# Low Dissipation Transport Measurement Scheme

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## Motivation

- The study of interplay between quantum criticality and unconventional superconductivity in the heavy fermions superconductors [1] (shown in Figure 1) enables us to understand the origin of the high temperature superconductivity.
- Transport measurement can be used to characterise these compounds. Since the critical temperature, $T_C$ of these compounds (e.g. $YbRh_2Si_2$) is found at millikelvin temperature, a low dissipation ultra-low temperature transport measurement scheme would be needed.

## Aim

- To develop a SQUID-based transport measurement scheme operating in ultra-low temperature.
- To study the practicality of the proposed scheme to measure the resistance of mΩ sample in liquid helium temperature, 4K.

## Proposed Measurement Scheme

- The proposed scheme in Figure 2 can be used to perform both SQUID Johnson noise measurement [3] (when the drive is off) and conventional transport measurement (when the drive is on). Flux induced by the current across the input coil is coupled to the SQUID loop. The SQUID signal is detected by a lock-in amplifier (SR844).

## Results

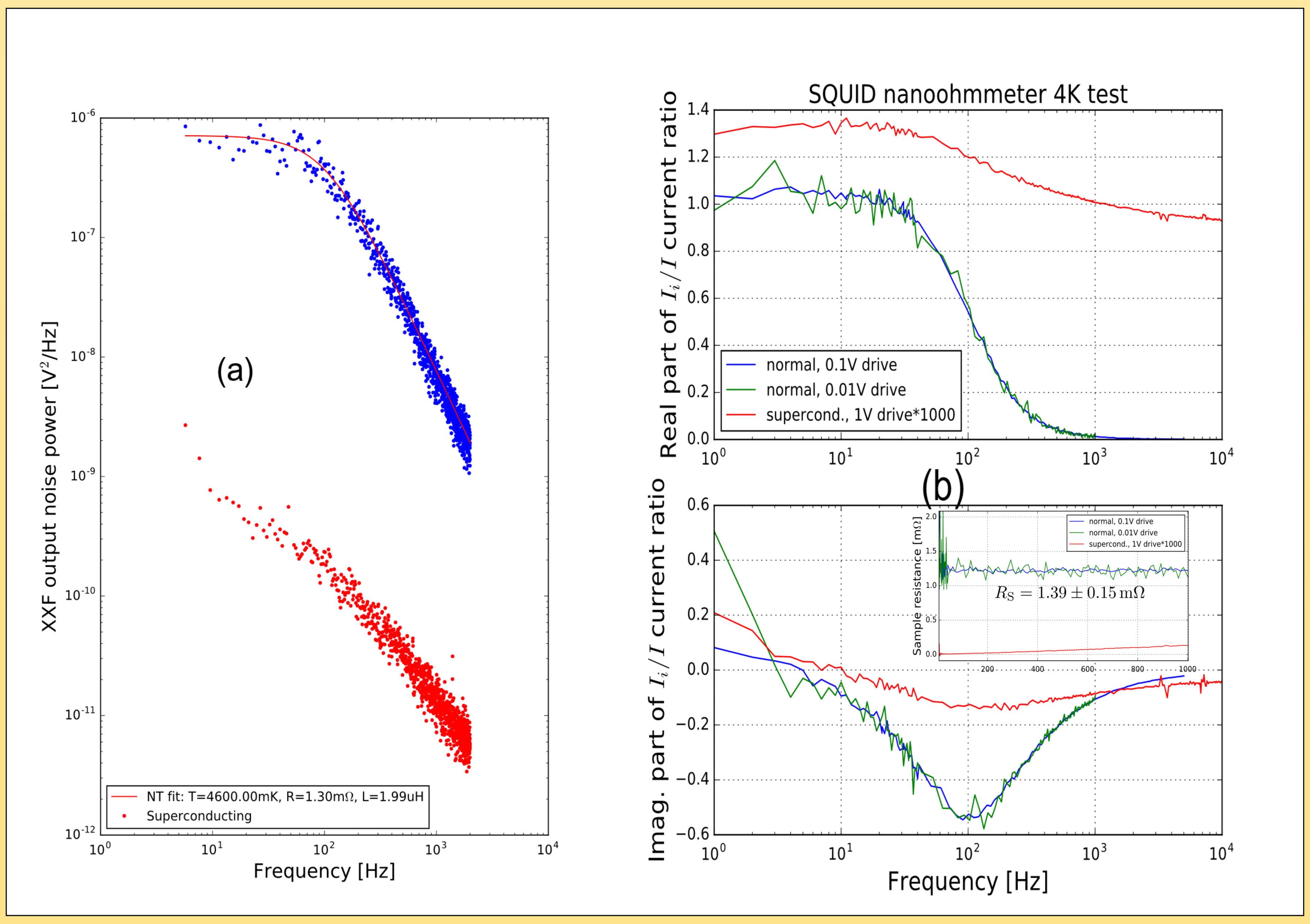


Figure 3: Resistance measurement of the tantalum sample using two different schemes: (a) SQUID Johnson noise measurement (b) SQUID-based conventional transport measurement (SQUID Nanoohmmeter). The measurement output when the sample is normal is compared to the superconducting case. They show excellent agreement to the theory.

