NMR Experiments using no RF coil: RF-Coilless NMR

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INTRODUCTION RF coils, as an exclusive means of NMR signal excitation and reception, have been always required in NMR systems. In this work we investigate an unusual NMR method that does not need RF coils for signal excitation and reception in various liquid and solid NMR samples. The proposed method, named RF-Coilless NMR, is based on the sample self-resonance (or dielectric resonance) property which enables sample itself to excite and receive NMR signal (1) without using the RF coil. The dielectric resonance has been evaluated in terms of the possibility of using it as a RF coil for human imaging at 4T or 170MHz (2) where the sample self-resonance can only be established in an unpractical-large-sized sample with high permittivity due to the resonance frequency in question is not high enough. With the advent of ultrahigh field MR or NMR, particularly, the 800MHz or the GigaHertz NMR, the wavelength of the resonance frequency becomes shorter and shorter, and the sample self-resonance can be setup in a regular sized NMR sample. Therefore NMR using sample self-resonance may become practical at ultrahigh field NMR or GigaHertz NMR. As demonstration, NMR spectra and images of a cylindrical water sample are presented at 7T. Water samples with various conductivities are evaluated. This method eliminates the RF coils in the conventional NMR transmit/receive system. Therefore, a SNR gain could be expected.

METHOD The multimodal resonance behavior of materials is governed by Maxwell equations and the boundary conditions and usually calculated numerically. To demonstrate the proposed RF-Coilless NMR method, we use a cylindrical water sample in this work. In a cylindrical shaped sample, the following empirical equations (3) obtained from the numerical results are used to estimate the resonant frequencies of its first two resonant modes (i.e., $TE_{01\delta}$ and $HEM_{11\delta}$).

$$f = \frac{1.394395\times10^4}{r}\varepsilon_r^{-0.465421}\left\{0.690841+0.319075\left(\frac{r}{h}\right)-0.035494\left(\frac{r}{h}\right)^2\right\}$$

for the $TE_{01\delta}$ mode; and

$$f = \frac{1.305845\times10^4}{r}\varepsilon_r^{-0.436076}\left\{0.54318+0.589025\left(\frac{r}{h}\right)-0.049591\left(\frac{r}{h}\right)^2\right\}$$

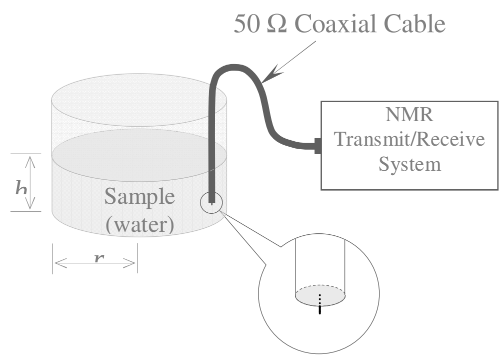

Fig 1. Experiment setup with no RF coils. As an example, cylindrical water sample was used in this work. The sample was fed by a dipole-like coaxial cable inserting in the sample at certain point as shown.

for the $HEM_{11\delta}$ mode, where *f* is the resonant frequency in MHz; ε_r is the dielectric constant of the sample; *r* and *h* are the radius and the length of the cylindrical sample in cm, respectively; *r* and *h* are also defined in Fig 1. As shown in Fig 1, the water sample with a diameter of 15 cm and a height of ~7 cm is excited electrically by a dipole-like 50-ohm coaxial cable inserting in the sample at a specific point. The other end of the coaxial cable directly connects to the T/R switch of the NMR system. Before NMR experiments, the resonance frequencies are estimated by the above equations and validated by scattering parameter S11 measurement taken on a network analyzer. Due to the desired field distribution pattern, the $HEM_{11\delta}$ mode is chosen for NMR experiments. To validate the method, we reduce the water height *h* to about 2.5 cm which has resonance frequencies far off from the 7T proton Larmor frequency. NMR experiments with the same setup and acquisition procedure are repeated. The resonance behavior of the 7-cm water samples with different NaCl concentrations of 50mM, 80mM and 100mM, leading to with different conductivities, are also investigated. The multimodal resonance still exists in those conductive samples although the input impedance varies. To simplify the question, we omitted the impedance match circuit in this experiment. Therefore the input impedance of the water sample is not well-matched to the system 50 Ohm. This will not affect the concept demonstration and the conclusion of this work. All MR experiments are performed on a 7T/90cm human MR system equipped with Varian INOVA console.

