QUTRIT AND QUOCT SPECTATORS FOR GAUSSIAN DEPHASING NOISE

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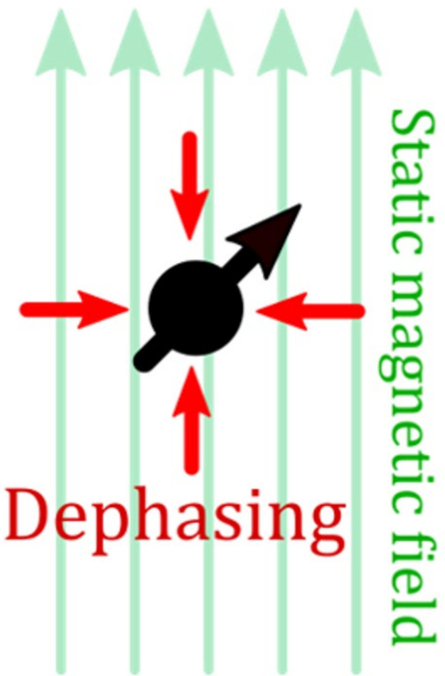
QuDit spectator framework

QuBit (Reminder)

$$H = \varepsilon_0(t)\,|0\rangle\langle 0| + \varepsilon_1(t)\,|1\rangle\langle 1|$$

$$= \beta_0(t) I + \beta_1(t) Z$$



QuTrit

$$H = \sum_{n\in\{0,1,2\}} \varepsilon_n(t)\,|n\rangle\,\langle n|$$

$$= \sum_{a\in\{0,\pm 1\}=\{0,1,2\}} \beta_a(t) Z^a$$

QuOct

$$H = \sum_{n\in\{0,\ldots,7\}} \varepsilon_n(t)\,|n\rangle\,\langle n| = \sum_{a,b\in\{0,\ldots,7\}} \beta_{ab}(t) Z^a X^b$$

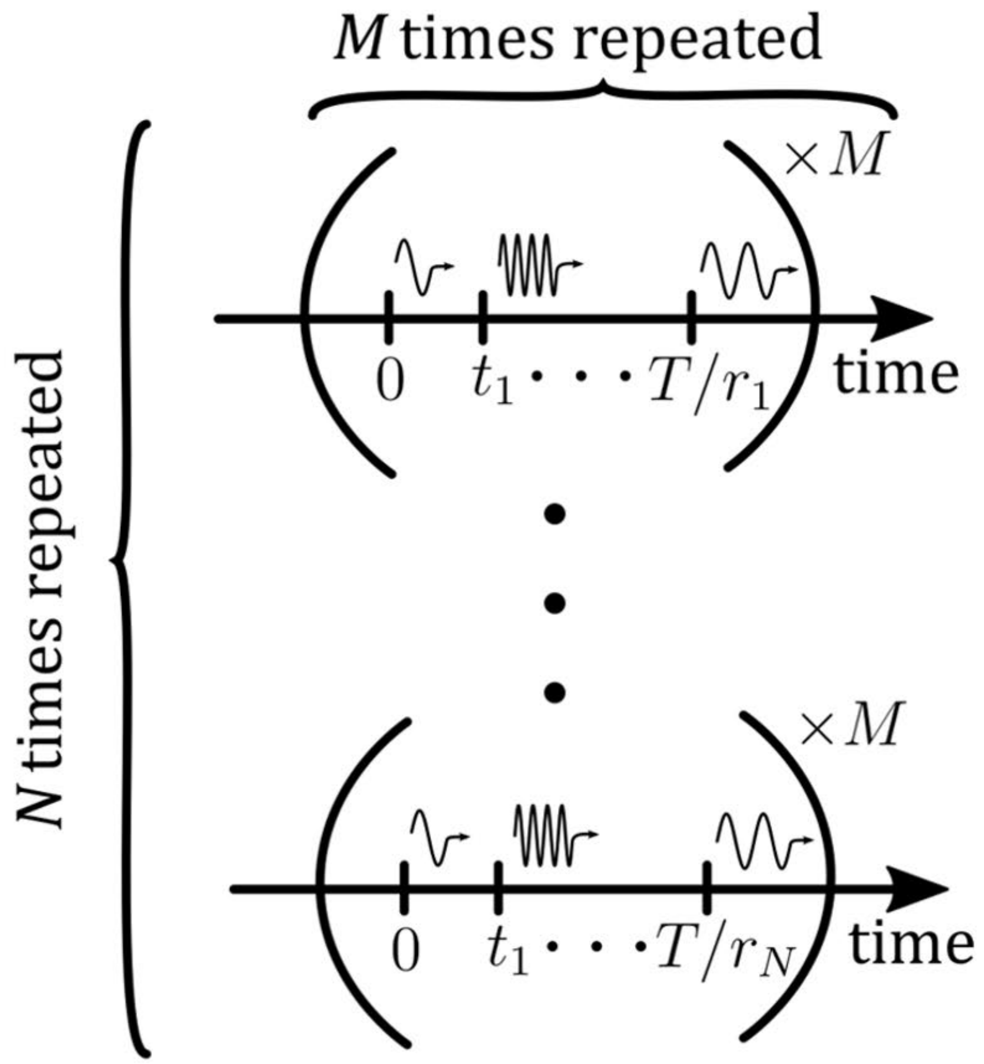
$$Z^a\,|i\rangle = \xi^a\,|i\rangle\,,\; X^a\,|i\rangle = |i \oplus a\rangle$$

