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Probabilistic teleportation of an arbitrary pure state of two atoms*

Yang Zhen-Biao(杨贞标)†, Wu Huai-Zhi(吴怀志), and Su Wan-Jun(苏万钧)

Department of Electronic Science and Applied Physics, Fuzhou University, Fuzhou 350002, China

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In the context of microwave cavity QED, this paper proposes a new scheme for teleportation of an arbitrary pure state of two atoms. The scheme is very different from the previous ones which achieve the integrated state measurement, it deals in a probabilistic but simplified way. In the scheme, no additional atoms are involved and thus only two atoms are required to be detected. The scheme can also be used for the teleportation of arbitrary pure states of many atoms or two-mode cavities.

Keywords: probabilistic teleportation, arbitrary pure state, Λ-type atom, two-mode cavity
PACC: 0365, 4250

Quantum teleportation,[1] which describes the disembodied transmission of information, is a central resource in quantum information and quantum computation.[2,3] Since its first suggestion,[1] much attention has been paid to it and a great deal of work has been done, which leads to its experimental demonstration in various systems, including optical systems,[4,5] nuclear magnetic resonance,[6] and trapped ions.[7,8]

Microwave cavity QED, with Rydberg atoms crossing superconducting microwave cavities, is one of the candidates for quantum computation and quantum information processing.[9] In the context of microwave cavity QED, a number of schemes have been proposed for the teleportation of an unknown atomic state,[10−16] and an unknown cavity field state.[17−19]

All the above schemes concentrate on single-qubit teleportation. Recently, schemes have been proposed for the teleportation of two-atom entangled states,[20−22] and two cavity-mode entangled states.[23−25] However, the teleported states are just in the form of $\alpha|01\rangle + \beta|10\rangle$, with $|\alpha|^2 + |\beta|^2 = 1$, which is not suitable for the extensible quantum computation, based on the more universal arbitrary pure states of two or many qubits,[2] i.e. $|\chi\rangle = \sum_{m_1,m_2,\ldots,m_N=0,1} c_{m_1\,m_2\,\ldots\,m_N}|m_1\,m_2\,\ldots\,m_N\rangle_{12\ldots N}$, with $\sum_{m_1,m_2,\ldots,m_N=0,1}|c_{m_1m_2\ldots m_N}|^2 = 1$. More recently, teleportation of arbitrary pure states of two qubits in optical systems has been reported[26] and it has been considered to be an important step toward teleportation of a complex system and able to boost up future experimental investigations on novel quantum communication and computation protocols.[2]

In the context of microwave cavity QED, schemes have been proposed for the teleportation of arbitrary pure states ($|\chi\rangle$) of two single-mode cavities,[27] and two atoms.[28] In Ref.[27], the quantum channel is firstly prepared by entangling two pairs of cavities in the form of EPR states. Each one of these two pairs of cavities and two cavities of which the state to be teleported are probed, by the resonant atoms passing through them, and later being detected. With the outcome of the detection, the receiver can apply appropriate transformations to complete the teleportation. In Ref.[28], two EPR states composed by four atoms serve as the quantum channel. Each one of these two pairs of atoms and two atoms carrying the unknown state are detected after the thermal-cavity-assisted atom–atom coupling, then the teleportation can be completed by appropriate transformations according to the corresponding detection outcome. Both schemes can get successful probability with unity based on the fact that the additional two cavities or two atoms are used and four atoms are detected. But what will the result of the teleportation be if no additional cavities or atoms are employed (for example, for the teleportation of an arbitrary pure

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†E-mail: yangzhenbiao@fzu.edu.cn

state of two atoms, only four atoms are involved, two for the sender and the other for the receiver)?

