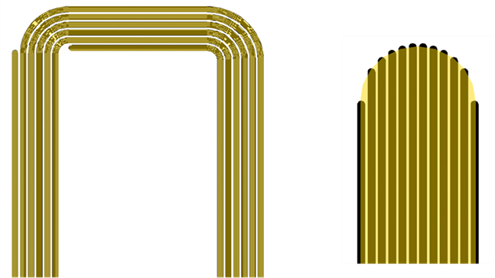
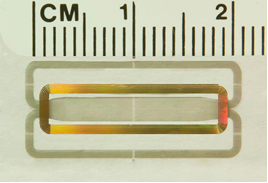
**1H-13C Dual-Optimized NMR Probe Based on Double-Tuned HTS Resonators**

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**Introduction**

NMR probes based on high-temperature superconductors (HTS) provide significant gains in sensitivity. HTS coils are patterned out of thin-film YBCO on planar sapphire substrates. In order to build multi-channel probes, the pairs of HTS coils are nested orthogonally, as in the case of a 1.5-mm 13C-optimized triple-resonance probe built by our group recently [1]. However with this approach, only one channel sensitivity can be optimized for a given probe configuration. Novel double-resonance coils are required in order to optimize the sensitivity of two channels in the same probe configuration.

(A) Photo of actual 1H-13C HTS coil. 13C coil is the spiral resonator. Figure-8 resonator for the 1H coil is visible through the substrate. (B) Drawing of an end of the 13C spiral shows the parallel slits in YBCO (in black) and unslit gold overlayer (in yellow).



**A**

**B**

**Experimental**

In the current work, we have developed 1.5-mm probe simultaneously optimized for 1H and 13C sensitivity at 14.1 T. Shown in figure A is a two-sided design for a 1H-13C resonator which produces strong and homogenous magnetic fields at both frequencies [2]. The magnetic fields at the resonance frequencies are made mutually orthogonal in order to minimize interaction. A figure-8 coil on the front of the substrate resonates at the 1H frequency with the magnetic field parallel to the substrate. A spiral coil on the back of the substrate resonates at the 13C frequency with the magnetic field perpendicular to the substrate. Faraday shield elements are incorporated into the design to suppress the electric field at the 13C frequency. In order to maintain the required homogeneity of the static magnetic field, the YBCO pattern is slit into thin parallel fingerlets. In order to suppress the resulting undesirable mode spectrum from the spiral, the slit fingerlets are covered by gold overlayer patterned into the spiral design without the fingerlet structure.

**Results and Discussion**

The probe was evaluated using a 14.1 T Agilent spectrometer at the University of Florida. The standard probe specifications are listed in Table I. The measured 1H SNR is approximately 60% higher than the 13C-optimized probe [1], and reflects the improvement in filling factor achieved by placing the resonator closer to the sample. Good RF magnetic field homogeneity was measured validating the design modifications on the figure-eight coil. The measured 13C SNR is approximately half that reported for the 13C optimized probe in [1]. The lower sensitivity for the 13C resonator design was correctly predicted in the EM simulation as lower magnetic field strength for the same input power. The Q-factor of the devices with the extra gold layer was lower than usual. It was also observed that 1H decoupling does not add any noise in the 13C measurement, showing there is very little interaction between the two channels even though they are on the same substrate. The best lineshape achieved on this probe is 0.9/22.4/28.1 Hz at 50%/0.55%/0.11% of the central peak height.

Reduction of substrates is an important factor in improving the capabilities and reducing the cost of these HTS-based NMR probes. The figure-eight resonator is a first in NMR probe design and represents a significant step in improving designs in future NMR probes.

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| Measurements of 1.5mm 1H-13C dual-optimized probe | | | |
|  | 1H | 13C | 2H |
| 90° Pulse Length | 7.3 µs | 31.0 µs | 280 µs |
| *B1* Homogeneity | 91.9% (450/90) 76.8% (810/90) | 81.2% (450/90) |  |
| SNR | 796a | 195b |  |
| Non-spinning lineshapec | 0.91/22.4/28.1 Hz |  |  |
| a 0.1% ethylbenzene in CDCl3 standard.  b 40% p-dioxane in C6D6 ASTM standard.  c 1% CDCl3 in acetone-D6 standard. | | | |

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**References**

1. Ramaswamy, V, et al., J. Magn. Reson., 235, 58-65 (2013)
2. Brey, W.W.; et al., U.S. Patent No. 8,779,768 (2014)