

## Mutual coupling study using a pair of fractal loop RF coils

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**Purpose:** Eliminating strong mutual coupling among the adjacent elements in a RF coil array is critical to increase the efficiency. Especially for multi-element array designs, often needed to gain increased imaging acceleration, decoupling the densely-packed resonant elements from each other becomes progressively difficult. Overlapping RF coil elements is commonly-used as a decoupling technique for loop-type RF coil arrays<sup>1</sup>. However, overlapping the RF coils has a space restraint in designing multi-element arrays because of mutual coupling among distant neighbor coils as well as decreases parallel imaging performance by degrading the geometric factor in the overlapping area of sensitivity. Therefore, a non-overlapped array design is often desired for current parallel imaging techniques to enable faster imaging but it is not readily feasible because of usage of crossover air inductors and shared capacitors. Inductive and capacitive decoupling methods implemented between two adjacent coil elements requires a dedicated circuit connecting adjacent coil, which lead to additional ohmic loss and difficulty in frequency tuning and matching for separate elements<sup>2-3</sup>. In this work, we introduce a fractal loop RF coil keeping the lower radiation loss than the corresponding loop RF coil, which may provide more adjustment of the coil positioning<sup>4</sup>.

**Method:** We designed a fractal loop RF coil (the Koch loop) that has 30mm radius (short axis) and 52mm radius (long axis), 3.0mm width and 0.1mm thickness strip-line, which is formed through two iterations from a basic triangle shape referred to as the initiator such as shown in Fig.1a-b. It is designed using a full wave electromagnetic field simulation program SEMCAD X (Ver. 14.2.1 Schmid & Partner Engineering AG, Zürich, Switzerland). To investigate the extent of mutual coupling, a pair of the fractal loop RF coils, tuned on 127.74MHz (3T MRI), is arranged on the parallel plane (X-Y plane) (Fig.1c) and isolation value was calculated per 3mm overlap distance step from the non-overlap location. In association with the simulation study, we constructed a pair of fractal loop RF coils identically dimensioned with the simulation study. Two pairs of circularly-shaped loop RF coils with radii of 40 mm and 52 mm each were also built for comparing of comparison. Decoupled fractal loop RF coils pair, with the other circular loop RF coils pairs, was settled on transparent Lucite plate (10mm thickness) for MR phantom imaging. MR images of a bottle-shaped phantom placed horizontally above each coil pair were acquired using a 2D T1-weighted spin-echo sequence with the following parameters: TR = 300 ms, TE = 10ms, matrix = 512x512, FOV = 250x250 mm, slice thickness = 3 mm, slice gap = 1 mm, NEX = 2, phase-encode direction = RL.

**Results:** As expected, the circular loop RF coil pairs each had a typical optimum overlap location that minimized mutual coupling according to isolation measurement. The isolation values were -37dB for an optimum 15 mm overlap and -27.4dB for an optimum 24 mm overlap for the 40mm and 52mm loop coils, respectively. However, we found an intriguing result for the fractal loop RF coil. Unlike the conventional loop coils, the fractal loop RF coil pair had two optimum locations for decoupling mutual inductance, one at 11 mm overlap with -35.1dB isolation and another at 31 mm overlap with -37.5dB isolation (FIG 2). This particular tendency of the fractal loop RF coil was also continued in the simulation study although the optimum overlap distance value showed discrepancy a bit. From the propagation of the magnetic vector flux on the plane of overlap fractal loop RF coils, at the optimized positions (Fig.3(a-b)), the magnetic vector flux on overlapped regions between the coils showed much larger than the un-overlapped regions unlike at the non-optimized positions (Fig.3(c-d)), which means the flux density through the overlapped part of one RF coil (Coil #1) is larger and cancels the flux density through the un-overlapped part of the other RF coil (Coil #2). In this case, the EMF induced by the Coil #1 is zero in Coil #2 and it indicates that the mutual inductance between these coils is minimal. In MR experiments, the fractal coil pair produced B<sub>1</sub> phantom images well without inhomogeneity by mutual coupling between adjunct RF coils (Fig.4).

**Discussion:** With measurements and simulation of the isolation properties about overlapping coil elements, we knew that a pair of fractal coils had two optimized locations to reduce mutual inductance between the adjacent coils, unlike the circular loop coils that had only a single location. Based on this important result, we performed MRI scans to test both optimized overlapping fractal coil assemblies. Both configurations produced homogenous B<sub>1</sub> phantom images as shown by Fig 4(a-b). Based on this notable fact, we expect that fractal coil will be a useful alternative in the design of phased

array coils with parallel imaging capability such as SENSE<sup>5</sup> or SMASH<sup>6</sup> because neighbor coils can be arranged with reduced overlap without adding additional components to cancel out mutual coupling. We anticipate that future research will lead to the development of larger fractal arrays capable of larger reduction factors in image acquisition. The fractal loop RF coils may also be beneficial to design of high efficiency transmit RF coil arrays by offering alternative geometrical layouts for minimizing coupling although much more investigation needed.