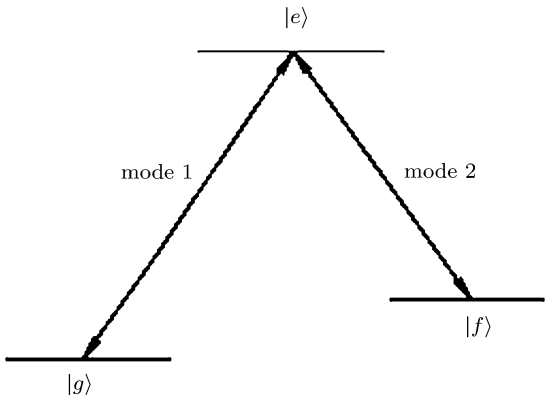


Fig.1. Schematic diagram of a Λ-type three-level atom interacting with a two-mode cavity field. The transitions $|e\rangle \leftrightarrow |g\rangle$ and $|e\rangle \leftrightarrow |f\rangle$ are resonantly coupled to the cavity modes 1 and 2 respectively. (The transition between levels $|g\rangle$ and $|f\rangle$ is dipole forbidden).

In this paper, we propose a new scheme for the teleportation of an arbitrary pure state of two atoms. The scheme involves only four atoms. Although the successful probability of the scheme is only 1/16, the procedure of the teleportation is greatly simplified. The scheme is very different from that which are based on the resonant interaction of two-level atoms with single-mode cavities,[27] or nonresonant interaction of driven two-level atoms with single-mode cavities,[28] it is based on the resonant interaction of Λ-type atoms with two-mode cavities (also known in the literature as bimodal cavities). In the scheme, the quantum channel is prepared by individually sending two Λ-type atoms to receive the teleported state through two respective bimodal cavities. Then two atoms carrying the teleported state are individually sent through these cavities and finally detected, respectively. With the outcome of the detection, the receiver can determine whether the teleportation succeeds or fails. Our scheme can be generalized for the teleportation of arbitrary pure states of many atoms or bimodal cavities.

We first consider the interaction of a Λ-type three-level atom with a two-mode cavity field, as shown in Fig.1. $|g\rangle$ and $|f\rangle$ are two lower states and $|e\rangle$ is the higher state. The transitions $|e\rangle \leftrightarrow |g\rangle$ and $|e\rangle \leftrightarrow |f\rangle$ are resonantly coupled to the cavity modes 1 and 2, respectively. Various dynamical properties of this and other correlative systems have been discussed.[29−34] In the interaction picture, the interaction Hamiltonian for the atom–cavity system under dipole and rotating wave approximation can be written as follows:[30,31]

$$H_{\text{eff}} = g(a^+|g\rangle\langle e| + b^+|f\rangle\langle e| + a|e\rangle\langle g| + b|e\rangle\langle f|), \quad (1)$$

where $a(a^+)$ and $b(b^+)$ are annihilation (creation) operators for the cavity modes 1 and 2 respectively. The coupling strengths for two modes are assumed to be same ($g_1 = g_2 = g$), which can be satisfied by choosing appropriate atomic transitions.[35] Such an effective Hamiltonian leads to the following evolutions:[25]

$$\begin{aligned}
|e\rangle|m,n\rangle \to{}& \cos(g\tau\sqrt{m+n+2})|e\rangle|m,n\rangle \; - \frac{\mathrm{i}\sin(g\tau\sqrt{m+n+2})}{\sqrt{m+n+2}} \\
&\times [\sqrt{m+1}|g\rangle|m+1,n\rangle + \sqrt{n+1}|f\rangle|m,n+1\rangle], \qquad (2)\\
|g\rangle|m+1,n\rangle \to{}& \frac{1}{m+n+2}[(m+1)\cos(g\tau\sqrt{m+n+2}) + n + 1]|g\rangle|m+1,n\rangle \\
&+ \frac{\sqrt{(m+1)(n+1)}}{m+n+2}[\cos(g\tau\sqrt{m+n+2}) - 1]|f\rangle|m,n+1\rangle \\
&- \mathrm{i}\frac{\sqrt{m+1}}{\sqrt{m+n+2}}\sin(g\tau\sqrt{m+n+2})|e\rangle|m,n\rangle, \qquad (3)\\
|f\rangle|m,n+1\rangle \to{}& \frac{1}{m+n+2}[(n+1)\cos(g\tau\sqrt{m+n+2}) + m + 1]|f\rangle|m,n+1\rangle \\
&+ \frac{\sqrt{(m+1)(n+1)}}{m+n+2}[\cos(g\tau\sqrt{m+n+2}) - 1]|g\rangle|m+1,n\rangle \\
&- \mathrm{i}\frac{\sqrt{n+1}}{\sqrt{m+n+2}}\sin(g\tau\sqrt{m+n+2})|e\rangle|m,n\rangle, \qquad (4)
\end{aligned}$$

where m and n denote the state with m photons in cavity mode 1, n photons in mode 2.

