Delphi 3

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Abstract

An optical communication system is proposed. The system should provide a unique operational capability that allows information to be sent from the future back to the present.

1. Introduction

This system relies on the results of the "before-before" experiment [1,2,3]. The system uses cascaded spontaneous parametric down-conversion (C-SPDC) similar to that described in [4]. Also, the system employs nonlocal interference like that described in [5].

A representation of the system is shown in Figure 1. The system is composed of a Source (Src), a Transmitter (Tx), and a Receiver (Rx).

The optical path length from the Source to the Receiver is very short. The optical path length from the Source to the Transmitter may be very long. The Source, Transmitter, and Receiver are all assumed to be stationary.

To simplify the description of this system, the effects of optical filters, detector quantum efficiency and dark counts, and most other potential losses are not included in the following discussion.

2. Notation

In the following discussion, both probability amplitude and probability will be calculated. As an example:

$$P[D2;D3,(\Delta)] = \left| pa[D2;D3,(\Delta)] \right|^2$$

In the above, $pa[D2;D3,(\Delta)]$ is the probability amplitude for the detection of an idler photon in detector D2 in the Receiver, followed by the detection of a signal photon in detector D3 in the Transmitter. The time parameter (Δ) is the time between the detection in D2 and the detection in D3.

$P[D2;D3,(\Delta)]$ is the probability for the same detection events.

As another example:

$$P[D1;D4,(\Delta_1);D5,(\Delta_2)] = \left| pa[D1;D4,(\Delta_1);D5,(\Delta_2)] \right|^2$$

In the above, $pa[D1;D4,(\Delta_1);D5,(\Delta_2)]$ is the probability amplitude for the detection of an idler photon in detector D1 in the Receiver, followed by the detection of one associated photon in detector D4 in the Transmitter, and the detection of a second associated photon in detector D5 also in the Transmitter. The time parameter (Δ_1) is the time between the detection in D1 and the detection in D4. The time parameter (Δ_2) is the time between the detection in D1 and the detection in D5.

$P[D1;D4,(\Delta_1);D5,(\Delta_2)]$ is the probability for the same detection events.

The variable designation "pa" is used, rather than "Ψ", to emphasize that the probability amplitude is a mathematical function (only).

Both intensity and amplitude variables are used in the following. As an example, for amplitude beam splitter ABS1:

$$R_1 = \left| r_1 \right|^2 \ , \ T_1 = \left| t_1 \right|^2 \ \text{ and } \ R_1 + T_1 = 1$$

In the above, R_1 is the intensity reflectance, T_1 is the intensity transmittance, r_1 is the amplitude reflection coefficient, and t_1 is the amplitude transmission coefficient of ABS1.

3a. Source

The Source (Src) contains a single-mode, continuous wave (cw) pump laser (LSR), a periodically-poled lithium niobate crystal (PPLN1), a dichroic mirror (DM1), a polarizing beam splitter (PBS1), and a beam stop (Stp).

Laser LSR has a stable output, and the coherence length of the pump photons from LSR is greater than 100 meters.

The PPLN1 crystal is temperature-controlled, and is set to allow collinear, non-degenerate, type II spontaneous parametric down-conversion (SPDC) in which a photon from pump laser LSR is annihilated and a signal and idler pair of photons is created. The signal photon is horizontally (H) polarized, and the idler photon is vertically (V) polarized.

The wavelength of an idler photon is twice that of a signal photon. The wavelength of a signal photon is longer than the wavelength of a pump photon from laser LSR.

Short wavelength pump photons from laser LSR that are not down-converted in PPLN1 are reflected at long pass dichroic mirror DM1 and are incident on beam stop Stp.

Polarizing beam splitter PBS1 is set to transmit incident H polarized photons and to reflect incident V polarized photons.

The longer wavelength signal and idler photons exit from PPLN1 and are transmitted through DM1 to PBS1. The H polarized signal photons are transmitted through PBS1 and travel to the Transmitter (Tx). The V polarized idler photons are reflected at PBS1 and travel to the Receiver (Rx).

3b. Receiver

The Receiver (Rx) contains two amplitude beam splitters (ABS1 and ABS2), two mirrors (m), and two detectors (D1 and D2). The fast detectors are capable of photon counting.