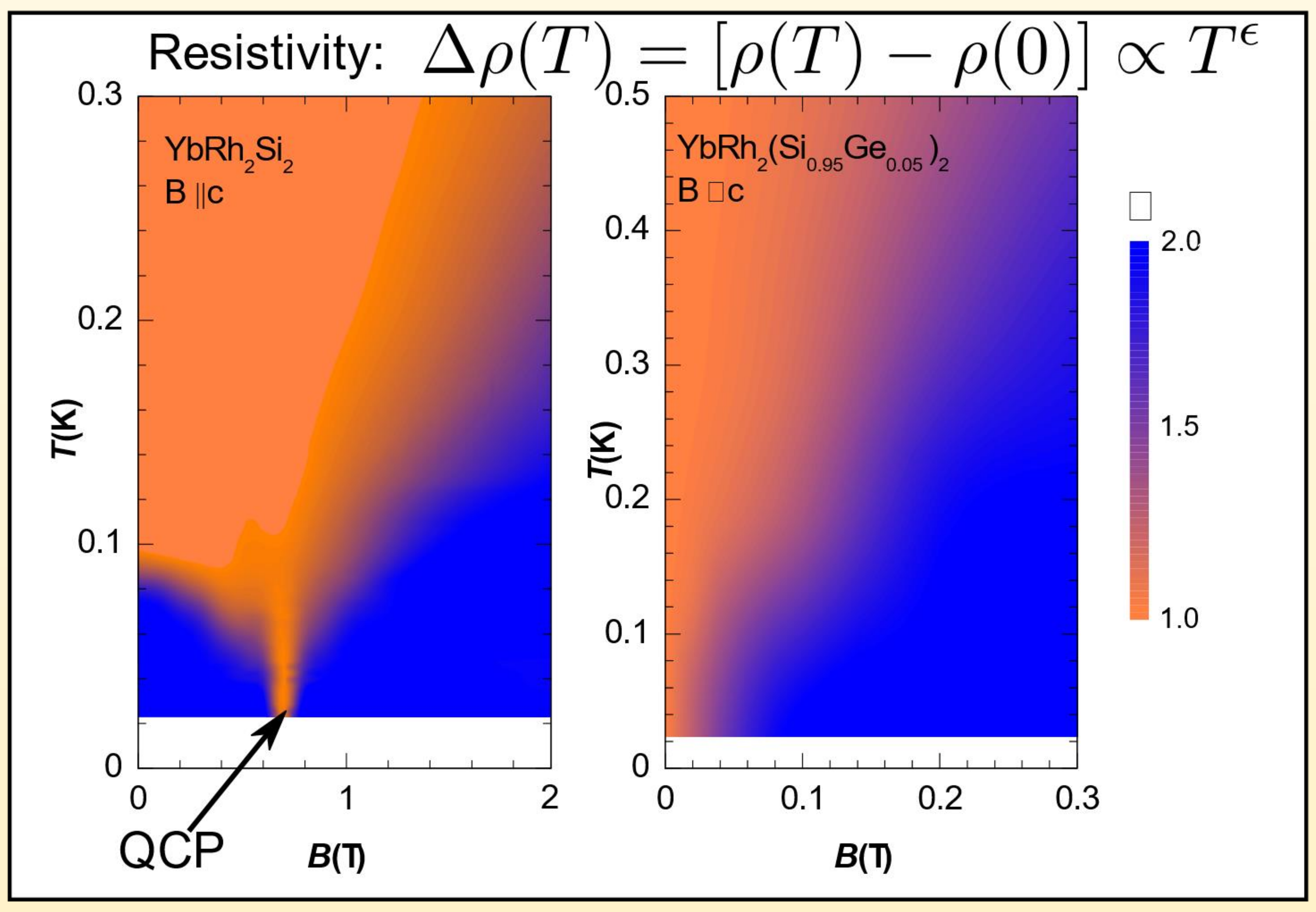


Figure 1: Temperature-field phase diagram of YbRh2($Si_{1-x}Ge_x$)$_2$ single crystals with the magnitude of the plot being the exponent of the temperature dependence of the resistivity of the compound, ε. Non-Fermi-liquid behaviour (bright orange) is found near the quantum critical point (QCP). Blue region exhibits Landau-Fermi liquid behaviour. The singular QCP at absolute zero produces a wide region of unusual behaviour in finite temperature without needing to reach absolute zero [2].