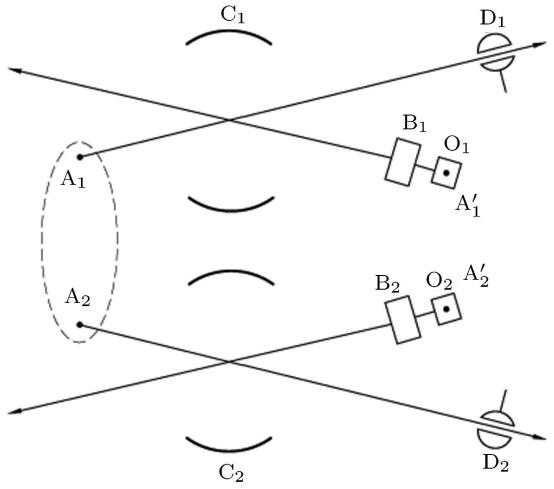


Fig.2. The diagram for teleportation of an arbitrary pure state of two $\Lambda-$type atoms. The atoms A_1 and A_2 are initially in the unknown pure state to be teleported. The atoms A'_1 and A'_2 receiving the teleported state are produced in Zones B_j by the excitation of velocity-selected atomic beam effusing from oven O_j $(j = 1, 2)$ respectively. C_1 and C_2 are two ideal millimetre-wave superconducting microwave cavities. D_1 and D_2 denote the state-selective field ionization detectors.

The setup for teleportation of an arbitrary pure state of two $\Lambda-$type atoms is shown in Fig.2. Assume that two atoms A_1 and A_2 are initially in the unknown pure state as follows:

$$|\psi\rangle_{A_1A_2} = c_{gg}|gg\rangle_{A_1A_2} + c_{gf}|gf\rangle_{A_1A_2} + c_{fg}|fg\rangle_{A_1A_2} + c_{ff}|ff\rangle_{A_1A_2}, \quad (5)$$

with $\sum_{m_1,m_2=g,f}|c_{m_1m_2}|^2 = 1$. Now we want to teleport this state to the other two atoms A'_1 and A'_2. Suppose that the atoms A'_1 and A'_2 are initially in the higher states $|e\rangle_{A'_j}$, and two cavities C_1 and C_2 are initially in the two-mode vacuum states $|0,0\rangle_{C_j}$ $(j = 1, 2)$. We first send each of these atoms through their respective cavities, i.e. atom A'_1 is sent through cavity C_1, while atom A'_2 is sent through cavity C_2. The state of the subsystem combined by atom A'_j and cavity C_j evolves according to Eq.(2). After an interaction time $\tau = \pi/2\sqrt{2}g$, two subsystems evolve to the following states:[25]

$$|\phi\rangle_{A'_1C_1} = \frac{-i}{\sqrt{2}}(|g\rangle_{A'_1}|1,0\rangle_{C_1} + |f\rangle_{A'_1}|0,1\rangle_{C_1}), \quad (6)$$

and

$$|\phi\rangle_{A'_2C_2} = \frac{-i}{\sqrt{2}}(|g\rangle_{A'_2}|1,0\rangle_{C_2} + |f\rangle_{A'_2}|0,1\rangle_{C_2}), \quad (7)$$

respectively. Now the whole system is in the state

$$|\psi\rangle_{A_1A_2} \otimes |\phi\rangle_{A'_1C_1} \otimes |\phi\rangle_{A'_2C_2}. \quad (8)$$