Amplitude beam splitters ABS1 and ABS2 may be partially-silvered plate beam splitters. ABS2 is a "50/50" amplitude beam splitter. The characteristics of the amplitude beam splitters are:

$$R_1 = \left|r_1\right|^2 \; ; \; T_1 = \left|t_1\right|^2$$
$$R_2 = \left|r_2\right|^2 = 0.5 \; ; \; T_2 = \left|t_2\right|^2 = 0.5$$

The two amplitude beam splitters and two mirrors are arranged to form an unbalanced Mach-Zehnder interferometer (MZ). The unbalanced MZ provides a short path and a long path between ABS1 and ABS2 for the idler photons.

Output A from the MZ goes to detector D1. Output B goes to detector D2.

The path lengths through the MZ are adjusted so that the net phase difference from input to output for a given path depends on the reflections at the mirrors and the reflections (or transmissions) at the beam splitters [6].

The time difference between the time an idler photon may be incident on detector D1 (D2) via the short path, and the time the photon may be incident on detector D1 (D2) via the long path through the MZ is equal to X.

The fixed time X should be of sufficient duration to allow the short path and the long path to be temporally distinct. Time X should be much longer than the coherence time of an idler photon but should also be much shorter than the coherence time of a pump photon from laser LSR in the Source.

3c. Transmitter

The Transmitter (Tx) contains a Pockels cell (PC), a periodically-poled lithium niobate crystal (PPLN2), two dichroic mirrors (DM2 and DM3), two polarizing beam splitters (PBS2 and PBS3), one

amplitude beam splitter (ABS3), two mirrors (m), and four detectors (D3-D6).

Polarizing beam splitters PBS2 and PBS3 are set to transmit incident H polarized photons and to reflect incident V polarized photons. The fast detectors are capable of photon counting.

The PPLN2 crystal is temperature-controlled, and is set to allow collinear, degenerate, type II SPDC that creates a pair of orthogonally-polarized, secondary down-converted (sdc) photons [4].

The Pockels cell (PC) may be used to rotate the polarization direction of a signal photon. If the PC is turned off, an H polarized signal photon will remain H polarized when it exits from the PC. If the PC is turned on, an H polarized signal photon will be V polarized when it exits from the PC.

Amplitude beam splitter ABS3 may be a partially-silvered plate beam splitter. The characteristics of amplitude beam splitter ABS3 are:

$$R_3 = \left| r_3 \right|^2 \; ; \; T_3 = \left| t_3 \right|^2$$

Signal photons from the Source travel to PPLN2. Most of the signal photons pass through PPLN2, are reflected by long pass dichroic mirror DM3, and are incident on detector D6.

On average, one of every 10^6 of the signal photons is annihilated within PPLN2 in a C-SPDC event that creates a pair of "associated" sdc photons [4]. The sdc photons are associated with the idler photon of the original down-converted pair from PPLN1 in the Source, because they are time-linked to this idler photon through the SPDC annihilation of its signal photon partner (due to conservation of energy).

One of the sdc photons is H polarized, and the other is V polarized. The wavelength of an sdc photon is equal to the wavelength of an idler photon from PPLN1 in the Source.

Long pass dichroic mirror DM3 transmits the longer wavelength sdc photons which then travel to ABS3. Some of the sdc photons immediately pass through ABS3 and travel to PBS3. Other sdc photons reflect from ABS3 and enter a feedback path. The feedback path is from reflection at ABS3, reflection at two mirrors, reflection from short pass dichroic mirror DM2, back through PPLN2 and DM3, and return to ABS3.

The path lengths through the feedback path are adjusted so that the net phase difference from input to output for an sdc photon depends on the reflections at the mirrors and the reflections (or transmissions) at the dichroic mirrors and the beam splitter [6].

The time required for an sdc photon to make one cycle around through the feedback path is equal to X. Note that time X is the

same as the time difference between the long and short paths through the MZ in the Receiver.

Note: To facilitate the following descriptions, it is assumed that there are an integer number of wavelengths between the Source and the Receiver, and also an integer number of wavelengths between the Source and the Transmitter.

4a. Binary Zero

To send a binary zero from the Transmitter to the Receiver, Pockels cell PC in the Transmitter is turned off at the time a signal photon reaches the PC.

