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High Sensitivity Nuclear Magnetic Resonance Spectroscopy Using HTS Resonators

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Nuclear magnetic resonance (NMR) is a powerful and widespread method for the detection of molecules and the determination of molecular structure. However, it has a relatively poor sensitivity compared to other techniques such as mass spectrometry. The very narrowband NMR signals are typically observed by Faraday induction in a resonant detector which is noise matched to a low noise preamplifier. In today's laboratory magnets, the NMR resonance bands of interest may be anywhere between ~40 MHz to above 1 GHz. For the most commonly observed isotopes, ^{1}H, ^{13}C, and ^{15}N resonance frequencies are very close to 10:2.5:1 ratio. We have improved the sensitivity of several spectrometers by using high-Q HTS resonators [1]. Some of the opportunities and challenges involved in using these resonators as NMR detectors will be presented.

An example of a useful resonant structure is the counterwound spiral shown in fig. A. Spirals of opposite helicity are patterned on a double-side coated wafer to produce a low frequency resonator for nuclides such as ^{13}C or ^{15}N. The relative orientation of the spirals confines most of the electric field within the dielectric substrate, reducing the electric coupling to the sample. This is important because NMR samples can be electrically lossy and are typically near room temperature. However, the high Q factor of the resonator limits both the reception and excitation bandwidth, requiring the use of techniques such as overcoupling and Q switching [2].

The HTS resonators are mounted to a cold head on either side of a liquid sample as shown in fig. B. In probes such as described in [1] there may be two or more sets of nested resonator pairs tuned to different frequencies, and interactions between the resonators must be taken into account. Problems also occur if the higher modes of ^{13}C transmission line resonators such as shown in fig. A are close to the ^{1}H resonance. Fortunately, modifications to the design of the transmission line resonator can be used to adjust its dispersion and move the modes away from other frequencies of interest [3].

[1] V. Ramaswamy et al. (2013) J. Magn. Reson. 235: 58–65.
[2] G. Amouzandeh et al. (2019) IEEE Trans. on Appl. Supercon. 29.
[3] J.W. Hooker et al. (2015). IEEE Trans. Microw. Theory Tech. 63: 2107–2114.

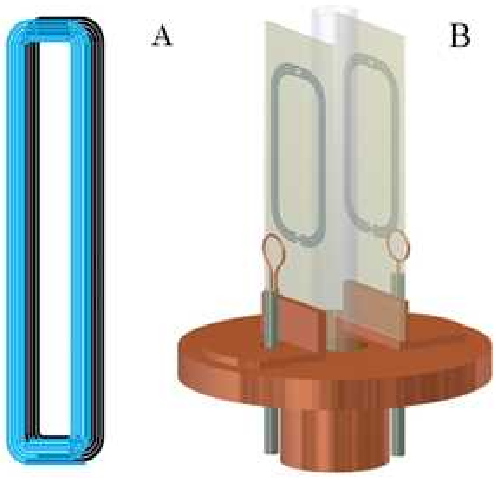

Fig. A. Counterwound spiral resonator; B. HTS resonators on both sides of the sample.

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