and a RSS addition does not suffer from destructive interference, which helps to prevent signal dropouts. Although acquisition of two modes doubles the scan time, it can be interpreted as signal averaging that improves SNR and image homogeneity. However, implications of the TIAMO reconstruction on local image contrast[5] must be considered. The 3-port antenna together with TIAMO may find application as a remote ^{1}H volume coil for anatomical localization and B_0 mapping, e.g. in non-proton experiments at 9.4 T[6]. The antenna can be rescaled or retuned for operation at 450 or 500 MHz to be used in upcoming 10.5 T and 11.7 T magnets.

References:

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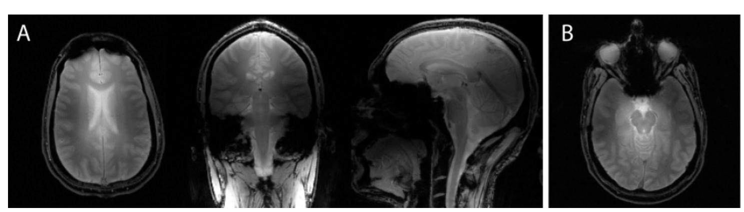

Fig.3: FLASH images using a global (A) and slice-optimized (B) TIAMO solution