Then we send atom A_1 through cavity C_1, and simultaneously atom A_2 through cavity C_2. After the same interaction time τ, the whole system evolves to the state

$$\begin{aligned}|\Psi\rangle_{A_1A_2A'_1A'_2C_1C_2} = & -\frac{1}{2}[c_{gg}|gg\rangle_{A'_1A'_2}|\varphi\rangle_{A_1C_1}|\varphi\rangle_{A_2C_2} + c_{gf}|gf\rangle_{A'_1A'_2}|\varphi\rangle_{A_1C_1}|\varphi'\rangle_{A_2C_2} \\ & + c_{fg}|fg\rangle_{A'_1A'_2}|\varphi'\rangle_{A_1C_1}|\varphi\rangle_{A_2C_2} + c_{ff}|ff\rangle_{A_1A_2}|\varphi'\rangle_{A_1C_1}|\varphi'\rangle_{A_2C_2} \\ & + c_{gg}(|gf\rangle_{A'_1A'_2}|\varphi\rangle_{A_1C_1}|\phi\rangle_{A_2C_2} + |fg\rangle_{A'_1A'_2}|\phi\rangle_{A_1C_1}|\varphi\rangle_{A_2C_2} \\ & + |ff\rangle_{A'_1A'_2}|\phi\rangle_{A_1C_1}|\phi\rangle_{A_2C_2}) + c_{gf}(|gg\rangle_{A'_1A'_2}|\varphi\rangle_{A_1C_1}|\phi'\rangle_{A_2C_2} \\ & + |fg\rangle_{A'_1A'_2}|\phi\rangle_{A_1C_1}|\phi'\rangle_{A_2C_2} + |ff\rangle_{A'_1A'_2}|\phi\rangle_{A_1C_1}|\varphi'\rangle_{A_2C_2}) \\ & + c_{fg}(|gg\rangle_{A'_1A'_2}|\phi'\rangle_{A_1C_1}|\varphi\rangle_{A_2C_2} + |gf\rangle_{A'_1A'_2}|\phi'\rangle_{A_1C_1}|\phi\rangle_{A_2C_2} \\ & + |ff\rangle_{A'_1A'_2}|\varphi'\rangle_{A_1C_1}|\phi\rangle_{A_2C_2}) + c_{ff}(|gg\rangle_{A'_1A'_2}|\phi'\rangle_{A_1C_1}|\phi'\rangle_{A_2C_2} \\ & + |gf\rangle_{A'_1A'_2}|\phi'\rangle_{A_1C_1}|\varphi'\rangle_{A_2C_2} + |fg\rangle_{A'_1A'_2}|\varphi'\rangle_{A_1C_1}|\phi'\rangle_{A_2C_2})], \end{aligned} \quad (9)$$

where

$$|\phi\rangle_{A_jC_j} = |g\rangle_{A_j}|0,1\rangle_{C_j}, \quad (10)$$

$$|\phi'\rangle_{A_jC_j} = |f\rangle_{A_j}|1,0\rangle_{C_j}, \quad (11)$$

$$|\varphi\rangle_{A_jC_j} = \Big(\frac{1}{2}|g\rangle_{A_j}|1,0\rangle_{C_j} - \frac{1}{2}|f\rangle_{A_j}|0,1\rangle_{C_j}$$

$$- \frac{\mathrm{i}}{\sqrt{2}}|e\rangle_{\mathrm{A}_j}|0,0\rangle_{\mathrm{C}_j}\Big), \tag{12}$$

$$|\varphi'\rangle_{\mathrm{A}_j\mathrm{C}_j} = \Big(\frac{1}{2}|f\rangle_{\mathrm{A}_j}|0,1\rangle_{\mathrm{C}_j} - \frac{1}{2}|g\rangle_{\mathrm{A}_j}|1,0\rangle_{\mathrm{C}_j} - \frac{\mathrm{i}}{\sqrt{2}}|e\rangle_{\mathrm{A}_j}|0,0\rangle_{\mathrm{C}_j}\Big), \quad (j=1,2). \tag{13}$$

Then two atoms A_1 and A_2 are detected. Suppose that both atoms are detected in their higher states $|e\rangle_{\mathrm{A}_1}$ and $|e\rangle_{\mathrm{A}_2}$ respectively, thus the other two atoms A_1' and A_2' are directly collapsed onto the state

$$|\psi\rangle_{\mathrm{A}_1'\mathrm{A}_2'} = c_{gg}|gg\rangle_{\mathrm{A}_1'\mathrm{A}_2'} + c_{gf}|gf\rangle_{\mathrm{A}_1'\mathrm{A}_2'} + c_{fg}|fg\rangle_{\mathrm{A}_1'\mathrm{A}_2'} + c_{ff}|ff\rangle_{\mathrm{A}_1'\mathrm{A}_2'}, \tag{14}$$

leaving the two cavities C_1 and C_2 in the two-mode vacuum states respectively. The probability of success is 1/16.

