Bilateral Breast Imaging using Split-Symmetric Parallel Transmission

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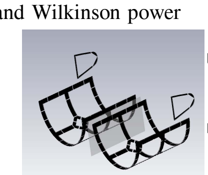
INTRODUCTION: Breast MRI at 7T is appealing because of the opportunity for improved contrast, spatial/temporal resolution, and spectral differentiation compared to clinical field strengths (1-6). However, a high-field bilateral system is challenging to design because of the conflicting requirements of a uniform transmit field and a large field-of-view (FOV), which is further complicated by the difficulty of accessing the deep regions such as the posterior breast, axillary tail, and axilla (lymph nodes). Parallel transmission can be utilized to homogenize the transmit field, but its application to breast imaging is not straightforward considering that most parallel transmit systems only provide eight or less transmit channels to cover the FOV. In this work, we propose a "split-symmetric" parallel transmission scheme in which a given RF shim or set of tailored pulses is replicated across identical lateral and contralateral coil arrays to effectively double the field-of-view without compromising uniformity. An important benefit of this configuration is that two transmit channels can be allocated to specifically target the lymph nodes, which have been difficult to visualize at 7T due to the inadequate B1+ penetration associated with standard local transmit coils.

METHODS: We assume that identical lateral and contralateral breast arrays will experience similar loading conditions and will have a low level of interaction (i.e. independent and separate FOVs), and will thereby generate similar field distributions. This framework substantially increases the degrees of freedom associated with the bilateral transmit optimization problem.

The split-symmetric parallel transmission system was realized by driving a set of six transmit/receive switches and Wilkinson power dividers with independent RF amplifiers; each of the Wilkinson outputs were subsequently fed to paired breast coils within the lateral and contralateral arrays (Fig. 1). The two remaining amplifiers independently drove lymph node coils (6×7cm^2); these coils were passively shielded to reduce excitation in the arms. The breast arrays consisted of six 8×8cm^2 coils arranged in a 2×3 grid covering a 1.5L aperture. A passive RF shield was inserted between the medial coils to reduce coupling to < -12dB, while reactive decoupling reduced interaction between adjacent coils to < -15dB. Signal reception was performed by combining signals from paired coils through the Wilkinson dividers, which were subsequently sent to preamplifiers via the transmit/receive switches. Imaging was performed on a whole-body 7T scanner equipped with an eight-channel parallel transmit system (MAGNETOM, Siemens) upon approval by our local IRB and after obtaining informed written consent from the participants.



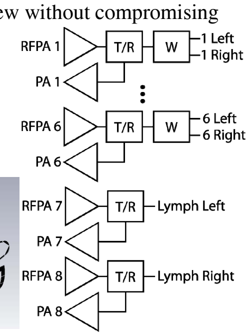


Fig. 1. Split-symmetric coil diagram (left) and system schematic (right).

RESULTS: The symmetric nature of the transmit fields generated by paired coil elements is illustrated in Fig. 2, serving to validate the framework of the split symmetric transmit scheme. While the individual transmitters in Fig. 2 appear to have low depth penetration, a straightforward phase-coherent RF shim provides excellent uniformity throughout the volume, as can be appreciated in T1w 3D GRE images (Fig. 3, left). Coverage is further improved using tailored parallel pulses, particularly in the posterior breast (Fig. 3, right). Transmit uniformity is again highlighted in T2w TSE images, a sequence that has been difficult to perform in the breast at 7T (Fig. 4). Acquisitions with and without the lymph node coils reveal the associated coverage expansion (Fig. 4).

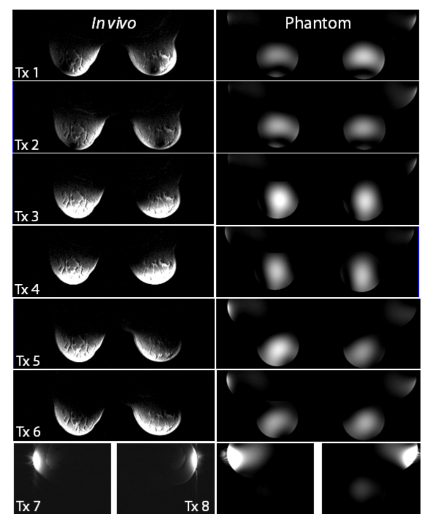


Fig. 2. Images acquired using individual transmitters illustrate the symmetric nature of the paired coils' field distributions.

