# Cantilever heterodyne mixing and filtering for MRI

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**Introduction:** We introduce a new mixing and filtering technique for MRI detection. We exploit the exquisite sensitivity of near-field (micron-distance) measurement techniques to force-detect RF-magnetic signals from distances necessary for *in-vivo* imaging. The Q of our capacitor-free surface coil is derived from the mechanical Q (which can be as high as ~10,000) of an ultra-sensitive cantilever, which is used for detection. Though thermal-noise limited, our frequency tunable, optically-detected system provides potential advantages over conventional NMR detector coils. We calculate the parameters affecting the sensitivity of the antenna and experimentally demonstrate their effects.

**Method:** The hybrid coil consists of a larger primary coil (which serves as the antenna/pick up coil) and an orthogonally oriented secondary coil giving negligible mutual coupling between the two (1). The dipole-dipole force, the product of the magnetic moment on the cantilever coil and the spatial gradient of the sample's magnetic field, results in a modulated force at the sum and difference of frequencies of the sample's response and the current on the cantilever. A significant response occurs when this difference is the mechanical resonant frequency of the cantilever. The deflection of the cantilever is measured by a laser shining on the cantilever and reflecting back to a photodiode. The secondary coil excites the coil on cantilever. In our case, the sample is an emitter coil, attached to a signal generator. '$I_1$' is the induced current in the receiver coil and 'h' is the distance of separation between the secondary coil and the cantilever. For given coil radii, 'a', and 'b', the condition for maximum force of interaction and power transfer with respect to distance of separation, 'h' between the coils, gives

$$\overline{F} \propto \sum \omega_i I_{1i} \left(\frac{\mu}{2a}\right) \mu_d \frac{\partial t}{\partial z} \propto \sum \frac{\omega_i V_{IDNMR}}{\sqrt{R^2{}_{coil} + \omega^2{}_i L^2{}_{coil}}} \left(\frac{\mu}{a}\right) \mu_d \frac{\partial t}{\partial z} = \alpha V_{IDNMR}$$

The minimum detectable force by the cantilever is given by its mechanical properties. The minimum detectable voltage can be found by taking the ratio of the minimum detectable force and the maximum of $\alpha$ .

**Results:** 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 predicted signal fall-off with distance is seen when this distance is comparable to the diameter of the outer coil. The output signal increases with the insertion of a dielectric core. The frequency response of the system is a filtered spectrum around the cantilever resonant frequency. Thus Q scales with the frequency of operation. Decreasing the radius of the secondary coil also increases the signal, as predicted. Figure 1 plots the cantilever vibration signal vs. drive signal power on the test dipole (1B) or cantilever (1A, 1C). Ideally increasing power will increase the magnetic moment and thus the measured signal will have linear dependence with power. But due to the presence of flat Johnson noise (from coil) and Lorentzian shaped Brownian noise (from cantilever) this is not the case. Compared to the Figures (1B) & (1A), Figure (1C) gives the resonant coil case and thus has comparatively lower Johnson noise, lowering the convolved output noise. The other two cases are non-resonant, so Brownian noise from the cantilever is amplified by Johnson noise. In both cases (1C and 1A), power in the cantilever is increased, yet we see noise spreading in the latter only because Johnson noise of the un-tuned coil dominates. Unlike the standard resonant coils, which are Johnson noise limited, here we can control the cantilever temperature/joule heating effect by cooling, thus improving sensitivity. We can also reduce the Brownian noise by using higher conductive materials for the pickup coil.

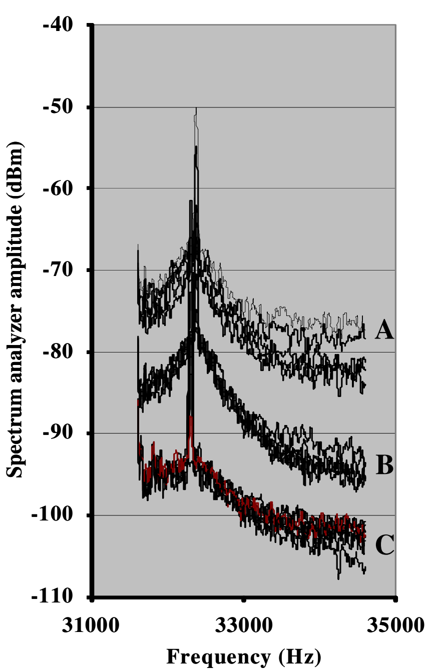


**Fig 1:** *Cantilever vibration vs. power on test dipole or cantilever and frequency.*

**Conclusion:** A frequency tunable, micro-mechanical detector suggested here can be used to exceed the performance of a standard NMR detector if Johnson noise can be eliminated via cryogenic cooling.

**Reference:** 1. **M. Banerjee, C. Paulson, D.W. van der Weide, T.M. Grist**, "**Force-detected wideband probe magnetic resonance optical imaging**", *Proc. 13th Int. Conf. on Magnetic Resonance in Medicine*, **May 9-13, Miami Beach (2005)**.