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Continuous variables quantum switch teleportation using two-mode squeezed light

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Abstract. We propose a novel quantum switch teleportation with a continuous variable, which can teleport a quantum state to two different receivers alternatively, using a pair of two-mode squeezed lights as the quantum switching to manipulate the transmission route. In this scheme, the EPR entangled beams shared by sender and receivers are produced by mixing a pair of two-mode squeezed lights on one beamsplitter and separating them by using a polarizing beam splitter. The teleportation capability of this system is examined by the criteria proposed by Ralph and Lam [10] from a small signal quantum optical point of view.

PACS. 03.67.-a Quantum information – 42.50.Dv Nonclassical field states; squeezed, antibunched, and sub-Poissonian states; operational definitions of the phase of the field; phase measurements

1 Introduction

Quantum information technology aims to create communication and computation systems superior to those based on classical physics by utilizing the nonlocal quantum correlations of entangled states. The standard approach to quantum information processing and quantum computation is to make use of discrete quantum entanglement such as single photon entanglement generated by parametric down conversion [1]. It has significantly improved our understanding of quantum systems likely to contribute to the realization of a quantum computer and has raised many interesting possibilities such as quantum dense coding, quantum cryptography, and quantum teleportation. Alternatively, instead of single particle entanglement, many-photon states of light can be used for quantum information. These states are described by continuous variables and have distinct advantage in terms of the availability of controlled sources, efficient detection systems and easy-to-handle processing using linear elements. One of the most striking features of quantum information is that it makes possible quantum teleportation [2,3]. In a quantum teleportation scheme, the quantum state of a system can be transmitted from one location to another through the direct transmission of only classical information, provided the sender and receiver share a non-locally entangled state of the Einstein, Podolsky, Rosen (EPR) type. Since continuous variable quantum teleportation of arbitrary coherent states has been realized experimentally [4] using parametric down conversion as an EPR source [5], much attention has been paid to the study of continuous variables in information processes. Continuous variables have been shown to be useful in performing quantum dense coding [6,7], quantum cryptography [8], quantum cloning [9] and so on. Furthermore, a teleportation scheme with bright squeezed light has been proposed [10]. The use of bright beams allows one to simplify the inverse Bell-state-like measurement. Recently, interest has focused on the generation of a bright squeezed state or EPR beams [11,12]. Other quantum techniques using continuous variables of light have also been discussed in detail [13,14].

Many attempts have been made at developing a quantum information system. One of them is to teleport a quantum state from one sender to many receivers by using a multiparticle entanglement state [15], *i.e.*, a realization of a quantum network. In the experiment, the two ways to generate EPR beams were by using the nondegenerate optical parametric amplifier (NOPA) and combing a pair of bright squeezed amplitude state [11,12]. What will we obtain when we combine a pair of two-mode squeezed lights at a beamsplitter? Another route is to develop an actual quantum device. Lots of quantum devices, such as quantum rulers [16], have been proposed. The first scheme for continuous variable switch teleportation was proposed by Zhang [17], in which two EPR sources shared by Alice and Bobs are produced by mixing a pair of two-mode squeezed state lights on two beamsplitters of 50%. In this paper we consider a similar arrangement but show that two two-mode squeezed sources can produce quantum switch teleportation only with one beamsplitter directly. By converting one of the two two-mode squeezed state lights between the amplitude squeezed and phase

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squeezed or by changing the relative phase between two lights; the original input signal can be conditionally teleported at either of two output stations, alternatively. The teleportation capability of the system is examined using the criteria proposed by Ralph and Lam from a small signal quantum optical point of view [10]. The conditional teleportation system might be developed as a practical quantum switching in future quantum communication.

2 Continuous variable quantum switching teleportation

We first give a short introduction providing an intuitive picture of two-mode squeezed state and how continuous variable entanglement manifests itself. Consider two spatially separated optical modes α_j $(j = 1, 2)$. The involved optical fields can be fully described by means of field quadratures, the amplitude quadrature $\widehat{X}_j = \widehat{a}_j^\dagger + \widehat{a}_j$ and the phase quadrature $\widehat{Y} = \mathrm{i}(\widehat{a}_j^\dagger - \widehat{a}_j)$. They obey the commutation rules $[\widehat{X}_j, \widehat{Y}_j] = 2\mathrm{i}\delta_{jk}$, $(j, k = 1, 2)$ and these commutation relations limit the combined variables that commute:

$$\left[\widehat{X}_1 + \widehat{X}_2, \widehat{Y}_1 + \widehat{Y}_2\right] = 4\mathrm{i}, \tag{1}$$

and

$$\left[\widehat{X}_1 - \widehat{X}_2, \widehat{Y}_1 - \widehat{Y}_2\right] = 4\mathrm{i}, \tag{2}$$

but leave the possibility for other combined variables of both modes that commute:

$$\left[\widehat{X}_1 + \widehat{X}_2, \widehat{Y}_1 - \widehat{Y}_2\right] = 0, \tag{3}$$

or

$$\left[\widehat{X}_1 - \widehat{X}_2, \widehat{Y}_1 + \widehat{Y}_2\right] = 0. \tag{4}$$

Hence quantum states are possible for which all the variables $\widehat{X}_j$, $\widehat{Y}_j$ are uncertain, but certain joint variables of two optical modes together are both well defined. In the quantum optical context this is known as two-mode squeezing for $\widehat{X}$ or $\widehat{Y}$. The variances of quadrature amplitude and phase for the two-mode squeezed state are expressed as follows [18]:

$$V\left(\widehat{X}_1 + \widehat{X}_2\right) \to 0, \quad V\left(\widehat{Y}_1 - \widehat{Y}_2\right) \to 0, \tag{5}$$

or

$$V\left(\widehat{X}_1 - \widehat{X}_2\right) \to 0, \quad V\left(\widehat{Y}_1 + \widehat{Y}_2\right) \to 0, \tag{6}$$

which correspond to the amplitude or phase component squeezed state. $V(\widehat{A}) = \langle \widehat{A}^2 \rangle - \langle \widehat{A} \rangle^2$ is the variance of operator $\widehat{A}$. This kind of state can be generated by a NOPA or by combining two single-mode squeezed states experimentally [11,12]. Equations (5, 6) also represent a measure of quantum correlation between two spatially separated optical modes, *i.e.*, for continuous variable entanglement.

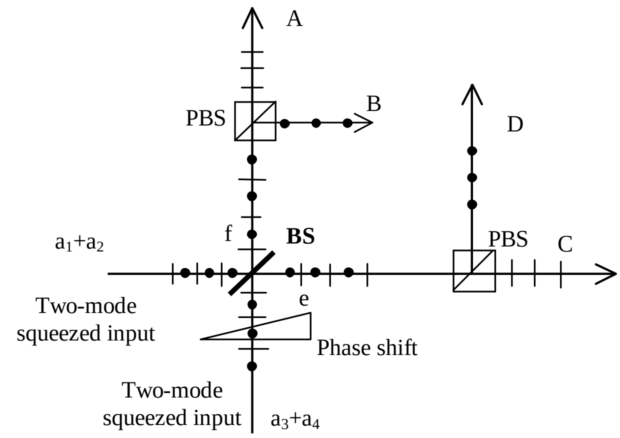

Fig. 1. Schematic of generation switching EPR beams. Dots: vertical polarization, short lines: horizontal polarization, BS: beam splitter, PBS: polarizing beam splitter.

2.1 Creating EPR switching state

It is well known that an entanglement source can be built from two single-mode squeezed lights combined at a beam-splitter [19]. The schematic diagram for the combination of a pair of two-mode squeezed lights is shown in Figure 1. A pair of two-mode squeezed beams, which are coupled by two modes with identical frequency but orthogonal polarization and denoted by $\widehat{a}_1 + \widehat{a}_2$ and $\widehat{a}_3 + \widehat{a}_4$, are combined on a beamsplitter with reflectivity r and transmissivity t, both being close to $2^{-1/2}$, and relative optical phase θ. The fields at the output ports (e, f) are then the linear superposition of the input fields:

$$\begin{pmatrix} \widehat{e} \\ \widehat{f} \end{pmatrix} = \begin{pmatrix} t & -r\mathrm{e}^{\mathrm{i}\theta} \\ r & t\mathrm{e}^{\mathrm{i}\theta} \end{pmatrix} \begin{pmatrix} \widehat{a}_1 + \widehat{a}_2 \\ \widehat{a}_3 + \widehat{a}_4 \end{pmatrix}. \tag{7}$$