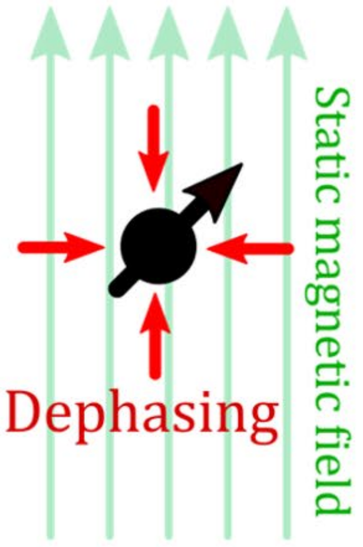
Antimony spin QuOct $= (\gamma_n \tilde{B}_0 \pm \frac{1}{2} A) I_z + Q I_x^2 + \gamma_n \tilde{B}_0 \cos(2\pi f t) I_y$

Mourik et al, Phys. Rev. E 98, 042206 (2018)

Stochastic

Alvarez-Suter Noise Spectroscopy Protocol





$$H^{Q\,bit}(t \in \tau_r) = \beta(t) y(t) Z$$

$$H^{Qutrit}(t \in \tau_r) = \sum_{a \in \{0, \pm 1\} = \{0,1,2\}} \beta_{-a}(t) y_{-a}(t) Z^{a}$$

$$H^{W}(t \in \tau_r) = \sum_{a,b,m,n \in \{0, \ldots, 7\}} \beta_{ab}(t) y^{ab}_{a'b'}(t) Z^{a'} X^{b'}$$

QuDit spectator framework

QuBit

$$H^{Qbit}(t \in \tau_r) = \beta(t) y(t) Z$$

$$F(\omega, t) = \int_0^{T/r} dt' y(t') e^{i\omega t'} \qquad S(\omega) = \int_{-\infty}^{\infty} dt \langle \beta(0)\beta(t)\rangle_c e^{i\omega t}$$

QuTrit

$$H^{Qutrit}(t \in \tau_r) = \sum_{a \in \{0, \pm 1\} = \{0,1,2\}} \beta_{-a}(t) y_{-a}(t) Z^a$$

$$F_a(\omega, t) = \int_0^{t} dt' \tilde{y}_a(t') e^{i\omega t'} \qquad S_{a,b}(\omega) = \int_{-\infty}^{\infty} dt e^{i\omega t} \langle \beta_a(0)\beta_b(t)\rangle_c$$

QuOct

$$H^{W}(t \in \tau_r) = \sum_{a,b,m,n \in \{0,\dots,7\}} \beta_{ab}(t) y^{ab}_{a'b'}(t) Z^{a'} X^{b'}$$

$$F^{ab}_{a'b'}(\omega, t) = \int_0^{t} dt' \, y^{ab}_{a'b'}(t) \, e^{i\omega t'} \qquad S^{\tilde{a}\tilde{b}}_{ab}(\omega) = \int_{-\infty}^{\infty} dt \langle \beta_{ab}(0)\beta_{\tilde{a}\tilde{b}}(t)\rangle_c e^{i\omega t}$$

$$S^{a'b'}_{ab}(\omega) = \sum_{i,\tilde{i}=0,1,2} \mathscr{B}^{aba'b'}_{i\tilde{i}} \tilde{S}_{i\tilde{i}}(\omega), \;\; \tilde{S}_{i\tilde{i}}(\omega) = \int_{-\infty}^{\infty} dt \langle B_i(0) B_{\tilde{i}}(t)\rangle_c e^{i\omega t} \qquad B_0, B_1(t), B_2(t) = 1, A(t), Q(t)$$

