Properties related to Q-factors and noise of quartz resonator-based systems at 4K

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It has been shown recently that premium grade quartz crystal resonators can exhibit outstanding quality-factors, *Q*, greater than 1 billion at liquid helium temperatures[1,2,3]. It is demonstrated that at low temperatures interaction between acoustic and thermal phonons is governed by the Landau-Rumer theory predicting $Q = const$ scaling law. This regime is distinct from the known Akhieser regime giving $Q \cdot f = const$ typically observed at room temperature. As a consequence, at low temperatures, the intrinsic *Q*-factor is independent of the resonant frequency making it advantageous to operate on higher overtones than the usual third or fifth overtones. Nevertheless, other loss mechanisms, such as surface or bulk scattering, can limit resonator performance, as discussed in the paper.

In addition, experiment also shows that the frequency flicker noise of acoustic devices is inversely proportional to Q^n, where n is close to 4, at the corresponding frequency[4,5].

It emerges from both previous points, i.e. the improvement of *Q*-factors at low temperature in one hand and noise related to the *Q*-factor in the other hand, that high frequency stabilities should be expected from quartz resonator-based frequency sources operating at cryogenic temperatures. Noise measurements of resonators cooled by means of a pulse-tube cryogenerator, have then been performed. Power spectral densities of fractional frequency in the order of $S_y(f = 1\ Hz) = 1\ 10^{-28}$ at 4 K have been achieved, that is to say two orders of magnitude lower than values already published. Resulting noise are described, and further promising applications are discussed.

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