

Versatile Volume Coil Implementation Using a Constellation Coil

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Introduction: The constellation coil approach was originally developed in pursuit of the ultimate spin excitation and signal detection performance allowed by electrodynamics¹⁻³. Recognizing that distributed external RF current is the means by which a scanner implements/optimizes performance-dictating B1 and E fields inside a subject, the new approach uses an approximately continuous RF structure as well as multiple distributed ports to support generally sophisticated RF current patterns responsible for the ultimate performance. Coincidentally, adopting the new approach and letting go some non-essential constraints inherent of a conventional coil approach also opens up opportunities for simplifying coil design and fabrication and for increasing operation robustness and versatility¹. One specific implementation meaningful in certain applications / MR systems then is to use constellation coil in place of a conventional volume transmit coil, creating a customizable configuration where, in emulation mode, the new coil uses a single Tx channel and emulates the conventional volume coil, and, in parallel mode, the new coil conducts parallel Tx / Rx should parallel Tx / Rx channels be accessible on the same scanner. Such an implementation offers the potential advantage of a versatile coil that does it all, lower hardware complexity and risk for failure, and reduced cost. The present study investigated the feasibility of the new volume coil implementation.

Methods and Results: Given that the B1 and E fields induced by a conventional volume coil is a specific solution to Maxwell's equations, and that a good constellation coil structure provides a continuum supporting equivalent external RF current distributions (Love's field equivalence theorem), in principle a constellation can operate, using a single Tx/Rx channel through a fixed combination of ports, to produce a birdcage or TEM coil's transmit field pattern. For implementing the emulation mode in practice however, there arises the question of where to position a finite number of ports. Depending on structural details, some constellation coil designs may be more amenable to straightforward port placement and combination (to support the emulation) than others. During RF receive, one has the flexibility of using the constellation coil as an emulated volume coil or a parallel receive coil array, with or without a separate receive-only surface coil or coil array.

In this study we investigated two constellation coils. The first was a prototype previously evaluated in 7T MR¹ (Fig.1A). Its design has two layers of helix conductor strips sandwiching a 0.79mm-thick FR4 board, with 8 ports located at the mid section of the structure. The second coil (Fig.1B) used a new design, which has two layers of mini patches sandwiching a 0.79mm-thick substrate of $\epsilon_r=10$. The mini patches are of size 15mm x 15mm, and each is capacitively coupled to its four immediate neighbors on the other side of the substrate. Unlike the first coil's design where the long conductor strips tend to create preferential current paths, this new design presents a more isotropic geometry to flowing surface current and tends to reduce stray capacitance buildup. The design has 32 ports covering the coil structure. In imaging experiments on a whole body Siemens 7 T scanner capable of 8-channel parallel Tx, 8 ports located near one end of the cylindrical shell structure are used. Both coils have an overall size of 20cm in diameter and ~20cm in length. For comparison, this study also used a commercial 7T knee coil (Invivo Corp) of same overall size.

Phantom imaging experiments were conducted. Fig.2 shows localizer images obtained of the same phantom at 16V Tx voltage using the first constellation coil (Fig.2A,B), the second constellation coil (Fig.2C,D), and the knee birdcage coil (Fig.2E,F). In driving the eight ports of either constellation coil, the weights applied to all eight ports were of the same magnitude but different phases. In each case the eight ports' phases were calculated, based on measurements from a calibration, to realize a CP mode drive. When compared to the birdcage results, the second constellation coil produced results indicating similar, and, to some extent, "cleaner", RF field profiles. Additionally incorporating 8 ports located at the other end of the coil structure in the CP mode drive is expected to improve coverage along z, as predicted from FDTD simulations of the imaging setup. Fig.3 shows axial- and sagittal-view B1 maps (in flip angle degrees) of the second constellation coil (Fig.3A,B) and the birdcage coil (Fig.3C,D). At the same Tx voltage of 60V, the constellation coil was able to produce a higher peak B1⁺, while the axial B1⁺ profile resembled that of the birdcage.

In a further experiment, two smaller phantoms were placed side-by-side inside the second constellation coil. The coil was driven under the same CP mode as in the larger phantom experiment described above. A separate 4-in diameter receive only loop coil was placed in the middle (Fig.1B) and was used in addition to the constellation coil during receive in a 9-port phased-array mode. Fig.4 shows localizer images sum-of-squares combined from all 9 Rx channels (A-C) and from only the loop coil Rx channel (D-F). Notice the greater contribution to Rx from the loop coil that was in closer proximity to the phantoms. S-parameter measurements on the bench additionally indicated low interaction between the two coils in this imaging setup – in an ideal design we expect the constellation structure to appear as an RF shield to an Rx coil placed inside.

Fig.5 shows a volunteer imaging result obtained by Tx in emulated volume coil mode and Rx in 8-channel mode using the second constellation coil. Acquisition employed a GRE sequence with 2x parallel Rx acceleration. Additional parameters include: 40V Tx voltage, TR=220ms, TE=5.4ms, slice thickness=4mm, NEX=1, 230x320 matrix and FOV=21.6x30.0cm².

Discussions: The feasibility of implementing a versatile volume coil using a constellation coil was demonstrated. A new constellation coil was shown to support well a customizable configuration where, in emulation mode, the coil uses a single Tx channel and emulates a conventional birdcage coil, and, in parallel mode, the coil conducts parallel Tx / Rx using parallel Tx / Rx channels. While being able to emulate a conventional coil during Tx might not be part of the ultimate goal, it could play a significant role on lower field strength MR systems or when simplicity in instrumentation or scan operation is highly desired. The versatility of constellation coil promises to offer additional and significant opportunities for employing other interesting / higher-performing transmit field patterns.

1.Y. Zhu, *18th ISMRM*, p 46, 2010. 2.R.Lattanzi, et al., *16th ISMRM*, p 614, 2008. 3.R.Lattanzi, et al., *MRM*, 61:315-334, 2009.