We now give a brief discussion on the experimental matter. Our scheme proposed here requires (i) resonant interaction between the Λ-type atom and two cavity modes, (ii) controlled interaction time between the atoms and cavity modes, (iii) no atomic spontaneous decay and negligible cavity loss during the whole teleportation process, (iv) detection of the atoms in the required states. In order to realize the proposed scheme, we may consider Rydberg atoms in high Rydberg states, which have the lifetime of about $T_{\mathrm{a}} = 30$ ms.[36] And we may employ the cavities like the ones used in the experiments performed by Haroche's group,[37] the photon damping time is about $T_{\mathrm{c}} = 130$ ms (corresponding to quality factor $Q = 4.2\times10^{10}$ and finesse 4.6×10^{9}), if the cavity is cooled to the temperature 0.8 K. The interaction time between each of the atoms and the cavity can be controlled by applying a velocity selector and Stark field adjustment. The detection of atoms in required states can be implemented by using the classical microwave field zones and field ionization counters. If we set $g = 2\pi\times25$ kHz,[37] we have $\tau = \pi/2\sqrt{2}g \simeq 7\ \mu$s in our scheme. Considering the travelling times of the atoms during the teleportation process,[38] we can assume the total required time to be $t = 10\times2\tau = 140\ \mu$s, which is much shorter than T_{a} and T_{c}. The infidelity induced by the atomic spontaneous emission and cavity decay is about $\Delta F = t/T_{\mathrm{a}} + t/T_{\mathrm{c}}$, thus the fidelity is about $F = 1-\Delta F = 0.9943$. The present scheme is a probabilistic one, the success of the scheme is based on the event that the two atoms carrying the teleported state are simultaneously detected in their higher states, with the success probability being $P = 1/16$.

The idea can easily be generalized for the teleportation of an arbitrary pure state of many Λ−type atoms. Assume that N atoms $\mathrm{A}_1, \mathrm{A}_2, \cdots, \mathrm{A}_N$ are initially in the arbitrary pure state as follows:

$$|\psi\rangle_{\mathrm{A}_1\mathrm{A}_2\ldots\mathrm{A}_N} = \sum_{m_1,m_2,\cdots,m_N=g,f} c_{m_1m_2\ldots m_N} \times |m_1m_2\ldots m_N\rangle_{\mathrm{A}_1\mathrm{A}_2\ldots\mathrm{A}_N}, \tag{15}$$

with

$$\sum_{m_1,m_2,\ldots,m_N=g,f} |c_{m_1m_2\ldots m_N}|^2 = 1,$$

and $|m_1m_2\ldots m_N\rangle_{\mathrm{A}_1\mathrm{A}_2\ldots\mathrm{A}_N} = |m\rangle_{\mathrm{A}_1}\otimes|m\rangle_{\mathrm{A}_2}\otimes\cdots\otimes|m_N\rangle_{\mathrm{A}_N}$. In order to teleport this state to the other N atoms $\mathrm{A}_1', \mathrm{A}_2', \ldots, \mathrm{A}_N'$, we first prepare these atoms $\mathrm{A}_1', \mathrm{A}_2', \ldots, \mathrm{A}_N'$ in their higher states $|ee\ldots e\rangle_{\mathrm{A}_1',\mathrm{A}_2',\ldots,\mathrm{A}_N'}$ and individually send them through corresponding two-mode vacuum cavities $\mathrm{C}_1, \mathrm{C}_2, \ldots, \mathrm{C}_N(\mathrm{A}_j' \to \mathrm{C}_j)$. After an interaction time $\tau = \pi/(2\sqrt{2}g)$, each subsystem combined by atom A_j and cavity C_j evolves to the state

$$|\phi\rangle_{\mathrm{A}_j'\mathrm{C}_j} = \frac{-\mathrm{i}}{\sqrt{2}}\Big(|g\rangle_{\mathrm{A}_j'}|1,0\rangle_{\mathrm{C}_j} + |f\rangle_{\mathrm{A}_j'}|0,1\rangle_{\mathrm{C}_j}\Big), \quad (j=1,2,\ldots,N). \tag{16}$$