DISCUSSION: The split-symmetric system exploited body and coil symmetries to double the coverage without reducing the degrees of freedom associated with the transmit optimization problem. These additional degrees of freedom were primarily translated into improved coverage with tailored transmit pulses, which was particularly beneficial in the posterior breast and axillary tail, regions that have been difficult to access with standard single channel transmit coils. In a similar manner, the split-symmetric scheme halved the channel count on each breast, allowing dedicated lymph node coils to be allocated for additional coverage. Independent control of the lymph node coils permitted, for example, local FOV imaging (with the coils enabled) or standard bilateral breast imaging (with the coils disabled). Second generation lymph node coils will be further optimized to satisfy tradeoffs between patient comfort and coverage. While the lymph node coils allowed flexible positioning, fixed coils embedded in the main coil housing may be advantageous for patient comfort.

The current system was restricted to eight transmit/receive switches and preamplifiers in which signals from paired coils were combined during reception. This caused the paired receive sensitivity maps to be artificially overlapped, which confounded unfolding algorithms and limited parallel imaging performance. A second-generation interface will include 14 transmit-receive switches and preamplifiers to presumably double the permitted acceleration factor in the left/right direction due to the natural spatial distinction associated with the distant coils.

We point out that coils 1 to 6 were paired in a *translational* manner; that is, left/lateral and right/medial coils were paired (see Fig. 1). This is advantageous due to the symmetry in their transmit field patterns. One disadvantage may be dissimilar loading; the lateral coils are adjacent to the arms and shoulders, whereas the medial coils are not. Pairing coils in a *mirrored* manner in which the left/lateral coil is paired with the right/lateral coil could alleviate this difference. However, the mirrored configuration may suffer from opposed "B_1^+ twisting", compromising the underlying framework of the split symmetric transmit scheme. In principle, though, the mirror-paired configuration could be trivially implemented with the proposed system by properly pairing the Wilkinson outputs and adding a 180° phase shift to the contralateral transmit path.

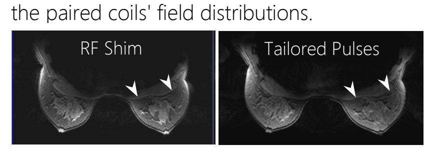


Fig. 3. T1w GRE images demonstrate improved coverage in the posterior breast using tailored excitation pulses (right) over the nominal phase-coherent shim (left).

In summary, the split-symmetric system demonstrated a means to exploit symmetries in the body anatomy by bilaterally replicating both the transmit array and associated transmit pulses. This system provided excellent B1+ uniformity and enabled improved coverage in the posterior breast with tailored pulses and in the lymph nodes with dedicated coils. Further, combined transmit/receive arrays may be beneficial in high-field breast imaging where spatial limitations make separate transmit and receive arrays difficult to package. Compared to body applications, high field breast imaging may be less susceptible to B_1^+ uniformity and penetration hurdles due to reduced volume and characteristically low dielectric effects. Additional study is required to investigate this method in patients with significantly asymmetric breasts (i.e. post-surgery). Nonetheless, it is anticipated that the proposed parallel transmission scheme will improve transmit-sensitive protocols such as T2w TSE and saturation-based fat suppression, provide improved coverage in the posterior breast, and offer the opportunity to locally excite the lymph nodes with independently controllable coils.

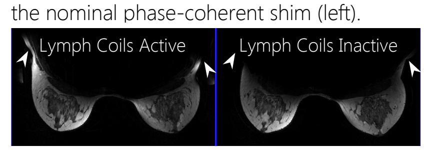


Fig. 4. T2w TSE images demonstrate excellent uniformity, while the lymph node coils provide improved coverage.

REF: 1. Brown R, et al. JMRI 2013. 2. Brown R, et al. Eur Radiol 2013. 3. Korteweg MA, et al. Invest Radiol 2011. 4. Umutlu L, et al. Acad Radiol 2010. 5. Zaric O, et al. ISMRM; 2013. 6. van de Bank BL, et al. NMR Biomed 2013.