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A Superconducting Resonant LC Displacement Sensor using a Digital Phase-Locked Loop

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A design is presented for a superconducting displacement sensor which could provide an alternative approach to the persistent current sensing scheme for the LGWA. The sensor is predicted to give a displacement sensitivity better than 1 fm Hz-1/2 over a frequency range from mHz up to kHz, with a working range of order 1 mm, without injecting heat or significant mechanical noise into the system. The basis of the measurement protocol is to use a digital Lock-In Amplifier (LIA) drive a high-Q (the target Q is about 106) superconducting LC circuit at its resonance at a frequency of around 5 MHz, producing a large current which can the be measured precisely with a two-stage SQUID. The sensing coil in the superconducting LC circuit is coupled to the test mass whose displacement is to be sensed. The motion of the test-mass modulates the inductance of the circuit, which changes its resonant frequency. Because of the high Q of the circuit, this produces a large change in the phase of the current measured by the DC SQUID. This measured signal is then fed back to to the LIA and the frequency is adjusted to be at the new resonant frequency of the LC circuit.

The displacement is therefore read out using the resonant frequency of a superconducting circuit, rather than the amplitude of the signal, and so the signal is largely insensitive to stray capacitance and inductance of the cables. Avoiding the requirement for persistent currents means that the circuit is easier to implement with thin-film superconductors such as NbN and NbTiN, so can be implemented at higher temperature.

Beyond this target application, the sensor could be applied in many other fields, such as inertial sensors for terrestrial gravitational wave detectors, gravity gradiometry, geophysics, and lunar and solar system planetary exploration. We aim to demonstrate the measurement principle, first using a room temperature version of the circuit, then with lithographically produced superconducting coils and capacitors, and to use a quiet cryogenic platform to demonstrate that we can reach the target sensitivity.

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