Introducing the quadrature amplitudes and phases for the outgoing fields in analogy to that for the squeezed lights and performing the algebra, we arrive at

$$\begin{pmatrix} \widehat{X}_e \\ \widehat{Y}_e \\ \widehat{X}_f \\ \widehat{Y}_f \end{pmatrix} = \begin{pmatrix} t & 0 & -r\cos\theta & r\sin\theta \\ 0 & t & -r\sin\theta & -r\cos\theta \\ r & 0 & t\cos\theta & -t\sin\theta \\ 0 & r & t\sin\theta & t\cos\theta \end{pmatrix} \begin{pmatrix} \widehat{X}_1 + \widehat{X}_2 \\ \widehat{Y}_1 + \widehat{Y}_2 \\ \widehat{X}_3 + \widehat{X}_4 \\ \widehat{Y}_3 + \widehat{Y}_4 \end{pmatrix}. \tag{8}$$

We can now readily write the cross correlation between the two outgoing fields by putting $t = r = 2^{-1/2}$

$$\begin{pmatrix} V(\widehat{X}_e + \widehat{X}_f) \\ V(\widehat{X}_e - \widehat{X}_f) \\ V(\widehat{Y}_e + \widehat{Y}_f) \\ V(\widehat{Y}_e - \widehat{Y}_f) \end{pmatrix} = \begin{pmatrix} 2 & 0 & 0 & 0 \\ 0 & 0 & 2\cos^2\theta & 2\sin^2\theta \\ 0 & 2 & 0 & 0 \\ 0 & 0 & 2\sin^2\theta & 2\cos^2\theta \end{pmatrix} \begin{pmatrix} V(\widehat{X}_1 + \widehat{X}_2) \\ V(\widehat{Y}_1 + \widehat{Y}_2) \\ V(\widehat{X}_3 + \widehat{X}_4) \\ V(\widehat{Y}_3 + \widehat{Y}_4) \end{pmatrix}. \tag{9}$$

From equation (9), it can be seen that the entangled outgoing fields can be obtained by choosing the proper relative phase and squeezing component of one squeezed light

$$
\begin{aligned}
V(\widehat{X}_A+\widehat{X}_B)&=\frac{1}{2}V(\widehat{X}_1+\widehat{X}_2)+\frac{1}{2}\cos^2\theta V(\widehat{X}_3+\widehat{X}_4)+\frac{1}{2}\sin^2\theta V(\widehat{Y}_3+\widehat{Y}_4),\\
V(\widehat{X}_A-\widehat{X}_B)&=\frac{1}{2}V(\widehat{X}_1-\widehat{X}_2)+\frac{1}{2}\cos^2\theta V(\widehat{X}_3-\widehat{X}_4)+\frac{1}{2}\sin^2\theta V(\widehat{Y}_3-\widehat{Y}_4),\\
V(\widehat{X}_A+\widehat{X}_D)&=\frac{1}{2}V(\widehat{X}_1+\widehat{X}_2)+\frac{1}{2}\cos^2\theta V(\widehat{X}_3-\widehat{X}_4)+\frac{1}{2}\sin^2\theta V(\widehat{Y}_3-\widehat{Y}_4),\\
V(\widehat{X}_A-\widehat{X}_D)&=\frac{1}{2}V(\widehat{X}_1-\widehat{X}_2)+\frac{1}{2}\cos^2\theta V(\widehat{X}_3+\widehat{X}_4)+\frac{1}{2}\sin^2\theta V(\widehat{Y}_3+\widehat{Y}_4),\\
V(\widehat{Y}_A+\widehat{Y}_B)&=\frac{1}{2}V(\widehat{Y}_1+\widehat{Y}_2)+\frac{1}{2}\cos^2\theta V(\widehat{Y}_3+\widehat{Y}_4)+\frac{1}{2}\sin^2\theta V(\widehat{X}_3+\widehat{X}_4),\\
V(\widehat{Y}_A-\widehat{Y}_B)&=\frac{1}{2}V(\widehat{Y}_1-\widehat{Y}_2)+\frac{1}{2}\cos^2\theta V(\widehat{Y}_3-\widehat{Y}_4)+\frac{1}{2}\sin^2\theta V(\widehat{X}_3-\widehat{X}_4),\\
V(\widehat{Y}_A+\widehat{Y}_D)&=\frac{1}{2}V(\widehat{Y}_1+\widehat{Y}_2)+\frac{1}{2}\cos^2\theta V(\widehat{Y}_3-\widehat{Y}_4)+\frac{1}{2}\sin^2\theta V(\widehat{X}_3-\widehat{X}_4),\\
V(\widehat{Y}_A-\widehat{Y}_D)&=\frac{1}{2}V(\widehat{Y}_1-\widehat{Y}_2)+\frac{1}{2}\cos^2\theta V(\widehat{Y}_3+\widehat{Y}_4)+\frac{1}{2}\sin^2\theta V(\widehat{X}_3+\widehat{X}_4).
\end{aligned}
\tag{11}
$$