The V polarized idler photon of a down-converted pair travels from the Source to the MZ in the Receiver. The idler photon then travels via either the short path or the long path through the MZ to either detector D1 or D2.

The H polarized signal photon of the down-converted pair leaves the Source and travels to the Transmitter. The signal photon passes through the PC unchanged, passes through PBS2, and is incident on detector D3 in the Transmitter. In the binary zero case, signal photons do not reach PPLN2 in the Transmitter.

If the idler photon of a down-converted pair travels from the Source and passes through the short path in the MZ and is detected in either detector D1 or D2 in the Receiver, and the signal photon of the pair travels to the Transmitter and is detected in detector D3, then the time between the detection of the idler photon in the Receiver and the signal photon in the Transmitter is equal to τ. Note that $\tau \gg X$.

If the time difference between the detection of an idler photon in the Receiver in detector D1, and the detection of the associated signal photon in the Transmitter in detector D3 is equal to τ, then there is no ambiguity as to which paths the photons travelled.

The idler photon travelled via the short path through the MZ to detector D1 in the Receiver, and the signal photon travelled directly to detector D3 in the Transmitter. The probability amplitude and probability for this are:

$$pa_0[D1;D3,(\tau)] = [it_1t_2][1]$$

$$P_0[D1;D3,(\tau)] = \left| pa_0[D1;D3,(\tau)] \right|^2 = T_1T_2 = T_1/2$$

If the time difference between the detection of an idler photon in the Receiver in detector D1, and the detection of the associated signal photon in the Transmitter in detector D3 is equal to $(\tau-$

X), then there is also no ambiguity as to which paths the photons travelled.

The idler photon travelled via the long path through the MZ to detector D1 in the Receiver, and the signal photon travelled directly to detector D3 in the Transmitter. The probability amplitude and probability for this are:

$pa_0[D1;D3,(\tau-X)] = [ir_1r_2][1]$

$P_0[D1;D3,(\tau-X)] = R_1R_2 = R_1/2$

If the time difference between the detection of an idler photon in the Receiver in detector D2, and the detection of the associated signal photon in the Transmitter in detector D3 is equal to τ, then there is no ambiguity as to which paths the photons travelled.

The idler photon travelled via the short path through the MZ to detector D2 in the Receiver, and the signal photon travelled directly to detector D3 in the Transmitter. The probability amplitude and probability for this are:

$pa_0[D2;D3,(\tau)] = [-t_1r_2][1]$

$P_0[D2;D3,(\tau)] = |pa_0[D2;D3,(\tau)]|^2 = T_1R_2 = T_1/2$

If the time difference between the detection of an idler photon in the Receiver in detector D2, and the detection of the associated signal photon in the Transmitter in detector D3 is equal to $(\tau-X)$, then, again, there is no ambiguity as to which paths the photons travelled.

The idler photon travelled via the long path through the MZ to detector D2 in the Receiver, and the signal photon travelled directly to detector D3 in the Transmitter. The probability amplitude and probability for this are:

$pa_0[D2;D3,(\tau-X)] = [r_1t_2][1]$

$P_0[D2;D3,\tau-X)] = R_1T_2 = R_1/2$

In the binary zero case, the probabilities for the detection of idler photons in detectors D1 and D2 in the Receiver are:

$P_0[D1] = (T_1/2) + (R_1/2) = 0.50$

$P_0[D2] = (T_1/2) + (R_1/2) = 0.50$

4b. Binary One

To send a binary one from the Transmitter to the Receiver, Pockels cell PC in the Transmitter is turned on at the time a signal photon reaches the PC.

The V polarized idler photon of a down-converted pair travels from the Source to the MZ in the Receiver. The idler photon then travels via either the short path or the long path through the MZ to either detector D1 or D2.

The H polarized signal photon of the down-converted pair leaves the Source and travels to the Transmitter. The signal photon has its polarization direction rotated to V polarized as it passes through the PC, reflects at PBS2, passes through short pass dichroic mirror DM2, and travels to PPLN2. In the binary one case, signal photons reach PPLN2 in the Transmitter.

Most of the signal photons pass through PPLN2, are reflected by long pass dichroic mirror DM3, and are incident on detector D6.

Some of the signal photons are annihilated within PPLN2 in a SPDC event that creates a pair of sdc photons. One of the sdc photons is H polarized, and the other is V polarized.

