HIGH STABILITY 40 KELVIN CRYO-COOLED SAPPHIRE OSCILLATOR

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We present initial test results for a new short-term frequency standard, the 40K Compensated Sapphire Oscillator (40K CSO). Included are measurements of resonator quality factor, operational frequency, turn-over temperature, acceleration (g) sensitivity, frequency drift, and preliminary frequency stability tests. Performance goals are a frequency stability of $1 \times 10^{-14}$ (1 second $\leq \tau \leq 100$ seconds) and a year or more continuous operation. Long-term operation is facilitated use of a small cryo-cooler (1KW wall power) with no moving cryogenic parts, and thus no preset service interval for the cold head. Initial tests with this single-stage pulse-tube cooler show a stability of $3 \times 10^{-14}$ (1 second $\leq \tau \leq 10$ seconds) and a flicker floor of $2 \times 10^{-14}$.

The 40K CSO[1] bridges the gap and builds upon the capabilities of two previous technologies; the 10K CSO[2] and 77K CSO[3]. In particular, the 10K CSO incorporates a two-stage Gifford-McMahon type of cryocooler to achieve a stability of a few times $10^{-15}$ with paramagnetic spin compensation, while the 77K CSO first developed the idea of thermo-mechanical compensation, achieving a stability of about $1 \times 10^{-13}$ at an operating temperature of 80 K. The 40K CSO is designed to provide most of the capability of the 10K CSO in a small, low power package.

The quality factor for the first tested resonator is $Q = 100$ million, compared to a value of 20 million required to achieve our stability goal. Success of the cryogenic self-assembling feature of the resonator was demonstrated by a low acceleration sensitivity of about $1 \times 10^{-10}/g$ – had the parts not engaged as they cooled, the center-support mechanism would have failed, resulting in a much higher g-sensitivity. Stable operation is only achieved near a preferred “turnover temperature” at which frequency sensitivity to temperature fluctuation is zero. The turnover temperature varies a little between cooldowns, typically 36 Kelvin plus or minus 0.5K. Other modes show turnover temperatures ranging from 30 to 60 Kelvin. The excited WGE$_{10,1,1}$ mode was designed for operation at 16.0 GHz and showed values 16.113 GHz plus or minus 6 MHz. After 3 weeks of operation the drift rate is $1.6 \times 10^{-10}$ per day, reduced from its initial value by almost 10x. The present value is 100x lower than was shown by the 77K CSO.

References


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