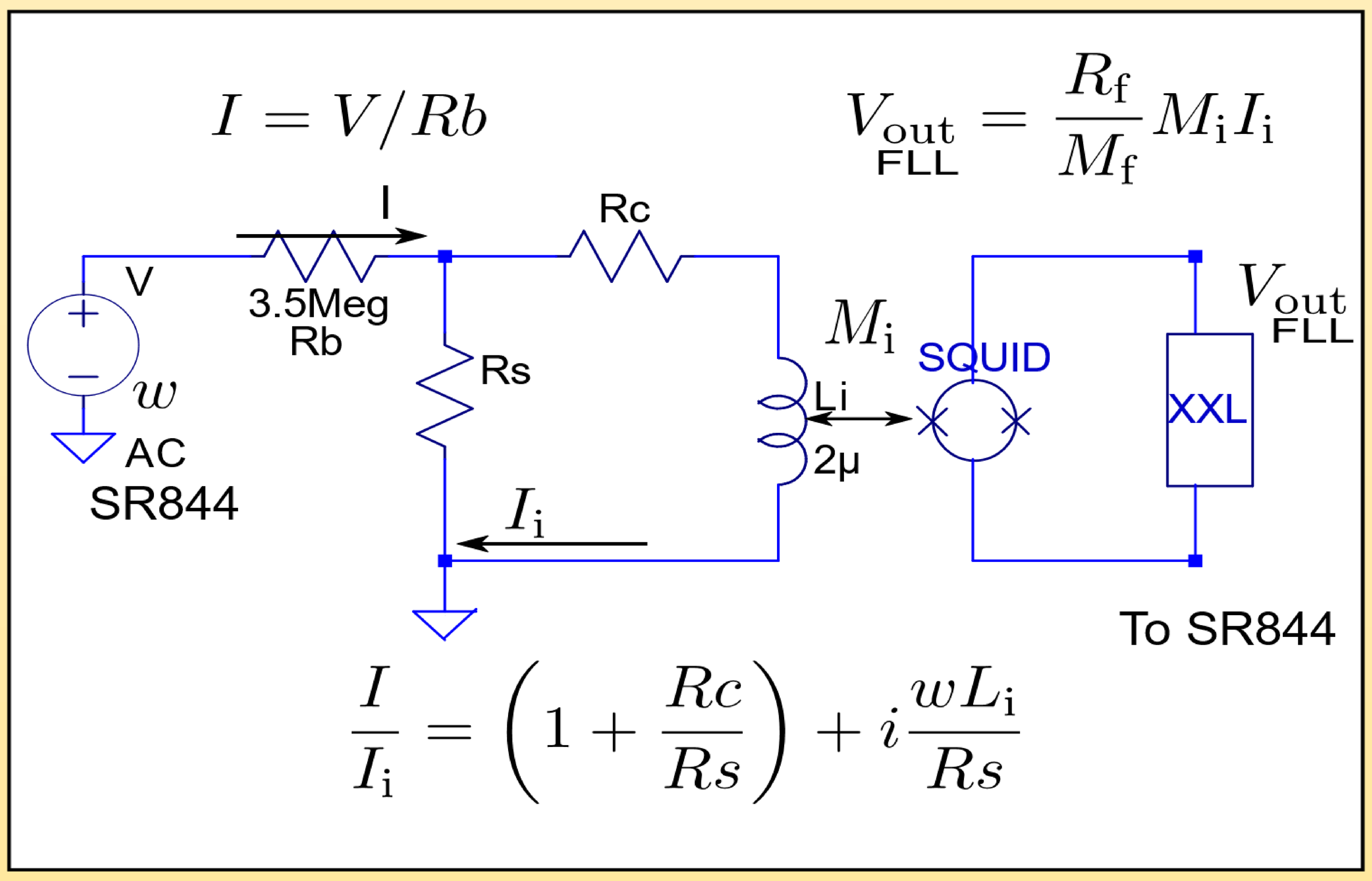


Figure 2: Proposed SQUID-based resistance measurement scheme. The SQUID is operated in flux-locked loop (FLL) mode. The voltage output, $V_{out,FLL}$ is proportional to the current in the input coil, $I_i$. The bias current, $I$ is of the order of μA due to the 3.5 MΩ shunt resistor.

## Possible Improvements

- The result for the superconducting case (in Figure 3(b)) does not agree with the model in Figure 2. Hence, there exist parasitic impedances in the input circuit due to non-ideal behaviour in components e.g. leads and wires. The inclusion of these impedances in the circuit schematics would be able to explain the experimental output better.
- Testing the setup with sample with lower resistance would allow us to examine its practical resistance measurement limit as well as to determine these parasitic impedances.

## References

1. P. Gegenwart *et al. Quantum criticality in heavy-fermion metals*. Nat Phys (2008)(3):186-197.
2. J. Custers *et al. The break-up of heavy electrons at a quantum critical point*. Nature, 424 (2003)(6948):524-527.
3. J. Li *et al. Current sensing noise thermometry for millikelvin temperatures using a DC SQUID preamplier.* Physica B: Condensed Matter, 280 (2000)(1-4):544-545.

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