A novel 7T transmit array using TE 01δ mode dielectric resonators

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Introduction: We propose a new transmit array design based on the use of multiple dielectric resonators for human head imaging at 7T. Conventional coil designs based on lumped element LC circuits face tuning challenges at high resonance frequencies [1,2], particularly as capacitor values decrease. Another known technical challenge with loop array designs is element coupling, which is known to cause both peak splitting and reduced $B1^+$ homogeneity. Array designs based on transmission line elements [3,4] have been proposed to address this problem. Our design is based on the dielectric resonator concept [5,6]; these use a dielectric material that serves as both inductance and capacitance. Our design aims to address the limitations of loop arrays and has additional advantages over microstrip designs: easier tuning of the array elements to higher frequencies, better inherent decoupling than loop arrays, and lower material costs by utilizing a low cost and nontoxic dielectric material (H_20). Using EM simulations, we have explored the design and application of the dielectric resonator array for parallel transmission [7].

$$f_{MHz} = \frac{3.4x10^3}{a\sqrt{\epsilon_r}}\left(\frac{a}{L} + 3.45\right)$$

Eq 1. Resonance frequency of the $TE_{01\delta}$ mode for dielectric cylinder where a is the radius in cm, L is the length in cm, and ϵ_r is relative permittivity.

Materials and Methods: We performed EM simulations using a finite difference time domain (FDTD) solver (SEMCAD X v 14.8, SPEAG). We created four cylindrical dielectric resonator coil elements (ϵ_r=80) to mimic deionized water. Starting with an initial theoretical estimate of the dimensions using Eq 1 [5], we iteratively tuned the resonator dimensions, reaching final parameters shown in Fig 1 to achieve a $TE_{01\delta}$ mode resonance frequency of 298MHz. To excite the dielectric resonators, we placed a non-resonant copper loop 5mm away from each resonator element. These copper loops were driven by separate power sources, for which we could independently modify amplitude and phase.

The inner diameter of the coil array was set to 28cm, appropriate for human head imaging, with four dielectric resonator elements positioned at 90º increments azimuthally (Fig. 2). The coils were driven in 90 degree phase increments to generate the most uniform mode. We acquired $|B1^+|$ and |E| maps for the array loaded with the head of a realistic body model (Ella, height: 1.63 m, 58.7 kg, from Virtual Family, IT'IS Foundation, Zürich). We defined a normalized efficiency metric as $|B1^+|/|E|$; this metric is a useful quality factor showing the ratio of "useful" field amplitude $|B1^+|$, which serves to excite the spin system, to the "undesired" field amplitude |E| which serves only to heat the sample. We also measured S21 parameters to assess coupling between array elements. For comparison purposes, we constructed a four element array of circular loops of identical diameter to the resonator elements, and measured the same $|B1^+|$, |E| and S21 parameters.

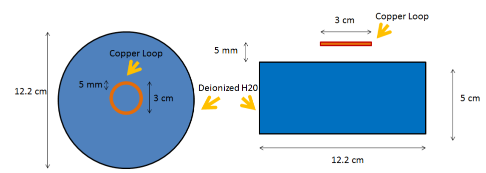

Figure 1. A) Top view B) Side view of the dielectric resonator array element

Results/Discussion: We tuned our resonators to 298 MHz easily by changing only dielectric resonator dimensions; the final dimensions were of a reasonable size for human head imaging. The error in resonance frequency for the final resonator design compared to the resonance frequency calculated using Eq 1 was ~2.3%, indicating strong agreement between simulation and theory for the $TE_{01\delta}$ mode resonance.

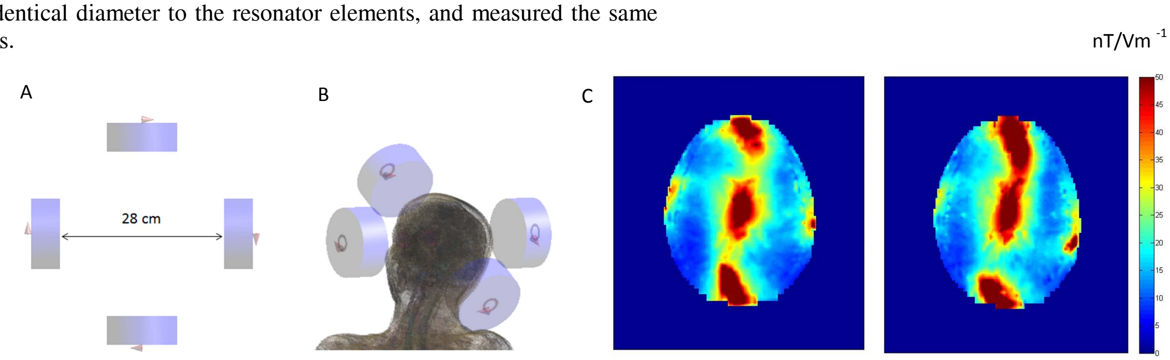

Figure 2. A) Top view of the dielectric resonator array B) Placement of Ella model inside array coil C) $|B1^+|/|E|$ within the head model using four loop coil (left) and dielectric resonator array (right).

After loading the dielectric array model with the Ella human phantom, we noticed an increased $|B1^+|$ near the center of the head, similar to what we would expect when using the nominal uniform mode of other head coil designs at 7T. We compared the efficiency of the dielectric array and the four loop array by viewing the $|B1^+|/|E|$ maps (Fig. 2C). The average value of $|B1^+|/|E|$ in this axial plane of the head for the four loop array was $23.3nT/Vm^{-1}$ while the dielectric resonator showed a 7.7% improvement in efficiency with an average of $25.1nT/Vm^{-1}$ across the same slice. The calculated S21 between nearest neighboring elements was -15.8dB for the four loop array and -20dB for the dielectric resonator array, indicating improved decoupling capability of the dielectric array elements.

Conclusions: Dielectric resonator arrays can be constructed easily and cheaply using the high dielectric properties of deionized water. Other high dielectric materials aside from water, such as D_20, can be used in future array construction. The dielectric resonator design is easily tuned to high resonance frequency. In addition, the dielectric resonator array demonstrates an improved decoupling performance and $|B1^+|$ efficiency as compared with a geometrically matched loop array, suggesting good potential as a transmit array design.

References: [1] Ackerman JJH, Nature 1980 [2] Bilgen M, MRM 2004 [3] Zhang X, MRM 2001 [4] Adriany G, MRM 2005 [5] Wen H, JMR B 1996 [6] A.G. Webb, ISMRM 2012 p538 [7] Katscher U, MAGMA 2005

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