Ultra-sensitive micron-cantilever detection for MRI

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Introduction: Resonant LC surface coil technology is the predominant technology for MR detection. However, the SNR performance of these coils is limited by the quality factor *Q*. Here we propose and evaluate the performance of an alternative to inductive detection for measurement of harmonic signals using mechanical mixing and filtering based on AC magnetic force microscopy (AC-MFM). AC-MFM uses micron-scale cantilevers, which can have an extremely low damping ratio and can be high $Q_{mechanical}$ detectors.

Materials and Methods: We used a custom-made receiver coil with primary and secondary loop radii 5cm and 60 micron respectively. The transmitter coil was attached to a signal generator (HP 83650L, 10 MHz-50 GHz).Current in the loop on cantilever was controlled by a signal generator (HP 83620A).We measured time-harmonic magnetic fields by measuring the amplitude change of the photodiode current as we changed the current and frequency of the sinusoidal signal applied to the coil-cantilever system. The photodiode signal was measured from the MFM scope (Topometrix 0696-017).

Results: To estimate the noise of the system, we measured the amplitude of the cantilever deflection by varying current power on coil on cantilever, keeping the current power on the transmitting coil constant and vice-versa for two sets. For the first data set, the difference (beat) frequency was equal to the cantilever mechanical resonance frequency (30.8 kHz) and gave the signal measurement whereas for the other data the difference frequency was far different from that of the mechanical resonance frequency, and thus gave the estimate of noise. For each measurement ten readings were taken and averaged. Figure 1 is a plot of the noise subtracted signal as a function of increasing injected current power in loop on cantilever. The input power on the coil is proportional to the square of the current and the noise-subtracted signal is proportional to the magnetic moment on the cantilever, hence linearly dependent on current. The plots are thus parabolic in shape as depicted from the fitting curves. Noise output from the second set measurement remained constant irrespective of the injected current power into the transmitting coil or loop on cantilever, thus concluding that the system is Brownian noise limited. Figure 2 is an illustration of the temperature distribution result of a Finite Element heat transfer analysis for the Si_3N_4 cantilever operating with 1mW of total heat dissipation. The heat transfer study assumed a constant volumetric heat generation rate per unit volume, so as to simply analysis. From this study, we are able to determine the maximum cantilever power dissipation rating for a given design temperature, thus guiding our selection of operating parameters of the cantilever system.

Conclusion: A frequency tunable, micro-mechanical detector suggested here can be used as an alternative to standard LC resonant coil detector if signal can be improved through efficient geometrical optimization and cryogenic cooling.

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Reference: 1. M. Banerjee, C. Paulson, D.W. van der Weide, T.M. Grist, " Cantilever heterodyne mixing and filtering for MRI", *Proc. 14th Int. Conf. on Magnetic Resonance in Medicine*, May 6-12, Seattle (2006).

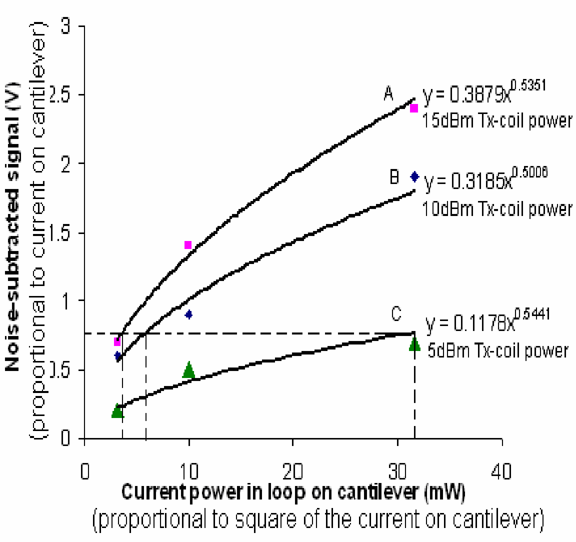

Fig.1. Relative noise subtracted signal plots for varying power on loop on cantilever. A, B and C curves represent different transmit power levels. The horizontal axis plots the input power on the coil on cantilever whereas the vertical axis plots the noise-subtracted signal. The dashed lines show how to compare the current power on loop on cantilever required detecting specific powered signal in transmitting coil.

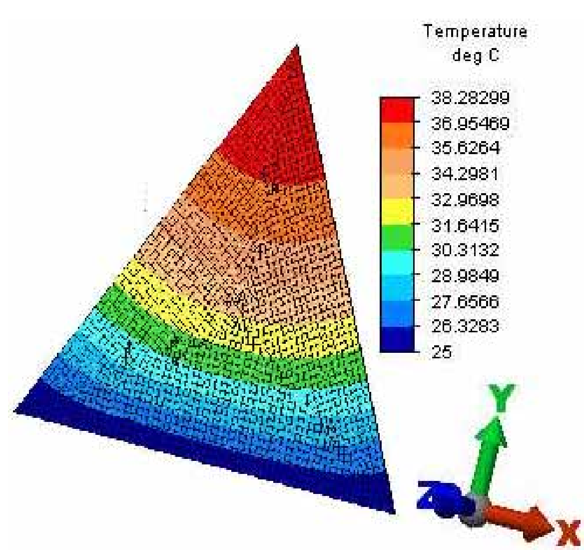

Fig.2.Temperature distribution plot for 200 micron equilateral triangular Si_3N_4 cantilever with 1mW total power dissipation.