SQUID systems for acoustic GW detectors: progress in sensitivity and long-term reliability

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• **A dc SQUID system in two-stage configuration has been successfully operated** as first stage amplifier of the capacitive transducer developed for the AURIGA gravitational wave detector (see JP Zendri, in this Conference) **with a true noise energy of the order of about 150 $\hbar$** at 900 Hz. However recently proposed next generation detectors (like DUAL) will require amplifiers with a noise close to the quantum limit (~$\hbar$) in the kHz frequency range. Further improvements are thus required.

• **The effective performance of a SQUID amplifier** operated on an acoustic GW detector at kHZ frequency **is determined by several factors**, involving not only the sensor but also the characteristics of the high Q input resonant load and the performance of the control electronics:

• **1/f noise**: not well-known, virtually unpredictable at ultracryogenic temperature.

• **Self heating mechanisms** at T≈100 mK, which prevent from further effective cooling and noise reduction (intrinsic white SQUID noise scales with T!).

→ Further investigation on new different sensors in order to approach the best possible intrinsic noise in the kHz frequency range. Try to improve the effective cooling of the sensor.

• Dynamic range problems due to the **large input signal** picked up by a real tranducer (both capacitive and inductive).

• Reduction of the effective long-term duty-cycle due to occasional **unlocks or bias point drifts**.

→ Development of reliable control electronics with high enough dynamic range, optimized for long-term operation on a real GW detector.

• **Stabilization of high Q resonances** in the low loss input load.

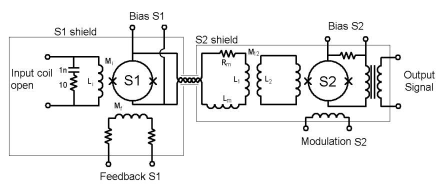
• Estimation and minimization of the **effective back-action noise** on the high Q resonant input load. Estimation of the device **true noise temperature.**

→ See P.Falferi et al, poster presented in this Conference.

Noise measurements on two different sensor SQUIDs at ultracryogenic temperatures

Experimental Configuration

- Two-stage readout
- Sensor SQUIDs S1: Quantum Design (QD) or Quantum Magnetics (QM).
- Amplifier SQUID S2 (Quantum Design SQUID).
- Electronics: see below.
- Chip boards mounted in Nb shields in thermal contact with the mixing chamber of a dilution refrigerator (but in vacuum!).



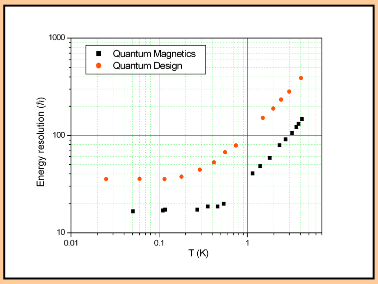
Parameters of the sensor SQUIDs:

Quantum Design SQUID

- Shunt resistor R_s=2Ω, loop inductance L_s=80 pH
- Input coil: M_i=10 nH, L_i=1.6 μH
- Gradiometric and symmetric layout

Quantum Magnetics SQUID

- R_s=10Ω, L_s=115 pH
- M_i=10 nH, L_i=1.0 μH
- Single loop washer ("Ketchen" type)



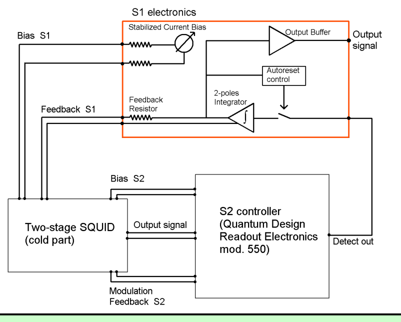
Experimental results (conventional energy resolution referred to input coil $L_i/2M_i^2 \times S_{\phi\phi}$)

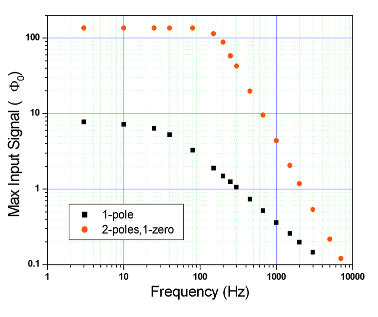
- QM is about 3 times better than QD at T>1K and 2 times better at low T. **Lowest measured noise is 16 $\hbar$.**
- **Low temperature saturation** related to a bad thermal sinking. Corresponding equivalent saturation temperatures 250 mK for QD and 440 mK for QM. Plan to improve thermal sinking and thus low temperature noise by using exchange ^{3}He gas.
- Noise measured at 5-7 kHz. At 1 kHz 1/f noise is non negligible. **1/ f contributions** at 1 kHz is about 13 $\hbar$ for QM and about 30 $\hbar$ for QD.

New control electronics for a two-stage SQUID optimized for a resonant GW detector

Main features

- Operates in series to a commercial (Quantum Design) electronics with modulation (used for the second stage SQUID signal readout).
- Optimized feedback **integrator with 2-poles and 1-zero** (Giffard, 1980).
- Bandwidth ≈ 100 kHz.
- **Automatic reset** to prevent integrator saturations.





Slew-rate measurement (max input signal before unlock)

- **Improvement by a factor 50 at 100 Hz** and a factor 10 at 1 kHz with respect to a standard 1-pole integrator with the same bandwidth.
- Dynamics **high enough** to deal with typical low frequency signals from both capacitive and inductive transducers of resonant GW detectors (Maximum some tens Φ_0).