RESULTS AND DISCUSSIONS By inserting a dipole-like open-circuited coaxial line to the water sample, multimodal resonance of the sample was excited and clearly observed with scattering parameter S_{11} measurement on a network analyzer. The calculated and measured frequencies of the $HEM_{11\delta}$ mode of the ~7cm high water sample are 288.0 MHz and 295.4 MHz, respectively. The discrepancy between calculated and measured frequencies is within 3%. Multiple-slice images were acquired in three orthogonal orientations with a gradient echo sequence. The acquisition parameters are- repetition time (TR) =100 msec or 1 sec, echo time (TE) = 4 ms, number of excitation (NEX) = 1, flip angle = 45^0, slice thickness = 5 mm, field of view (FOV) = 18 × 18 cm^2, and matrix size = 128 × 128. Single pulse NMR spectrum is acquired with different RF transmit power. Fig 2 illustrates a normal behavior of NMR signal intensity change with a RF power array. Fig 3 shows the coronal and sagittal images of the cylindrical water sample using no RF coils. Impressively, the whole image of a relatively large water sample of 15 cm (diameter) by ~7 cm (height) is obtained without using a RF coil. As expected, no NMR signals and thus image are received from the ~2.5 cm (height) water sample because it is not on resonance (Fig 4). Based on the general SNR equation, $1/SNR_{overall}=1/SNR_{sample}+1/SNR_{coil}+1/SNR_{receiver}$, conventionally low temperature or superconductive coil (4-6) is used to increase the RF coil's SNR, thus increasing the overall NMR SNR. In the RF-Coilless method, RF coils are eliminated. Therefore, a gain of overall NMR SNR could be expected.

CONCLUSIONS The RF-Coilless NMR method using sample self-excitation and reception become feasible and practical at ultrahigh fields, and may offer a simple and sensitive way to performing ultrahigh field NMR.

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REFERENCES (1) Zhang X, 48th ENC 217 (2007); (2) Wen H, et al JMR B 110:117-123 (1996); (3) Kishk A, et al, Progress in Electromagnetics Research, PIER 33: 97-118(2001); (4) Styles P, et al, JMR 60: 397-404 (1984); (5) Hall A, et al, MRM 20: 340-343 (1991); (5) Black R, et al Science 259: 793-795 (1993).

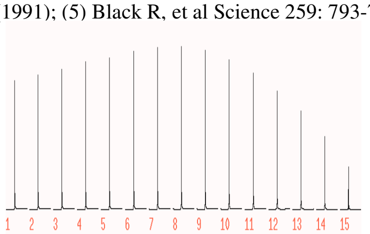

Fig 2. Proton NMR signals acquired with an RF power array (1dB increment). The RF power of achieving 90^0 flip angle is well-defined. The signal intensity change with RF power is well-behaved.

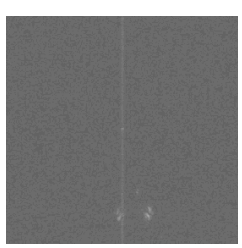

Fig 4. No NMR signal or image is observed from the ~2.5-cm water sample

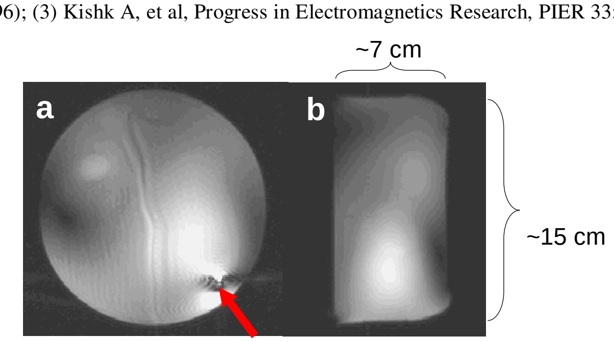

Fig 3. The coronal (a) and sagittal (b) images of the cylindrical water sample acquired using no RF coils. The red arrow indicates the coaxial cable inserted into the sample.