Ultra-Stable Microwave Cryogenic Sapphire Oscillator based on a Gifford-McMahon Cryocooler

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We demonstrate for the first time an ultra-stable microwave cryogenic oscillator operated with a Gifford- McMahon (GM) cryocooler. Despite the high level of vibration generated by the GM, we show that an optimized design, with simple passive solutions, enables a sufficient mechanical decoupling to achieve a state-of-the-art frequency stability. The implemented 10 GHz cryogenic oscillator features a fractional frequency stability (ADEV) $\sigma_y(\tau)<3\times10^{-15}$ for 1 s$\leq\tau\leq10^4$ s.

The CSO is based on a sapphire mono-crystal resonating at 10 GHz in a whispering gallery mode, cooled near 6 K for zero thermal sensitivity and optimal quality factor. In our most advanced technology, codenamed ULISS-2G, the cryostat optimization has enabled to operate the CSO with a low power Pulse-Tube (PT) cryocooler consuming only 3 kW (single phase)[1]. The PT technology has been initially chosen for its low level of mechanical vibrations. ULISS-2G has been optimized to work with the Cryomech PT403 cryocooler[2], which, to our knowledge, has no equivalent product readily available on the market. For an obvious reasons of availability and to not hinder our future developments, we are actively looking for an alternative. Oppositely, the Gifford-McMahon (GM) cryocooler is available from number of manufacturers with an extended range of cooling power. It is produced in larger quantities and generally cheaper. A secondary advantage of the GM is its ability to operate in any orientation. This provides additional degrees of freedom in the cryostat design and could open the path for new applications. However, the main drawback of the GM cryocooler is its high level of vibrations compared to the PT. Nevertheless, the lessons learned and the many experiments gained over the past 10 years in building more than a dozen CSOs at the Femto-ST Institute have led us to the conclusion that a GM-based CSO is feasible. This paper summarizes our design approach and the first tests carried out on such a prototype. It demonstrates that the GM cryocooler is an alternative solution to achieve an ultra-stable microwave oscillator.

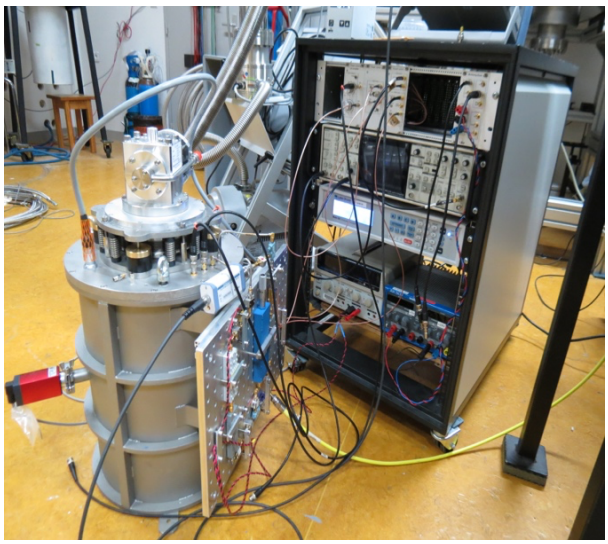

Fig. 1: Prototype of the new CSO operated with a Gifford-McMahon Cryocooler

[1] C. Fluhr, B. Dubois, G. L. Tetu, V. Soumann, J. Paris, E. Rubiola, V. Giordano, Reliability and reproducibility of the cryogenic sapphire oscillator technology, IEEE Trans. on IM 72 (2023) 1–8. doi:10.1109/TIM.2023.3277940.

[2] http://www.cryomech.com/ (Accessed Aug. 17, 2023).