Entanglement in the nonlinear three-atom Jaynes-Cummings model

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Hamiltonian

$$H = (1/2)\hbar\Delta\sum_{i=1}^{3} R_i^z + \hbar\gamma\sum_{i=1}^{3}(\eta^+ R_i^- + R_i^+\eta) + \hbar\Xi\eta^{+2}\eta^2$$

Initial qubits states

a) Separable $|\Phi_1(0)\rangle_{A_1 A_2 A_3} = |+,-,-\rangle$

b) biseparable $|\Phi_2(0)\rangle_{A_1 A_2 A_3} = \cos\theta|+,+,-\rangle + \sin\theta|+,-,+\rangle$

c) W entangled state $|\Phi_3(0)\rangle_{A_1 A_2 A_3} = a|+,+,-\rangle + b|+,-,+\rangle + c|-,+$

Fock cavity field $\hat{\rho}_F(0) = |n\rangle\langle n|,$

Time-dependent density matrix

$$\hat{\rho}(t) = |\Psi_n(t)\rangle\langle\Psi_n(t)|$$

$$\hat{\rho}_{qubit1-qubit2-qubit3}(t) = Tr_F\hat{\rho}(t)|$$

$$\hat{\rho}_{qubit1-qubit2}(t) = Tr_{qubit3}\hat{\rho}_{qubit1-qubit2-qubit3}(t)$$

The negativity between i and j qubits $\varepsilon_{ij} = -2\sum_i \mu_i^-.$

Here μ_i^- is the eigenvalues of the partial transpose matrix

$$\rho_S^{T_1}(t) = \begin{pmatrix} (\rho_S)_{11} & 0 & 0 & (\rho_S)_{23}^* \\ 0 & (\rho_S)_{22} & 0 & 0 \\ 0 & 0 & (\rho_S)_{33} & 0 \\ (\rho_S)_{23} & 0 & 0 & (\rho_S)_{44} \end{pmatrix}$$

Therefore

$$\varepsilon(t) = \sqrt{\left((\rho_S)_{11}(t) - (\rho_S)_{44}(t)\right)^2 + 4\left|(\rho_S)_{23}(t)\right|^2} - (\rho_S)_{11} - (\rho_S)_{44}.$$

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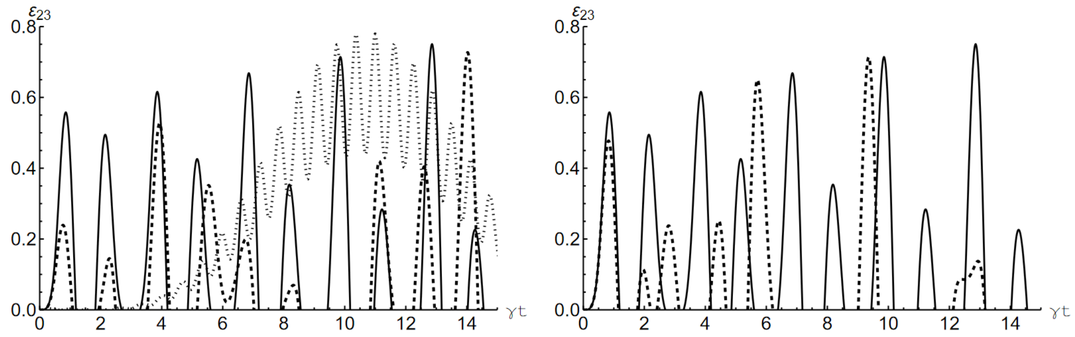
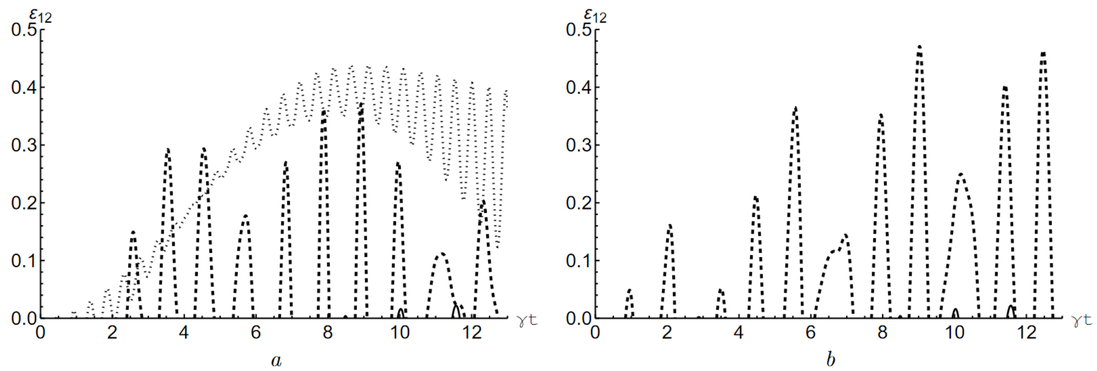
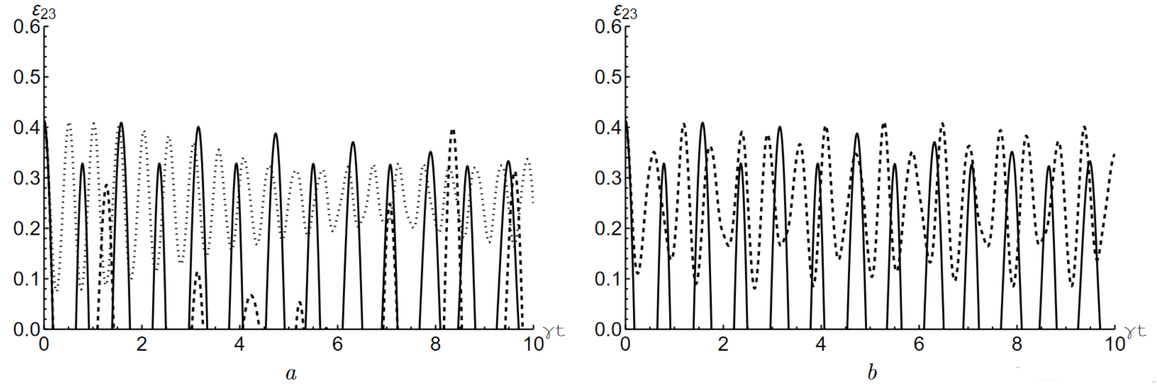
Simulations



