A Scalable Constellation Coil Design for 3T Body Imaging

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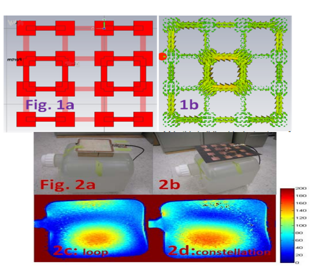
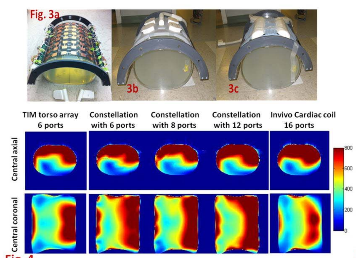
Introduction: Based on the field equivalence principles of electrodynamics, a previous study [1] introduced a unifying solution to RF coil, suggesting that a single surface structure and a surface current driving mechanism may enable not only emulations of but higher performance than any externally applied RF coil. A full-wave EM simulation included therein further demonstrated a particular 128-port constellation coil structure's potential as a unifying solution. In an effort to leverage these results and possibly improve today's clinical MR systems that have varying numbers of parallel RF channels, the present study explored a constellation coil design that was adapted to suit a small as well as a large number of channels. MR imaging experiments on a clinical 3T scanner were conducted to quantify SNR behavior of the same coil as the number of implemented ports increases. Commercial phased array coils were used as comparison references.

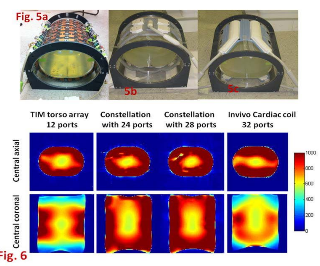
Method and Results: This study investigated a type of constellation coil structure that is constructed based on "interconnected patches". With this type each of many pairs of conductor patches sandwich a substrate sheet and forms a capacitor. Conductor strips distributed on the two sides of the sheet link the patches according to a certain pattern. The currents on the conductor strips, together with the displacement currents across the substrate at the distributed capacitor locations, form a continuous network of current flow. The construction emphasizes an end result that is mesh-like at radiofrequency, and is supportive of many configurations of ports and a multitude of field patterns. Adding ports to leverage an increase in RF parallelism is possible without changing the coil structure, which is not the case with a conventional phased array structure. A particular focus of the present study was to ensure decent performance even when the number of channels is relatively low.

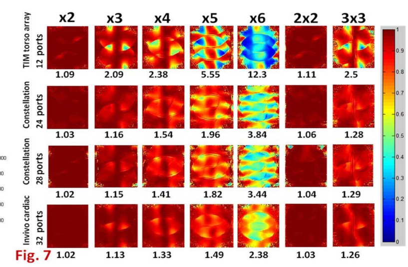
3T body imaging was chosen as the target application. One challenge body imaging commonly faces is depth, or, receive sensitivity in imaging deep-lying regions. In order to provide, with a small or moderate number of parallel receive channels, good coverage of the depth as well as an overall volume, the design of the constellation coil structure searched for a candidate that naturally accommodates multiple ports each sensitive to a volume of good size and depth. A useful intuition is that such ports tend to be each associated with an expansive current path over the structure when individually driven.

Full-wave EM simulations (CST Microwave Studio, Computer Simulation Technology AG) were performed to assist the search. Adjusting the values of the distributed components arrived at an example building block geometry (Fig.1a) that, when driven at a single port location (red dot in Fig.1b), gave rise to an expansive RF current distribution composed mainly of two in-phase concentric current loops (Fig.1b). With slight adaptation a 3x3 building block that is of 3.1cm x3.1cm in patch size and 17.1cm x 17.1cm in overall size was fabricated on a double-sided PCB (Fig.2b), and compared with a conventional square loop coil of a similar overall size (Fig.2a) on a Siemens TRIO 3T scanner. Flip angle-normalized SNR maps at the center coronal slice location within a block phantom indicated that this particular building block design could achieve a similar SNR profile and slightly better receive performance (Fig.2d), compared with the conventional loop coil (Fig.2c). With this building block design as the template a full-size coil for 3T body imaging was fabricated using two pieces of 0.381mm-thick high-frequency laminates (Rogers Corp) each of 52cm-length and 40cm-width. The two finished pieces were then mounted onto a clamshell torso former (Fig.5a) and matched ports were further added.