while the squeezing component of the other light is fixed. There is no advantage to this except that the outgoing mode is coupled by four modes compared with the case of combining a pair of single-mode squeezed states. Now, we turn to look at fields A, B, C, and D, which are separated from the outgoing fields by a polarizing beam splitter (PBS) based on their polarization. They can be written as

$$
\begin{pmatrix}\widehat{A}\\ \widehat{B}\\ \widehat{C}\\ \widehat{D}\end{pmatrix}=\begin{pmatrix}\sqrt{2}/2 & 0 & \sqrt{2}/2\mathrm{e}^{\mathrm{i}\theta} & 0\\ 0 & \sqrt{2}/2 & 0 & \sqrt{2}/2\mathrm{e}^{\mathrm{i}\theta}\\ \sqrt{2}/2 & 0 & -\sqrt{2}/2\mathrm{e}^{\mathrm{i}\theta} & 0\\ 0 & \sqrt{2}/2 & 0 & -\sqrt{2}/2\mathrm{e}^{\mathrm{i}\theta}\end{pmatrix}\begin{pmatrix}\widehat{a}_1\\ \widehat{a}_2\\ \widehat{a}_3\\ \widehat{a}_4\end{pmatrix}
\tag{10}
$$

and we can get the cross correlations of the quadrature component among them:

see equations (11) above.

From (11), it is obvious that choosing a suitable relative phase and component of squeezing, which can easily be done by inserting a phase shift or converting the relative phase between the pump and injected signal fields of the NOPA, results in entanglement between mode A and mode B or between mode A and mode D, alternatively. For example, mode A will be entangled with mode B if we select a relative phase of zero ($\theta = 0$) and one of two-mode squeezed lights is squeezed in the component of $\widehat{X}_1 - \widehat{X}_2$ ($\widehat{Y}_1 + \widehat{Y}_2$) and the other one is squeezed in the component of $\widehat{X}_3 - \widehat{X}_4$ ($\widehat{Y}_3 + \widehat{Y}_4$). However, mode A will be entangled with mode D by changing the squeezed component from $\widehat{X}_3 - \widehat{X}_4$ ($\widehat{Y}_3 + \widehat{Y}_4$) to $\widehat{X}_3 + \widehat{X}_4$ ($\widehat{Y}_3 - \widehat{Y}_4$). Furthermore, when we fix the squeezed component of $\widehat{X}_1 - \widehat{X}_2$ ($\widehat{Y}_1 + \widehat{Y}_2$) for one two-mode squeezed light and $\widehat{X}_3 - \widehat{X}_4$ ($\widehat{Y}_3 + \widehat{Y}_4$) for the other light, the above mentioned entanglement can be obtained by choosing a relative phase of $\theta = 0$ or $\theta = \pi/2$. More generally, other kinds of entanglements can be obtained by choosing a different relative phase between the two fields and their squeezed component. Accordingly, the difference in entanglement conditions lets the sender control the quantum information transmitted to different receivers.

2.2 Teleportation using a EPR switching state

The schematic diagram for the quantum switch teleportation is shown in Figure 2. One of the switching EPR beams is sent to where we wish to measure the input signal. There it is mixed with an input signal beam on the second 50:50 beamsplitter (BS2). The bright output beams are directly detected by the detectors. The sum and difference of the photocurrents represent the quadrature amplitude and phase noise power [6], respectively. The photocurrents are separated into two parts and sent to amplitude and phase modulators at two output stations. The amplitude and phase modulators transform the photocurrent signals into one beam of EPR sources, after which the input signal is recovered.