Зависимость отрицательностей ε_{23} (a) от приведенного времени γt для начального состояния кубитов $|+,-,-\rangle$. Число фотонов в моде резонатора выбрано равным $n = 1$. Значения параметров расстройки керровской нелинейности в случае a): $\Delta = 0.01\gamma$, $\Xi = 0.01\gamma$ (сплошная линия); $\Delta = 2.5\gamma$, $\Xi = 0.01\gamma$ (штриховая линия) и $\Delta = 9.5\gamma$, $\Xi = 0.01\gamma$ (пунктирная линия). В случае $б$): $\Delta = 0.01\gamma$, $\Xi = 0.01\gamma$ (сплошная линия) и $\Delta = 0.01\gamma$, $\Xi = \gamma$ (пунктирная линия)



Dependence of the negatives ε_{12} (a) on the reduced time γt for the initial state of qubits $(1/\sqrt{2})(|+,+,-\rangle + |+,-,+\rangle)$. The number of photons in the resonator mode is chosen equal to $n = 2$. The values of the parameters of the Kerr nonlinearity detuning in the case of a): $\Delta = 0.01\gamma$, $\Xi = 0.01\gamma$ (solid line); $\Delta = 5\gamma$, $\Xi = 0.01\gamma$ (dashed line) and $\Delta = 13\gamma$, $\Xi = 0.01\gamma$ (dotted line). In case b): $\Delta = 0.01\gamma$, $\Xi = 0.01\gamma$ (solid line) and $\Delta = 0.01\gamma$, $\Xi = \gamma$ (dotted line)



Dependence of negatives ε_{23} (a) on the reduced time γt for the initial state of qubits $(1/\sqrt{3})(|+,+,-\rangle + |+,-,+\rangle + |-,+,+\rangle)$. The number of photons in the resonator mode is chosen to be $n = 1$. Values of Kerr nonlinearity detuning parameters in case a): $\Delta = 0.01\gamma$, $\Xi = 0.01\gamma$ (solid line); $\Delta = 3.5\gamma$, $\Xi = 0.01\gamma$ (dashed line) and $\Delta = 12\gamma$, $\Xi = 0.01\gamma$ (dotted line). In case b): $\Delta = 0.01\gamma$, $\Xi = 0.01$ (solid line) and $\Delta = 0.01\gamma$, $\Xi = 2.5\gamma$ (dotted line)