In a first experimental investigation, the work-in-progress top-half was evaluated with 6, 8 and 12 finished ports (Fig.3a). Two product coils were used as references: a Siemens 3T Body Matrix TIM array in 6-channel parallel receive mode (Fig.3b) and the top-half piece (16 channels) of an InVivo 3T 32-channel cardiac coil (Fig.3c). For SNR measurement and comparison, the coils were mounted tightly on identical half-clamshell formers (Fig.3) and a same body-sized phantom (35cm wide, 26cm thick, with electrical properties mimicking that of human tissue at 123MHz) was used. The scanner's body coil was used for RF transmission. Imaging parameters for SNR calculation were: TR=500ms, TE=3.61ms, 128x128 matrix, FOV=460mm, and slice thickness =5mm. The optimal combined SNR maps were calculated based on signal and noise raw data according to the Kellman's method [2]. Flip-angle maps of the signal acquisitions were additionally obtained using the method described in Ref. 3. Impact of transmit field magnitude on SNR comparison was removed, voxel-by-voxel, through division of the SNR maps by sin(local flip angle).

A second investigation further evaluated the clamshell-configured constellation torso coil with 24 and then 28 finished ports. Either case used symmetric ports locations and an equal number of ports between the top-half and the bottom-half (Fig.5a). Two Siemens 3T Body Matrix TIM arrays tightly mounted on an identical clamshell former (Fig.5b) and configured for 12-channel parallel receive was used as a comparison reference. The InVivo 3T 32-channel cardiac coil similarly mounted (Fig.5c) and configured for 32-channel parallel receive was used as another reference. The phantom was centrally positioned inside the former, with a gap of 3.5cm from the top/bottom coil structures. All other measurement details were kept the same as that of the first investigation. SENSE g-factor [4] was further quantified based on the raw data acquired. 1/g maps [5] as well as maximum g over field-of-view were compared among the cases.

For the center axial and coronal locations inside the phantom, Fig. 4 shows the flip angle-normalized SNR maps of the new coil's top-half, the 6-channel TIM body array, and the top-half of the 32-channel InVivo cardiac coil. The SNR of the work-in-progress new coil showed progressive improvements in deep region SNR as well as overall SNR, surpassing that of the TIM array when the structure had 8 ports and rivaling the InVivo cardiac coil when the structure had 12 ports. Comparison of flip angle-normalized SNR obtained from the second investigation is shown in Fig.6. Forming an enclosing structure with the support of a bottom piece and more receive channels improved depth and volume coverage in general. The constellation coil in particular, as the number of ports increased from 24 to 28, continued the upward trend in deep region SNR as well as overall SNR, attaining higher SNR than the 12-port TIM body array and the 32-port InVivo cardiac coil. For center axial slice imaging with SENSE accelerations, Fig.7 shows the inverse g-factor maps for the coils under 1D (horizontal) and 2D (both horizontal and vertical) acceleration settings. Maximum g-factor values for the cases are additionally marked below the maps. With the number of ports increasing from 24 to 28, the constellation coil appeared to approach acceleration performance of the 32-port cardiac coil. Either coil performed better than the 12-port TIM body array

Discussions: This study represents an initial effort to develop a Tx-Rx constellation coil for 3T body imaging on commonly available MR scanners. The present design appears to offer comparatively decent SNR operating over a range of receive channel counts. There are some indications of its decent transmit efficiency as well, but we yet need to conduct direct experimental assessments on a 3T scanner with parallel transmission capability. Certainly of further interest is the continuing development of the constellation coil structure itself. It is expected that designs with other patch- / strip-sizes, or other geometries, may exhibit different SNR behavior as the number of ports increases, including some that may start to deliver adequate performance with smaller number of channels as well as some that are especially suited for significantly higher RF parallelism. The present design is a good baseline in the continuing development efforts.

[1] Y. Zhu, 20th ISMRM, 2012, p432. [2] Kellman P, et al, MRM 54:1439-1447, 2005. [3] Fautz HP, et al, 16th ISMRM, 2008, p1247.
[4] Pruessmann KP, et al, MRM 42:952-962, 1999. [5] G.C. Wiggins, et al, MRM 62:754-762, 2009.