An Investigation of RF Frontend Scalability
Yudong Zhu1, Xing Yang1, Bei Zhang2, and Leeor Alon1
1NYU School of Medicine, New York, New York, United States

Introduction: Phased array is an effective RF frontend scheme due to its support for tailoring spatial sensitivity and optimizing multi-port signal combination. The scheme is the foundation for numerous MR coils, including an arsenal of dedicated workhorse receive coils each optimized for a certain body region, parallel MRI acceleration, and nucleus or Lamor frequency. To improve scan workflow a significant recent development strives to consolidate a clinical scanner’s suite of phased array coils with a multi-element coil ensemble that encloses a subject in a fixed fashion but allows application-dependent multi-port signal selection/combination (through hardware/reconstruction).

The ultimate task of creating a “one-structure-fits-all” coil that can replace various dedicated coils with comparable or better performance is very challenging. Against the backdrop of lowering parts cost and increasing channel count, it appears meaningful to explore the perspective of scalability. The ion case, volume profiles of both the (see Fig.1) that defines an inside region V1 containing the body and an outside region V0 containing radiating sources (RF coils). Love’s equivalence theorem states that the EM field within the entire Vp produced by the given sources in V0 is the same as that produced by a system of virtual sources on the surface S. Furthermore, if the field produced by the original sources is E, H, then the virtual sources on S consist of a current sheet of density \( \mathbf{n} \times \mathbf{H} = \mathbf{E} \times \mathbf{n} \), where the normal \( \mathbf{n} \) points from V0 into V1. This statement’s assertion on completeness has implications for MR – an enclosing surface capable of accommodating diverse surface current distributions can possibly replace any external MR coils, and further, act as a coil creating EM fields that delivers ultimate performance5. The transmit and receive channels have the role of being the driver for surface current distributions (the receive case is understood with the principle of reciprocity5), and a large channel count tends to facilitate the creation or control of desired distributions. In other words, as far as EM fields and inherent performance are concerned, the combination of a single surface structure and a surface current driving mechanism, in theory, can do what existing MR coils can, and more. This is an intriguing aspect underpinning the scalability perspective.

Method and Results: Full-wave EM simulations were performed at 3T frequency with xFDTD (Remcom, State College, PA) to investigate scalability. Approximation of a continuous surface structure with controllable RF current distribution was done using a constellation coil that accommodates various RF current grid patterns at 128MHz. The structure encloses the mid section of a uniform 36cm x 22cm x 70cm elliptical phantom (\( \varepsilon = 6.5 \varepsilon_0 \) and \( \sigma = 80 \)) in a two-piece clamsHELL form, spanning 60cm and 38cm in horizontal and longitudinal directions respectively (Fig.2a).

A first study tested the coil’s ability emulating various MR coils that included a quadrature-drive birdcage coil (\( S = 61cm, L = 45cm \), a 10cmx10cm loop coil above the phantom, a 20cm-long adapted 1/2 dipole antenna above the phantom, and a torso array composed of 12 loop elements driven under an arbitrary set of port coefficients (Fig.2b). In each emulation case, volume profiles of both the B and E fields were simultaneously targeted, and the set of port coefficients applied to the constellation coil’s 128 ports were determined by least squares fitting. Fig.3 shows comparisons of B1 components at a center trans-axial slice location. Comparisons at other locations, of E fields, and with loop and dipole coils also show good agreement between profiles created by a target coil and by the emulating constellation coil, despite the fact that the surface current distribution is confined by the limited coverage/contiguity of the surface and the finite number of ports.

A further study compared relative SNR of all five coils. In the constellation, the coil array, and the 2-port birdcage cases, optimal voxel-by-voxel combination of multi-port signals was applied (where B1’s were derived from B’s and noise covariance matrices were calculated using \( \varepsilon \) and E’s). For the four conventional coils Fig.4 shows, for the center trans-axial slice location, their SNR maps (a-d) and the ratio of constellation coil SNR to their SNR (e-h). The improvement in SNR with the constellation coil was found to be at least 50% in the torso volume.

Discussions: In this study the task of developing a “one-structure-fits-all” coil is investigated from the perspective of scalability. The theoretical and simulation analysis indicate that a structure that best accommodates various current distributions on an enclosing surface may enable not only emulations of higher performance than existing externally applied coils, and further, for approaching ultimate versatility and performance. Prior studies suggested that phased array has the potential to support scalability to the point where dense small loops start to suffer from coil noise dominance or fabrication difficulty. Constellation coil offers alternative structures that are potentially more scalable. An experimental investigation is on-going comparing the scalability of phased array and constellation structures. For the latter there are indications that the classic recipe for interfacing a phased array with parallel receive chains may not be applicable. Low input impedance pre-amp decoupling for example tends to substantially impede the flow of RF current at the port locations, working against the principle of having structural continuity for RF current. In addition to interface electronics, designing a constellation structure to work with 32 or less channels is also important given the typical configurations of existing scanners.