Data analysis technique

$$\langle\langle \hat{O}(t = MT/r)\rangle\rangle_c^r = \eta - \frac{1}{2}\int_0^t \int_0^t dt' dt'' \sum_{\mathscr{A}_\Sigma, \tilde{\mathscr{A}}_\Sigma \in S} \lambda_{\mathscr{A}_\lambda} y_{\mathscr{A}_y}(t') y_{\tilde{\mathscr{A}}_y}(t'') \langle \beta_{\mathscr{A}_\beta}(t') \beta_{\tilde{\mathscr{A}}_\beta}(t'')\rangle_c,$$

$$= \eta - \frac{1}{4\pi}\int_{-\infty}^{\infty} d\omega \sum_{\mathscr{A}_\Sigma, \tilde{\mathscr{A}}_\Sigma \in S} \lambda_{\mathscr{A}_\lambda} F_{\mathscr{A}_F}(\omega, t) F^*_{-\tilde{\mathscr{A}}_F}(\omega, t) S_{\mathscr{A}_S}(\omega),$$

$$\approx \eta - \frac{M}{2T/r} \sum_{k=-\infty}^{\infty} \sum_{\mathscr{A}_\Sigma, \tilde{\mathscr{A}}_\Sigma \in S} \lambda_{\mathscr{A}_\lambda} F_{\mathscr{A}_F}(rk\omega_0, T/r) F^*_{-\tilde{\mathscr{A}}_F}(rk\omega_0, T/r) S_{\mathscr{A}_S}(kr\omega_0),$$

Assumptions

Dephasing noise is a stochastic process, with zero-mean Gaussian probability distribution

Stationary condition of dephasing noise

$$\langle \beta_h(t') \beta_{h'}(t'')\rangle_c = \langle \beta_h(0) \beta_{h'}(t'' - t')\rangle_c,\ t'' > t'$$

Data analysis technique

QuBit

$\beta^*(t) = \beta(t)$

Stationary assumption of dephasing noise

$S(\omega)$ is a real function not complex

$$\begin{bmatrix} \langle\langle \hat{O} \rangle\rangle_c^{r=1} \\ \langle\langle \hat{O} \rangle\rangle_c^{r=2} \\ \vdots \\ \langle\langle \hat{O} \rangle\rangle_c^{r=N} \end{bmatrix} = \begin{bmatrix} & func\{F(\omega)\} & \end{bmatrix} \begin{bmatrix} S(\omega_0) \\ S(2\omega_0) \\ \vdots \\ S(N\omega_0) \end{bmatrix}$$

QuTrit

$$S_{1,1}(\omega) = R_1(\omega) + iI_1(\omega),\ S_{-1,-1}(\omega) = R_1(\omega) - iI_1(\omega),$$
$$S_{1,-1}(\omega) = E(\omega) + D(\omega),\ S_{-1,1}(\omega) = E(\omega) - D(\omega)$$

$$\underbrace{\begin{bmatrix} \langle\langle \hat{O}_1 \rangle\rangle_c^{r=1} \\ \vdots \\ \langle\langle \hat{O}_1 \rangle\rangle_c^{r=N} \\ \langle\langle \hat{O}_2 \rangle\rangle_c^{r=1} \\ \vdots \\ \langle\langle \hat{O}_2 \rangle\rangle_c^{r=N} \\ \langle\langle \hat{O}_3 \rangle\rangle_c^{r=1} \\ \vdots \\ \langle\langle \hat{O}_3 \rangle\rangle_c^{r=N} \end{bmatrix}}_{3\text{Nx}1} = \underbrace{\begin{bmatrix} & func\{F(\omega)\} & \end{bmatrix}}_{3\text{Nx}3\text{N}} \underbrace{\begin{bmatrix} R_1(\omega_0) \\ I_1(\omega_0) \\ E(\omega_0) \\ R_1(2\omega_0) \\ I_1(2\omega_0) \\ E(2\omega_0) \\ \vdots \\ R_1(N\omega_0) \\ I_1(N\omega_0) \\ E(N\omega_0) \end{bmatrix}}_{3\text{Nx}1}$$

Numerical example: QuTrit spectator