**References:** 1. Roemer PB., et al, Magn. Reson. Med.1990;16:192-225. 2. Nabeshima T., et al U.S. patent.1996;489,847. 3. Jevtic J., et al, Proc. ISMRM. 2003;pp 428. 4. Puente C., et al, Electronics Letters.1996; 32:1-2. 5. Pruessmann KP., et al, Magn Reson Med.1999; 42:5:952-962. 6. Sodickson DK., et al, Magn Reson Med.1997; 38:4:591-603.

**Acknowledgements:** This research was supported in part the World Class University program through the National Research Foundation of Korea funded by the Ministry of Education, Science and Technology, Republic of Korea [grant no. R31-20004-(ON)].

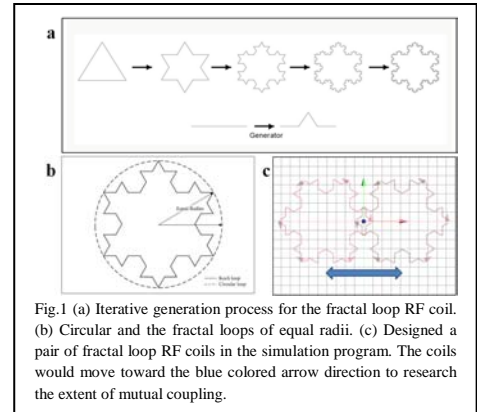


Fig.1 (a) Iterative generation process for the fractal loop RF coil. (b) Circular and the fractal loops of equal radii. (c) Designed a pair of fractal loop RF coils in the simulation program. The coils would move toward the blue colored arrow direction to research the extent of mutual coupling.

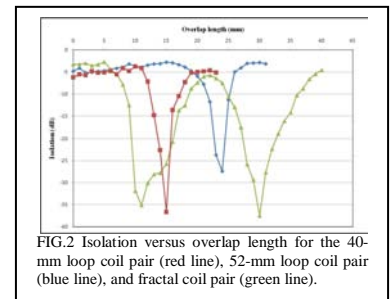


FIG.2 Isolation versus overlap length for the 40-mm loop coil pair (red line), 52-mm loop coil pair (blue line), and fractal coil pair (green line).

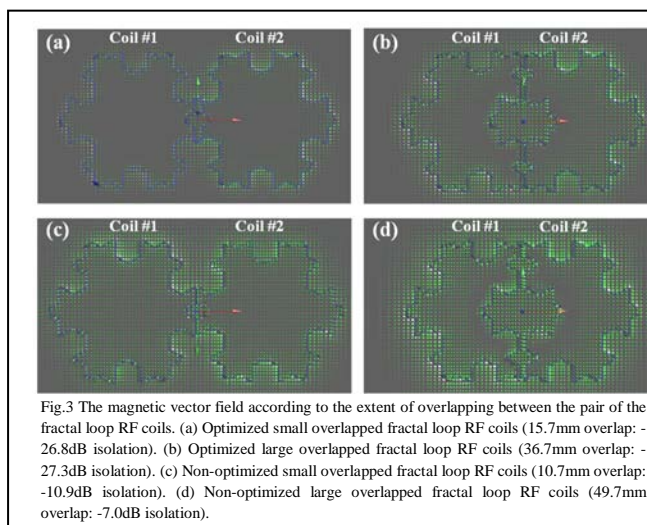


Fig.3 The magnetic vector field according to the extent of overlapping between the pair of the fractal loop RF coils. (a) Optimized small overlapped fractal loop RF coils (15.7mm overlap: -26.8dB isolation). (b) Optimized large overlapped fractal loop RF coils (36.7mm overlap: -27.3dB isolation). (c) Non-optimized small overlapped fractal loop RF coils (10.7mm overlap: -10.9dB isolation). (d) Non-optimized large overlapped fractal loop RF coils (49.7mm overlap: -7.0dB isolation).

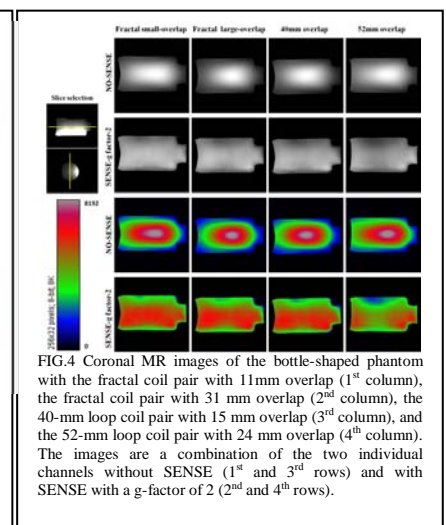


FIG.4 Coronal MR images of the bottle-shaped phantom with the fractal coil pair with 11mm overlap (1<sup>st</sup> column), the fractal coil pair with 31 mm overlap (2<sup>nd</sup> column), the 40-mm loop coil pair with 15 mm overlap (3<sup>rd</sup> column), and the 52-mm loop coil pair with 24 mm overlap (4<sup>th</sup> column). The images are a combination of the two individual channels without SENSE (1<sup>st</sup> and 3<sup>rd</sup> rows) and with SENSE with a g-factor of 2 (2<sup>nd</sup> and 4<sup>th</sup> rows).