Ultra-high stability cryocooled sapphire microwave oscillators

Hilton A.P[1,2], Hartnett J.G.[1], Ivanov E.N.[2], and Luiten A.N.[1,2]

[1]IPAS and the School of Chemistry and Physics, the University of Adelaide, Adelaide, SA/Australia

[2]School of Physics, the University of Western Australia, Crawley, WA/Australia

E-mail: John.Hartnett@adelaide.edu.au

Two nominally identical microwave cryocooled sapphire oscillators (CSO) have been implemented at the University of Adelaide. The sapphire resonators have a turning point in their frequency-temperature dependence at approximately 6 K, which delivers first-order insensitivity to temperature fluctuations when operated at this point. Using a closed system ultra-low vibration pulse-tube cryocooler with a specially design cryostat [1], it is possible to control the rms temperature fluctuations at the resonator to the 10 μK level, while maintaining a low vibration environment. Combined with a loaded Q-factor of about 10^9, similar oscillators have shown an Allan deviation of fractional frequency fluctuations of $\sigma_y = 5.8\times10^{-16}$ at 1 s [2].

In addition to the temperature control servo on the resonator, frequency and power control servos are implemented on the loop oscillator. The self-noise of these systems has been measured, under operating conditions, using a novel parallel measurement arrangement, which provides strong noise rejection of the noise measurement and probing systems.

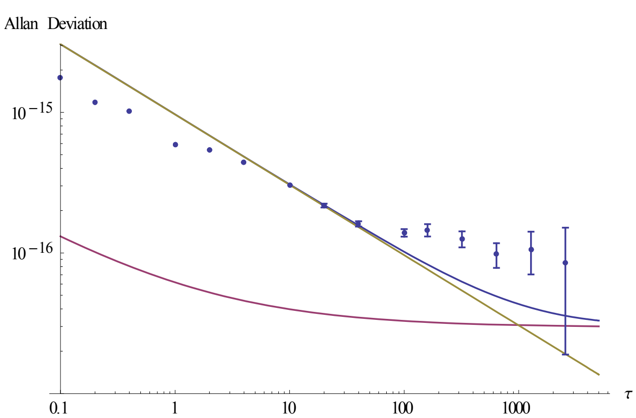

Fig. 1: *Allan Deviation of the fractional frequency of a previously measured CSO [2] compared to the stability from the noise model developed here. The power control system (Red), frequency control system (Brown), and their summed contribution to the oscillator (Blue) are shown.*

Using these measurements, taken as a function of power, allowed us to build a detailed noise model, which can explain the current CSO performance in terms of measurable parameters, as shown in Fig. 1. One can see that the short-term performance is dominated by noise in the frequency control system. Perhaps more excitingly, this model allows us to better optimize the operational parameters and minimize the noise floors associated with the control systems' self-noise.

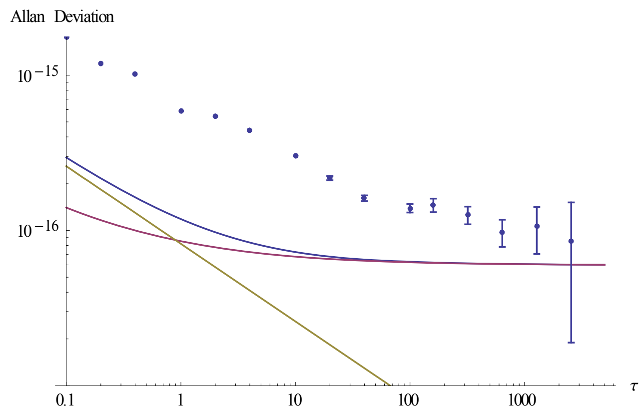

Fig. 2: *Allan Deviation of the oscillator fractional frequency as predicted by our noise model with optimized operational parameters. The blue points represent the stability of the previously measured CSO. The power control system (Red), frequency control system (Brown), and their summed contribution to the oscillator noise (Blue) are shown.*

As seen in Fig. 2, by varying the operational conditions of the oscillator we predict an improvement of frequency stability performance into the low 10^{-16} range. The specific changes called for by the model are a variation in the circulating power in the system, the proportion of power incident on the power-control detector, and in the modulation index. We are currently implementing these modifications to realize the predicted result. Details and measured CSO performance outcomes will be reported at the conference.

References

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