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A Magnetically Excited And Sensed MEMS-Based Resonant Compass.

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The incorporation of a MEMS-based magnetic compass with portable electronics or even wristwatches provides additional customer-demanded features such as personal navigation, and motion sensing functionalities to these devices. A number of magnetic sensors, such as flux gate magnetometers and Hall-effect devices, have been reported to be sufficiently sensitive to the Earth's magnetic field for use in this application. However, the power requirement of these devices is typically prohibitive for a long-term, portable application[1]. Earlier, we reported an electrostatically-driven micromachined resonator incorporating a permanent magnet. It exhibited very low power consumption with sensitivity high enough for measuring the earth's magnetic field[2]. However, electrostatically driven micro devices require relatively high operating voltage[3], incompatible with CMOS driving circuitry. In this paper, we report an all-magnetic MEMS-based resonant compass, driven electromagnetically by an excitation coil and sensed using a Hall-effect sensor. The magnetic amplification provided by the resonator makes it potentially suitable for compact, low voltage portable navigation systems.

The structure consists of a permanent magnet torsionally supported on a resonant MEMS disc. The interaction between an external magnetic field H such as the Earth's magnetic field and the magnetization of the permanent magnet M generates a torque which changes the stiffness of the beam, resulting in a change of the resonant frequency of the sensor. By monitoring the changes of the resonant frequency while changing the orientation of the sensor with respect to the external magnetic field H, the direction of the external magnetic field can be determined as a function of the resonant frequency.

Sensor fabrication is based on a two-mask, two-wafer Si bulk micromachining process. An insulation oxide layer is thermally grown on a Si substrate followed by fusion bonding of two wafers. The bottom Si substrate under the moving part is ICP etched so that the device can be released without stiction causing interaction between the moving structure and the substrate. The upper Si wafer is ICP etched to realize a movable resonant disc structure (containing a recess for a permanent magnet), support beams, and contact electrodes. The permanent magnet is adhered to the center of the moving disc(Fig1), and the external excitation coil and the Hall-effect sensor are assembled for actuation and sensing of the fabricated device. The gap between the Hall-effect sensor and the permanent magnet is less than 500um to make the Hall-effect sensor sufficiently sensitive to the vibration of the permanent magnet(Fig2). The external excitation coil has 200 turns, a 1.64mm diameter, and a 16.8mm length, and an approximately 50ohm resistance.

To drive the actuator, a sinusoidal driving signal was applied to the coil with a peak-to-peak voltage of 100mV. The resonant frequency of the system was successfully measured as a function of the direction of the Earth's magnetic field. Fig3 shows the system resonance frequency as a function of orientation angle in two cases: one for the earth's magnetic field and the other for an applied external field. As expected, both external fields show a similar trend with a different magnitude of frequency shift. This approach demonstrates that magnetic amplification combined with resonant MEMS structures can be used to sense the direction of the Earth's magnetic field.

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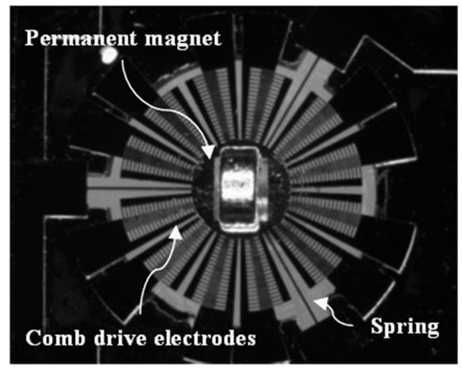
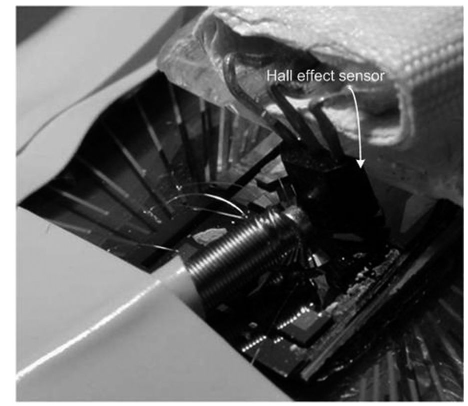
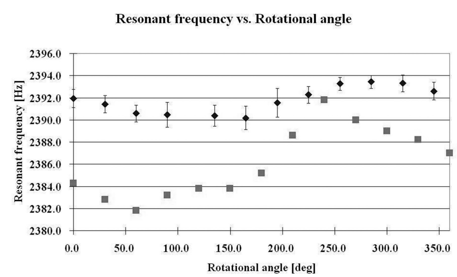


Fabricated device with a permanent magnet glued



Completed earth magnet field sensor with the external excitation coil and the Hall-effect sensor mounted



Resonant frequency vs. the angle between the permanent magnet orientation and the earth magnetic field (upper curve), and 0.4 mT external magnetic field (bottom curve)