Quantum computer-aided design (QCAD) of atomic clocks

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1 Pros and cons of building atomic clocks out of VQE

Building quantum clocks on the Variational-Quantum-Eigensolver (VQE) has several advantages and disadvantages. First of all, such quantum devices possess high accuracy because they are stable with respect to the quantum projection noise [1]. However, these quantum clocks are affected by the Dick effect that limits their performance [2].

2 Theory

Fault-tolerant quantum computers can be used to improve the design of atomic clocks. Let us note that fault-tolerant quantum computing requires the error-corrected fidelity, $\mathcal{F}$, more than 99%. One can relate this quantity to the accuracy of the atomic clock and the angle on the Bloch sphere as [3]

$$\mathcal{F} = \frac{2 + e^{-\frac{\theta^2}{2N}}}{3}. \tag{1}$$

Following this, we can express the accuracy as

$$N = -\frac{\theta^2}{2\log(3\mathcal{F} - 2)}. \tag{2}$$

Substituting the values for the fidelity, we obtain

$$N \leq -\frac{\theta^2}{2\log(0.97)} \approx 16.4\ \theta^2. \tag{3}$$

By reducing the angle on the Bloch sphere, θ, we increase the accuracy of the quantum clock according to this relationship $N \leq 16.4\ \theta^2$.

References

[1] Takamoto, M., Takano, T. & Katori, H. Frequency comparison of optical lattice clocks beyond the dick limit. *Nature Photonics* **5**, 288–292 (2011).

[2] Schioppo, M. *et al.* Ultrastable optical clock with two cold-atom ensembles. *Nature Photonics* **11**, 48–52 (2017).

[3] Xuereb, J., Erker, P., Meier, F., Mitchison, M. T. & Huber, M. Impact of imperfect timekeeping on quantum control. *Physical Review Letters* **131**, 160204 (2023).