The sdc photons pass through DM3 and are incident on ABS3. Some of the sdc photons immediately pass through ABS3 and travel to PBS3. Other sdc photons reflect at ABS3. These sdc photons then make one or more cycles around through the feedback path in the Transmitter before finally passing through ABS3 and travelling to PBS3.

If the idler photon of a down-converted pair travels from the Source and passes through the short path in the MZ and is detected in either detector D1 or D2 in the Receiver, and the signal photon of the pair travels to the Transmitter and is annihilated in PPLN2 in a down-conversion event and a resultant sdc photon immediately passes through ABS3 without entering the feedback path and is then detected in detector D4 or D5, then the time between the detection of the idler photon in the Receiver and the sdc photon in the Transmitter is equal to ∂. Note that ∂ is slightly greater than τ.

If the time difference between the detection of an idler photon in the Receiver in detector D2, and the detection of both of the associated sdc photons in the Transmitter in detectors D4 and D5 was equal to ∂, then there would be an ambiguity as to which paths the photons travelled.

The idler photon may have travelled via the short path through the MZ to detector D2 in the Receiver, and the sdc photons may have both immediately passed through ABS3 without entering the feedback path and then travelled to and were detected in detectors D4 and D5 in the Transmitter.

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Alternately, the idler photon may have travelled via the long path through the MZ to detector D2 in the Receiver, and the associated sdc photons may have both reflected at ABS3 and travelled one cycle around through the feedback path, then passed through ABS3 and travelled to and were detected in detectors D4 and D5 in the Transmitter.

Because of this ambiguity, nonlocal, two-photon interference occurs and the probability amplitudes for the two possibilities must be added together [5]:

$$pa_1[D2;D4,(\partial);D5,(\partial)] = [-t_1r_2][it_3][it_3] + [r_1t_2][it_3r_3][it_3r_3]$$

With $t_1 = r_1r_3{}^2$:

$$pa_1[D2;D4,(\partial);D5,(\partial)] = 0$$

$$P_1[D2;D4,(\partial);D5,(\partial)] = \left| pa_1[D2;D4,(\partial);D5,(\partial)] \right|^2 = 0$$

If the time difference between the detection of an idler photon in the Receiver in detector D2, and the detection of both of the associated sdc photons in the Transmitter in detectors D4 and D5 was equal to $(\partial+X)$, then there would also be an ambiguity as to which paths the photons travelled.

The idler photon may have travelled via the short path through the MZ to detector D2 in the Receiver, and the sdc photons may have both reflected at ABS3 and travelled one cycle around through the feedback path, then passed through ABS3 and travelled to and were detected in detectors D4 and D5 in the Transmitter.

Alternately, the idler photon may have travelled via the long path through the MZ to detector D2 in the Receiver, and the associated sdc photons may have both reflected at ABS3 and travelled two cycles around through the feedback path, then passed through ABS3 and travelled to and were detected in detectors D4 and D5 in the Transmitter.

Because of this ambiguity, nonlocal, two-photon interference occurs and the probability amplitudes for the two possibilities must be added together [5]:

$$pa_1[D2;D4,(\partial+X);D5,(\partial+X)] = [-t_1r_2][(it_3r_3)^2] + [r_1t_2][(it_3r_3{}^2)^2]$$

$$pa_1[D2;D4,(\partial+X);D5,(\partial+X)] = pa_1[D2;D4,(\partial);D5,(\partial)] \bullet r_3{}^2 = 0$$

$$P_1[D2;D4,(\partial+X);D5,(\partial+X)] = 0$$

In general, there is an ambiguity, so nonlocal, two-photon interference occurs producing:

$P_1[D2;D4,(\partial+NX);D5,(\partial+NX)] = 0$

For integer $N \geq 0$

    If the time difference between the detection of an idler photon in the Receiver in detector D2, and the detection of the H polarized sdc photon in detector D4 in the Transmitter is equal to ∂, and the detection of the V polarized sdc photon in detector D5 is equal to $(\partial+X)$, then there would be an ambiguity as to which paths the photons travelled.

    The idler photon may have travelled via the short path through the MZ to detector D2 in the Receiver, and the H polarized sdc photon may have immediately passed through ABS3 without entering the feedback path and was then detected in detector D4, and the V polarized sdc photon reflected at ABS3 and travelled one cycle around through the feedback path, then passed through ABS3 and travelled to and was detected in detector D5 in the Transmitter.