Thus the whole system is in the state

$$|\psi\rangle_{\mathrm{A}_1\mathrm{A}_2\ldots\mathrm{A}_N}\otimes|\phi\rangle_{\mathrm{A}_1'\mathrm{C}_1}\otimes|\phi\rangle_{\mathrm{A}_2'\mathrm{C}_2}\otimes\cdots\otimes|\phi\rangle_{\mathrm{A}_N'\mathrm{C}_N}. \tag{17}$$

Then we individually send atoms $\mathrm{A}_1, \mathrm{A}_2, \ldots, \mathrm{A}_N$ through these corresponding cavities $\mathrm{C}_1, \mathrm{C}_2, \ldots, \mathrm{C}_N$ $(\mathrm{A}_j \to \mathrm{C}_j)$. After another interaction time τ, the whole system evolves into the state

$$\begin{aligned}|\Psi\rangle_{\mathrm{A}_1\mathrm{A}_2\ldots\mathrm{A}_N\mathrm{A}_1'\mathrm{A}_2'\ldots\mathrm{A}_N'\mathrm{C}_1\mathrm{C}_2\ldots\mathrm{C}_N} &= \Big(-\frac{\mathrm{i}}{2}\Big)^N[|e\rangle_{\mathrm{A}_1}|e\rangle_{\mathrm{A}_2}\ldots|e\rangle_{\mathrm{A}_N}|0,0\rangle_{\mathrm{C}_1}|0,0\rangle_{\mathrm{C}_2} \\ &\ldots|0,0\rangle_{\mathrm{C}_N}\Big(-\frac{\mathrm{i}}{2}\Big)^N\sum_{m_1,m_2,\ldots,m_N=g,f} c_{m_1m_2\cdots m_N} \\ &\times|m_1m_2\ldots m_N\rangle_{\mathrm{A}_1'\mathrm{A}_2'\ldots\mathrm{A}_N'}] + |\Psi\rangle_{\mathrm{residual}},\end{aligned} \tag{18}$$

where $|\Psi\rangle_{\mathrm{residual}}$ is used to include the terms which do not contain the component $|e\rangle_{\mathrm{A}_1}|e\rangle_{\mathrm{A}_2}\ldots|e\rangle_{\mathrm{A}_N}$. We shall not give the explicit form of $|\Psi\rangle_{\mathrm{residual}}$ as in our following step, we need to perform a measurement on the N atoms $\mathrm{A}_1, \mathrm{A}_2, \ldots, \mathrm{A}_N$ by means of atomic state ionization detection, and, only when we detect all these atoms in their higher states the teleportation succeeds.

Suppose that all these atoms are detected in their higher states, the other N atoms $\mathrm{A}_1', \mathrm{A}_2', \ldots, \mathrm{A}_N'$ are

directly collapsed onto the state

$$|\psi\rangle_{\mathrm{A}_1'\mathrm{A}_2'\ldots\mathrm{A}_N'} = \sum_{m_1,m_2,\ldots,m_N=g,f} c_{m_1m_2\cdots m_N} \times |m_1m_2\ldots m_N\rangle_{\mathrm{A}_1'\mathrm{A}_2'\ldots\mathrm{A}_N'}, \quad (19)$$

which leaves all the cavities in the two-mode vacuum states. The probability of success is $1/4^N$.