Teleportation is usually quantified by the fidelity of the process. Fidelity is a measurement of the overlap of the input and output states. In a general experiment, one could completely characterize individual input and output states via optical homodyne tomography and thus calculate the fidelity. However, most experimentally realizable optical states have Gaussian statistics and can therefore be fully characterized by measurements of the first- and second-order moments of orthogonal quadrature amplitudes, such as the amplitude and phase quadratures [4]. Other criteria are two-dimensional and, in analogy with quantum non-demolition measurement (QND) criteria [20], are based on the information transfer and

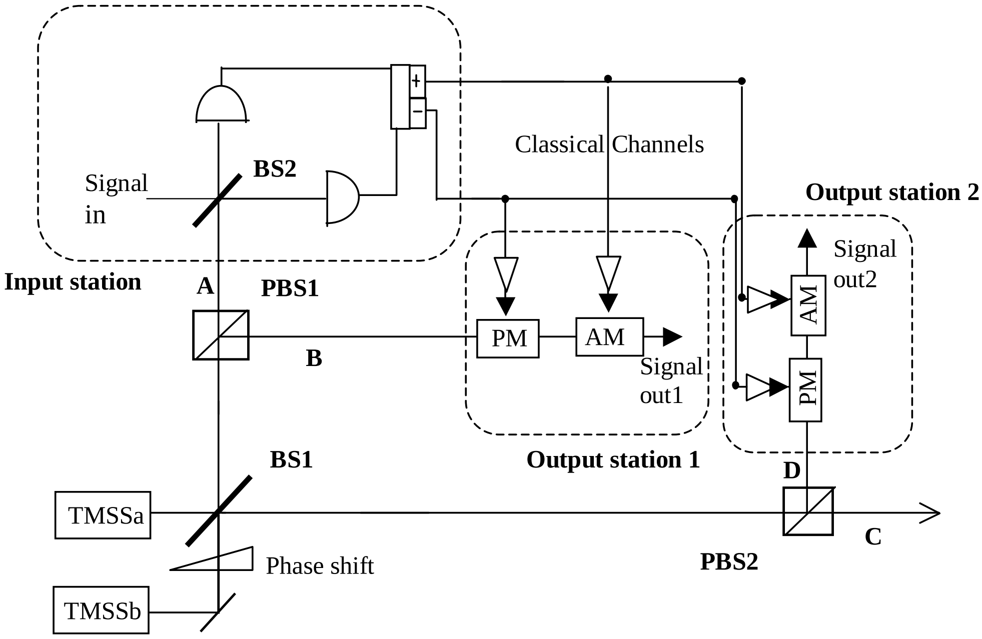

Fig. 2. Schematic of switching teleportation arrangement. TMSSa and TMSSb: two-mode squeezed state, PM: phase modulation, AM amplitude modulation, BS1 and BS2: 50:50 beam splitters, PBS: polarizing beam splitter.

quantum correlation proposed by Ralph and Lam [10]. The transfer coefficient, $T = SNR_{\rm out}/SNR_{\rm in}$, represents allowable information transfer and the conditional variances, $V_{\rm CV} = V_{\rm out} - |\langle \delta A_{\rm in} \delta A_{\rm out}\rangle|^2 / V_{\rm in}$, measure the similarity of the input and output beams. Here SNR stands for the signal-to-noise ratios of the input and output quadratures. Unlike QND, both quadratures of the teleported beam are considered. By examining the limits imposed on these quantities in any classical transmission scheme, criteria for defining quantum teleportation are derived, that is $2 \geq T_{\rm q} = T^+ + T^- > 1$ and $0 \leq V_{\rm q} = V_{\rm CV}^+ + V_{\rm CV}^- < 2$, where the superscript $+$ and $-$ denote the amplitude and phase quadratures respectively. In the following, we will examine our system using these criteria.

Suppose the signal in field $\widehat{a}_{\rm in}$ is mixed with one of the switch EPR beams on a 50:50 beam splitter (see Fig. 2). We can write the input light amplitude noise spectrum as $\mathrm{Var}(\widehat{X}_{\rm in}) = \mathrm{Var}(\widehat{X}_{\rm s}) + \mathrm{Var}(\widehat{X}_{\rm n})$ where $\mathrm{Var}(\widehat{X}_{\rm s})$ is the signal power and $\mathrm{Var}(\widehat{X}_{\rm n})$ is the quantum noise power. Similarly, the phase noise spectrum can be written $\mathrm{Var}(\widehat{Y}_{\rm in}) = \mathrm{Var}(\widehat{Y}_{\rm s}) + \mathrm{Var}(\widehat{Y}_{\rm n})$. The sum and difference of output photocurrents are [6]

$$\widehat{i}^+ = \frac{\sqrt{2}}{2}[\widehat{X}_{\rm in} - \widehat{X}_A],$$
$$\widehat{i}^- = \frac{\sqrt{2}}{2}[\widehat{Y}_{\rm in} + \widehat{Y}_A]. \qquad (12)$$

