A Broadband Tunable Surface Coil and Magnetic Force Detector for MRI

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We present an experiment that detects the force between a magnetically-tipped cantilever and a sample by sensing vibrations of a cantilever. This force is written $F = m_c \bullet \nabla B$. Here, m_c is the magnetic moment on the cantilever, and the gradient, ∇B, originates from a sample. If m_c and ∇B vary harmonically in time, then this product produces sum and difference frequency terms as force components of F.

We use a scanning force microscopy (SFM) cantilever that has an aluminum loop integrated onto its surface[1]. A high frequency alternating current is driven in the loop, inducing magnetic moment, $m_c(t)$. When the difference frequency (hereafter referred to as Δf,) between $m_c(t)$ and the frequency of a sample's magnetic moment, is equal to the cantilever's mechanical resonance frequency[2], ω_c, the cantilever is driven into vibration. We've implemented an intermediate magnetic field transformer coil that gathers magnetic flux with a large loop of radius r_1, and concentrates it into a small solenoidal coil of radius r_2, where the cantilever is located.

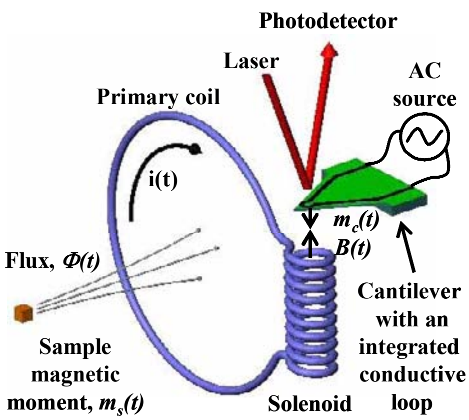

Figure 1. A sample magnetic moment, $m_s(t)$, is depicted as source of magnetic flux, $\Phi(t)$, which drives current in the coil. Cantilever vibration is detected through movement in a reflected laser beam using a position-sensitive photodetector.

The primary coil of our detector does not require capacitors, in contrast to conventional MRI coils. This minimizes dielectric coupling. This wideband measurement system also allows detection of multiple nuclei frequencies, where [1]H (42.6 MHz/T), [13]C (10.7 MHz/T), and [31]P (17.2 MHz/T) nuclei can all be detected with this one detector, in a single experiment. A wide range frequencies were detected in the experimental demonstration shown in Figure 2. The demodulation bandwidth (spectral resolution) is about 1 kHz wide.

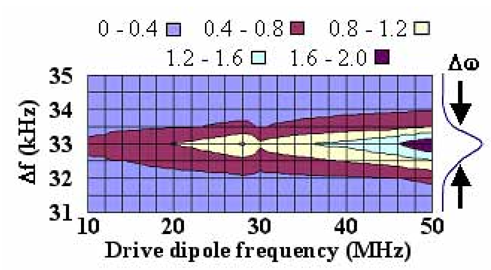

Figure 2. The vibration amplitude of our cantilever as a function of the frequency of a test dipole moment, and the difference frequency, Δf, as described in the text.

[1] Agrawal, V., Neuzil, P., van der Weide, D. W., "A microfabricated tip for simultaneous acquisition of sample topography and high-frequency magnetic field," Appl. Phys. Lett. **71**, 2343 (1997).
[2]S. Rast, C. Wattinger, U. Gysin, E. Meyer, "The Noise of Cantilevers", Nanotechnol., **11**, 169 (2000).