# Evaluation on coupling strategies for ultra-high field MRI probe made of cylindrical dielectric resonator

Rui Liu[1], Wei Luo[2], Thomas Neuberger[3,4], and Michael Lanagan[1,2]

[1]*Engineering Science and Mechanics, Pennsylvania State University, University Park, Pennsylvania, United States,* [2]*Material Research Insititute, Pennsylvania State University, University Park, Pennsylvania, United States,* [3]*Huck Institute of Life Science, Pennsylvania State University, University Park, Pennsylvania, United States,* [4]*Department of Biomedical Engineering, Pennsylvania State University, University Park, Pennsylvania, United States*

**Targeted audience**: Engineers who are interested in utilizing dielectric resonators to replace traditional MRI coils.

**Introduction**: Cylindrical dielectric resonators (CDR) operating in $TE_{01\delta}$ mode and $HEM_{11\delta}$ mode have been used to replace traditional RF coils in MRI probes for high-field strength ($B_0 \geq 7T$)[1-5] applications. Various inductive coupling mechanisms were utilized to excite the CDR, such as placing loops on the sides of the resonator at half-height to excite the $HEM_{11\delta}$ mode[3,4], locating a single loop at the bottom of the resonator to excite the $TE_{01\delta}$ mode[5], or resting a single loop aside of the resonator at half-height for the $TE_{01\delta}$ mode[1,2]. However few have explored the optimal coupling scheme for the CDRs in MRI applications.

In this study, different coupling methods for $TE_{01\delta}$ mode including the ones previously explored[1,2] were investigated and compared. The best coupling method was selected based on the analysis of the scattering parameters. The results from this study will be useful for the new designs on MRI probe head made of CDR.

**Methods**: A cylindrical hollow bore dielectric resonator (outer diameter: 46.1 mm, inner diameter: 5.32 mm, height: 33.7 mm) made of ceramic $CaTiO_3$ (relative permittivity of 156) with a Q-factor of 2225 was used in $TE_{01\delta}$ mode to create a MRI probe head for 14 Tesla. Five coupling methods (totally 6 setups) were evaluated using this CDR in this study: (I) a single loop aside of the resonator at half-height, (II) a full loop around the resonator, (III) a double loop around the resonator, (IV) a triple loop around the resonator, and (V) a quadruple loop around the resonator. The detailed configurations of these five coupling methods are shown in Fig. 1 and Table 1. The CDR was placed in a copper shield (diameter: 54.0 mm) during all the evaluations of these coupling methods and a sensor probe was placed in the bore center of the CDR to measure the S21 and its Q-factor using a network analyzer (Anritsu 37369D Lightning, Richardson, TX)[6].

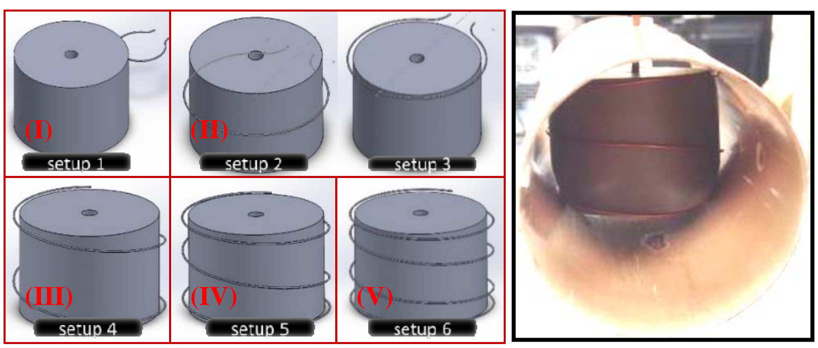


Figure 1: CAD models of all setups in five coupling methods studied in this abstract (Left) : (I) a single loop aside of the resonator at half-height, (II) a full loop around the resonator, (III) a double loop around the resonator, (IV) a triple loop around the resonator, and (V) a quadruple loop around the resonator. A photograph of the triple loop coupling setup is showed on right.

Table 1: The S21 values and Q-factors for all six setups.

| Setup | S21 | Q-factor |
|---|---|---|
| 1 | -20.0 dB | 1095 |
| 2 | -15.0 dB | 108.5 |
| 3 | -11.9 dB | 253.7 |
| 4 | -13.3 dB | 179.5 |
| 5 | -9.20 dB | 716.2 |
| 6 | -9.87 dB | 393.2 |

**Results**: The Q-factors and their S21 values of five coupling methods are presented in Table 1. By replacing a small coupling loop on aside of the resonator with a large coupling loop surrounding the resonator, we were able to increase the S21 value with a sacrifice in Q-factor, which means a gain in B1+ field strength with a trade-off in SNR. As the number of the turns of the large coupling loop increased from one to three, the S21 value increased from -15.0 dB to -9.20 dB, a 26% improvement and the Q-factor also increased from 108.5 to 716.2, a 6.6 folds increase. With four turns in the large coupling loop, the S21 value and Q-factor shown a diminishing return. Therefore, among all the coupling methods, the triple loop yielded the best coupling scheme with a Q-factor around 716.2 and S21 value of -9.20 dB.

**Discussions**: The measured Q-factors shown in Table 1 are related to other contributions in the resonant system as $1/Q = 1/Q_c + 1/Q_d + 1/Q_{rad} + 1/Q_{ex}$, where $Q_c$, $Q_d$, $Q_{rad}$, and $Q_{ex}$, are the Q-factors that are due to losses in conductor, dielectric, radiation, and external circuitry. The $Q_{ex}$ value decreases when the external coupling increases, so there is a trade-off between S21 and $Q_{ex}$ [6-7]. By using large and multi-turn loops, we managed to balance the effects of coupling on $Q_{ex}$ with the additional contributions $Q_c$, and $Q_{rad}$. Such that, the S21 value was improved by 91.7% with the Q-factor decrease of 34.6%. Future work will include the quantification of different Q-factors in simulations and the numerical optimization on the coupling scheme targeted to an imaged sample.

**Reference**: [1]Haines *et al*., JMR, 2002;200:349-53. [2] Neuberger *et al*., CONCEPT MAGN RESON B, 2002;33B:109-14. [3] Aussenhofer *et al*., MRM, 2004;68:1325-31. [4] Aussenhofer *et al*., NMR Biomed, 2011;26:1555-61. [5] Aussenhofer *et al*., JMR, 2014;243:122-9. [6] Pozar, D, *Microwave engineering*. 1998, New York: John Wiley & Sons. [7] Kajfez, D, *Q Factor*. 1994, Oxford, MS: Vector Fields.