The actions of the modulators can be considered to be additive, and we will assume that they are ideal in the sender in that loss is negligible and the phase modulator produces pure phase modulation and similarly for the amplitude modulator. The two output fields are give by [10]

$$\widehat{A}_{\rm out1} = \widehat{B} + g_1^+ \widehat{i}^+ + {\rm i} g_1^- \widehat{i}^-,$$
$$\widehat{A}_{\rm out2} = \widehat{D} + g_2^+ \widehat{i}^+ + {\rm i} g_2^- \widehat{i}^-, \qquad (13)$$

where $g_i^{\pm}$ $(i = 1, 2)$ describe the gains of amplitude and phase, and their quadratures noise spectra are

$$V_{\rm out1}(\widehat{X}) = \frac{1}{2}\left|g_1^+\right|^2 V(\widehat{X}_{\rm in}) + \frac{1}{2} V^{g_1^+}\left(\widehat{X}_2 - \frac{1}{\sqrt{2}} g_1^+ \widehat{X}_1\right) + \frac{1}{2}\cos^2\theta V^{g_1^+}\left(\widehat{X}_4 - \frac{1}{\sqrt{2}} g_1^+ \widehat{X}_3\right) + \frac{1}{2}\sin^2\theta V^{g_1^+}\left(\widehat{Y}_4 - \frac{1}{\sqrt{2}} g_1^+ \widehat{Y}_3\right),$$
$$V_{\rm out1}(\widehat{Y}) = \frac{1}{2}\left|g_1^-\right|^2 V(\widehat{Y}_{\rm in}) + \frac{1}{2} V^{g_1^-}\left(\widehat{Y}_2 + \frac{1}{\sqrt{2}} g_1^- \widehat{Y}_1\right) + \frac{1}{2}\sin^2\theta V^{g_1^-}\left(\widehat{X}_4 + \frac{1}{\sqrt{2}} g_1^- \widehat{X}_3\right) + \frac{1}{2}\cos^2\theta V^{g_1^+}\left(\widehat{Y}_4 + \frac{1}{\sqrt{2}} g_1^+ \widehat{Y}_3\right),$$
$$V_{\rm out2}(\widehat{X}) = \frac{1}{2}\left|g_2^+\right|^2 V(\widehat{X}_{\rm in}) + \frac{1}{2} V^{g_2^+}\left(\widehat{X}_2 - \frac{1}{\sqrt{2}} g_2^+ \widehat{X}_1\right) + \frac{1}{2}\cos^2\theta V^{g_1^+}\left(\widehat{X}_4 + \frac{1}{\sqrt{2}} g_1^+ \widehat{X}_3\right) + \frac{1}{2}\sin^2\theta V^{g_2^+}\left(\widehat{Y}_4 + \frac{1}{\sqrt{2}} g_2^+ \widehat{Y}_3\right),$$
$$V_{\rm out2}(\widehat{Y}) = \frac{1}{2}\left|g_2^-\right|^2 V(\widehat{Y}_{\rm in}) + \frac{1}{2} V^{g_2^-}\left(\widehat{Y}_2 + \frac{1}{\sqrt{2}} g_2^- \widehat{Y}_1\right) + \frac{1}{2}\sin^2\theta V^{g_2^-}\left(\widehat{X}_4 - \frac{1}{\sqrt{2}} g_2^- \widehat{X}_3\right) + \frac{1}{2}\cos^2\theta V^{g_1^+}\left(\widehat{Y}_4 - \frac{1}{\sqrt{2}} g_1^+ \widehat{Y}_3\right), \qquad (14)$$

where $V^g(\widehat{A}_i \pm g\widehat{A}_j)$ are the adjusted correlation and are always smaller than the correlation between A_i and $A_j(V(\widehat{A}_i \pm \widehat{A}_j))$ [5]. Clearly, the output fields contain some information about the input signal but it is not the exactly the input state due to additional noise from quantum channels. However, if we choose the proper relative phase (θ) and two-mode squeezed lights, which have the correlation between the amplitude or phase quadrature, the additional noise in equation (14) can be canceled, *i.e.*, teleportation of our input field is achieved. We fix the relative phase $\theta = \pi/2$. For the case of ideal two-mode squeezed lights and measurement process $g_i^{\pm}(i = 1, 2) = \sqrt{2}$, we choose two two-mode squeezed lights in $V(\widehat{X}_2 - \widehat{X}_1) = V(\widehat{Y}_2 + \widehat{Y}_1) = 0$ and $V(\widehat{X}_4 + \widehat{X}_3) = V(\widehat{Y}_4 - \widehat{Y}_3) = 0$. Without considering the loss of the signal, the transfer coefficient can be written as the function of input and output noise, $T = \mathrm{Var}(A_{\mathrm{out}})/\mathrm{Var}(A_{\mathrm{in}})$. Then we can get the transfer coefficient and conditional variances at output station 1 and output station 2