The scheme can also be used for teleportation of an arbitrary pure state composed by two-mode one-photon states ($|0,1\rangle$ and $|1,0\rangle$) of many two-mode cavities $\mathrm{C}_1,\mathrm{C}_2,\cdots,\mathrm{C}_N$ (the setup for its implementation is shown in Fig.3, which only gives the condition $N=2$). Assume that these cavities are initially in the following unknown pure state:

$$|\psi\rangle_{\mathrm{C}_1\mathrm{C}_2\ldots\mathrm{C}_N} = \sum_{m_1,m_2,\cdots,m_N=\tilde{0},\tilde{1}} c_{m_1m_2\cdots m_N} \times |m_1m_2\ldots m_N\rangle_{\mathrm{C}_1\mathrm{C}_2\ldots\mathrm{C}_N}, \quad (20)$$

where $|\tilde{1}\rangle = |1,0\rangle$, $|\tilde{0}\rangle = |0,1\rangle$, and

$$\sum_{m_1,m_2,\ldots,m_N=\tilde{0},\tilde{1}} |c_{m_1m_2\ldots m_N}|^2 = 1.$$

To implement the teleportation of such state, firstly, each of the other N cavities $\mathrm{C}_1',\mathrm{C}_2',\ldots,\mathrm{C}_N'$ receives the teleported state which should be respectively entangled with one Λ-type atom to prepare the quantum channel of the form

$$|\phi\rangle_{\mathrm{A}_j\mathrm{C}_j'} = \frac{-\mathrm{i}}{\sqrt{2}}(|g\rangle_{\mathrm{A}_j}|\tilde{1}\rangle_{\mathrm{C}_j'} + |f\rangle_{\mathrm{A}_j}|\tilde{0}\rangle_{\mathrm{C}_j'}), \quad (j=1,2,\ldots,N). \quad (21)$$

Then these atoms are individually sent through respective cavities $\mathrm{C}_1,\mathrm{C}_2,\ldots,\mathrm{C}_N$ for the same interaction time τ and then detected. Based on the event that all these atoms are detected in their higher states, the state of Eq.(20) can successfully be teleported from cavities $\mathrm{C}_1,\mathrm{C}_2,\ldots,\mathrm{C}_N$ to $\mathrm{C}_1',\mathrm{C}_2',\ldots,\mathrm{C}_N'$, with the probability of success being $1/4^N$.

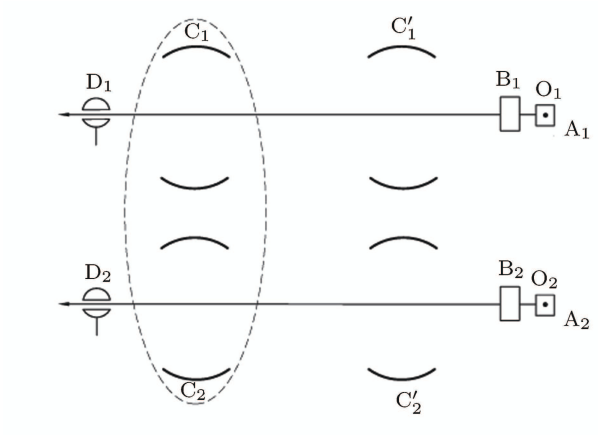


Fig.3. The diagram for teleportation of an arbitrary pure state composed by two-mode one-photon states of two bimodal cavities. $\mathrm{C}_1,\mathrm{C}_2,\mathrm{C}_1',\mathrm{C}_2'$ are four ideal millimetre-wave superconducting microwave bimodal cavities. The cavities C_1 and C_2 are initially in the unknown pure state to be teleported, the cavities C_1' and C_2' are the ones receiving the teleported state. The atoms A_1 and A_2 are produced in Zones B_j by the excitation of velocity-selected atomic beam effusing from oven O_j ($j=1,2$) respectively. D_1 and D_2 denote the state-selective field ionization detectors.

To conclude, based on the model depicting the resonant interaction of a Λ-type atom with two cavity modes, we have shown that an arbitrary pure state of two atoms can be teleported to the other two atoms without the assistance of additional atoms, the success of the scheme lies on the event that the two atoms of which the state is to be teleported are both detected in their higher states. The scheme is probabilistic but very simplified, and very different from the previous one that needs two additional atoms and the detection of four atoms.[28] The scheme can also be generalized for teleportation of arbitrary pure states of many atoms or bimodal cavities. The present scheme may find applications in testing the quantum computation protocols.[2]

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