Entanglement in information transmission

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Our study of the role of entanglement in quantum communication and quantum information has evolved in two directions. We have continued the analysis of the role of entanglement in the classical capacity of a particular class of quantum channels with memory.
Furthermore we have studied the optimal entanglement transfer between bosonic systems and qubits.

The classical capacity of a quantum channel [1,2] is, roughly speaking, the amount of classical information that can be reliably transmitted by using quantum states in the presence of a noisy environment.
In our previous reporting period we have shown [3] that entanglement is a precious resource to increase the information transmission when the noise introduced by the channel exhibits some correlations among subsequent uses of a depolarizing channel. In particular, for the depolarizing channel with correlated noise our results show that higher mutual information can indeed be achieved above a certain memory threshold, by entangling two consecutive uses of the channel.

In this reporting period we have extended our analysis [4] and we have analitically proved for the first time the optimality of a set of entangled input signal states for a class of Pauli channels. To this end we have first obtained an upper bound on the channel capacity. We have then shown that for the general case of Pauli channels with an arbitrary degree of memory this bound is saturated by states of minimal output entropy. For a class of Pauli channels we have derived these states explicitly. They turn out to be entangled above a given memory threshold and product states below it.

A second research lines has focused on the optimal entanglement transfer between bosonic systems and qubits. The control of the dynamics of a complex quantum system requires a trade-off between tunability and protection against noise. To this end one is interested in processes where some physical properties of a subsystem are reliably transferred onto the state of a second one (of perhaps different nature) where information can be manipulated. The connection between the two subsystems is effectively realized via a physical interface. An interface is a communication channel used to connect the elements of a quantum register to perform quantum information processing or a physical mechanism that gives full access to the system under investigation and allows manipulating it.

We have proposed two different set-ups where our scheme can be implemented [5,6].

The first is a cavity-QED system in which the qubits are embodied in two-level atoms crossing two optical cavities.

The second proposal exploits the recent ideas about solid-state systems/quantum optics interfaces and uses superconducting qubits integrated in microstrip resonators [7]. This second scenario, in particular, offers the advantages of a strong coupling regime of interaction (that is hard to get with optical cavities) without the difficulties connected with the management of flying qubits.

We have discussed in detail a mechanism for the transfer of entanglement from a two-mode squeezed state to a pair of qubits. Here, the information sheltered in the electromagnetic medium may be manipulated, using just single-qubit operations, when transferred to the solid-state subsystem. This may offer advantages with respect to integrability and scalability.

In particular, we consider the field modes to interact with a pair of (initially independent) Superconducting-Quantum-Interference-Devices (SQUIDs)

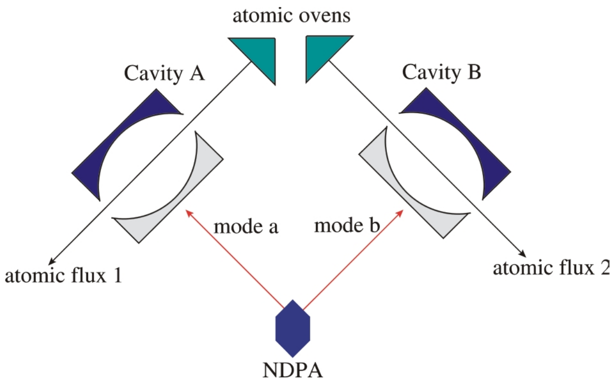

Fig. A

Fig. 1
Two experimental setups for the transfer of entanglement between two continuous modes and two physical qubits:
Fig. A two atoms interacting with the field injected in a microwave cavity,
Fig. B two squids capacitively coupled to a microwave field.

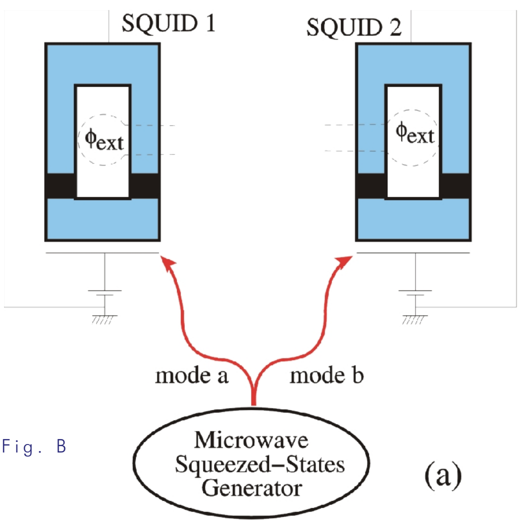

Fig. B

that embody two charge qubits [8]. Direct experimental evidence of the use of these systems as controllable coherent two-level systems has already been provided [9,10]. We find that a nearly maximally entangled state of two qubits can be tailored, with our interaction model, via an effective process of transfer of quantum correlations.

The entanglement poured into the joint state of the qubits can be regulated controlling the interaction times between qubits and field modes. At the interaction time corresponding to the maximum of the transferred entanglement, the qubits are in an almost pure state that may be used for efficient quantum information processing. Furthermore how much a non-Gaussian two-mode field can generate entanglement in a bipartite qubit system by the respective mode-qubit interaction is used to quantify entanglement of the two-mode field.

The CV field, which is defined in an infinite large dimensional Hilbert space, transfers its entanglement to a system defined in a small two dimensional Hilbert space, by nearly exhausting its entanglement. This is an interesting observation as an infinite dimensional system is projected onto the two-dimension and loses its entanglement by their interaction. We have seen that the entangling power left in the CV system after the first pair interaction can be transferred to the next pair of qubits.

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