$$\begin{aligned} &T_q^1 = 2,\ V_q^1 = 0, \\ &T_q^2 = 0,\ V_q^2 \to \infty, \end{aligned} \tag{15}$$

where the superscript denotes output station. This means that perfect teleportation is accomplished at output station 1, however no signal is received, except huge noise, at the output station 2. If we convert one of the input squeezed states from $V(\widehat{X}_4 + \widehat{X}_3) = V(\widehat{Y}_4 - \widehat{Y}_3) = 0$ to $V(\widehat{X}_4 - \widehat{X}_3) = V(\widehat{Y}_4 + \widehat{Y}_3) = 0$, the transfer coefficient and conditional variances, $T_{\mathrm{q}}^2 = 2$, $V_{\mathrm{q}}^2 = 0$ and $T_{\mathrm{q}}^1 = 0$, $V_{\mathrm{q}}^1 \to \infty$, are obtained. Obviously switching teleportation is achieved by converting the input states. Furthermore, when we fix the squeezed component of $V(\widehat{X}_2 - \widehat{X}_1) = V(\widehat{Y}_2 + \widehat{Y}_1) = 0$ and $V(\widehat{X}_4 + \widehat{X}_3) = V(\widehat{Y}_4 - \widehat{Y}_3) = 0$, the above mentioned switching teleportation can be obtained by choosing the relative phase of $\theta = \pi/2$ or $\theta = 0$.

In equation (14), it is obvious that the output noise spectra relate the correlations between two inter-modes of two-mode squeezed lights different from reference [10], in which it relates the two orthogonal quadrature components of two squeezed lights (Eq. (13) in Ref. [10]). The equation (13) in reference [10] obviously indicates that the teleportation penalty may be reduced for one quadrature by introducing two squeezed light in orthogonal quadrature simultaneously, but any improvement in the teleportation of one quadrature necessarily leads to a degradation in the teleportation of the other. To teleport an input state in two quadratures, we have to select the output variances that include the squeezed component of one light and anti-squeezed component of another light in the same quadrature. The noise, which comes from the anti-squeezed component, can be completely canceled by correct choice of the electronic gain. This is the reason for the opposite and carefully chosen gain for the amplitude modulation and the phase modulation in the scheme of reference [10]. However for our system, the correlations between inter-modes of two-mode squeezed light act to cancel the noise, so it is possible to use the correlation and anticorrelation to completely cancel the noise in the same quadrature. In this case, the teleportation condition is less dependent on the sign and value of the gain and this will give more freedom in the experiment. In practice of course, the best teleportation occurs when the smallest noise adding into the system, this means the gain should be selected for best correlation between $X_i(Y_i)$ and scaled quantities $(1/\sqrt{2})gX_j((1/\sqrt{2})gY_j)$, which has been well studied in references [5,21]. Simply put, the signal can always be teleported to the output station when the squeezing is greater than 50% and the gain is below $\sqrt{2}$.

For the experiments, the most important work, generation of two-mode squeezed light, has been completed [11]. Furthermore, noiseless signal amplification using positive electro-optic feed forward for one quadrature has been demonstrated experimentally [21]. The maturation of the technique makes it valuable for performing experiments.

3 Conclusion

In summary, we have shown that a switching EPR-type correlation source can be established using a pair of two-mode squeezed lights on one beamsplitter. This kind of source can be utilized to design switching teleportation in quantum information. The control condition is only to change the squeezed component of one of two two-mode squeezed lights from its amplitude quadrature to its phase quadrature or to change the relative phase between the two lights. The teleportation capability of the switch was examined using the criteria proposed by Ralph and Lam from a small signal quantum optical point of view. This conditional teleportation system might be developed as a practical quantum switch in future quantum communication systems. Furthermore, our scheme will give more freedom for experimentation than the scheme proposed by Ralph and Lam.

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