    Alternately, the idler photon may have travelled via the long path through the MZ to detector D2 in the Receiver, and the associated H polarized sdc photon may have reflected at ABS3 and travelled one cycle around through the feedback path, then passed through ABS3 and travelled to and was detected in detector D4, and the associated V polarized sdc photon may have reflected at ABS3 and travelled two cycles around through the feedback path, then passed through ABS3 and travelled to and was detected in detector D5 in the Transmitter.

    Because of this ambiguity, nonlocal, two-photon interference occurs and the probability amplitudes for the two possibilities must be added together [5]:

$pa_1[D2;D4,(\partial);D5,(\partial+X)] = [-t_1r_2][it_3][it_3r_3] + [r_1t_2][it_3r_3][it_3r_3{}^2]$

$pa_1[D2;D4,(\partial);D5,(\partial+X)] = pa_1[D2;D4,(\partial);D5,(\partial)] \cdot r_3 = 0$

$P_1[D2;D4,(\partial);D5,(\partial+X)] = 0$

    In general, there is an ambiguity, so nonlocal, two-photon interference occurs producing:

$pa_1[D2;D4,(\partial+NX);D5,(\partial+MX)] = pa_1[D2;D4,(\partial);D5,(\partial)] \cdot r_3{}^{(N+M)}$

With $t_1 = r_1r_3{}^2$:

$pa_1[D2;D4,(\partial+NX);D5,(\partial+MX)] = 0$

$P_1[D2;D4,(\partial+NX);D5,(\partial+MX)] = \left|pa_1[D2;D4,(\partial+NX);D5,(\partial+MX)]\right|^2 = 0$

For integer N ≥ 0, integer M ≥ 0, N not necessarily equal to M

    If the time difference between the detection of an idler photon in the Receiver in detector D2, and the detection of both of the associated sdc photons in the Transmitter in detectors D4 and D5 is equal to $(\partial-X)$, then there is no ambiguity as to which paths the photons travelled.

    The idler photon travelled via the long path through the MZ to detector D2 in the Receiver, and the sdc photons both immediately passed through ABS3 without entering the feedback path and then travelled to and were detected in detectors D4 and D5 in the Transmitter. The probability amplitude and probability for this are:

$pa_1[D2;D4,(\partial-X);D5,(\partial-X)] = [r_1t_2][it_3][it_3] = -r_1t_3{}^2/(\sqrt{2})$

$P_1[D2;D4,(\partial-X);D5,(\partial-X)] = \left| pa_1[D2;D4,(\partial-X);D5,(\partial-X)] \right|^2 = R_1T_3{}^2/2$

    In order for the probability amplitude to be non-zero, the time between the detection of the idler photon in the Receiver and the detection of at least one of the associated sdc photons in the Transmitter must be equal to $(\partial-X)$.

    If the time difference between the detection of an idler photon in the Receiver in detector D2, and the detection of the associated H polarized sdc photon in the Transmitter in detector D4 is equal to $(\partial-X)$, and the detection of the associated V polarized sdc photon in detector D5 is equal to ∂, then there is no ambiguity as to which paths the photons travelled.

    The idler photon travelled via the long path through the MZ to detector D2 in the Receiver, and the associated H polarized sdc photon immediately passed through ABS3 without entering the feedback path and then travelled to and was detected in detector D4 in the Transmitter, and the associated V polarized sdc photon reflected from ABS3, travelled one cycle around through the feedback path, then passed through ABS3, and travelled to and was detected in detector D5. The probability amplitude and probability for this are:

$pa_1[D2;D4,(\partial-X);D5,(\partial)] = [r_1t_2][it_3][it_3r_3] = -r_1t_3{}^2r_3/(\sqrt{2})$

$P_1[D2;D4,(\partial-X);D5,(\partial)] = R_1T_3{}^2R_3/2$

    In general, in this $(\partial-X)$ case, there is no ambiguity:

$pa_1[D2;D4,(\partial-X);D5,(\partial+MX)] = pa_1[D2;D4,(\partial-X);D5,(\partial)] \cdot r_3{}^M$

$P_1[D2;D4,(\partial-X);D5,(\partial+MX)] = R_1T_3{}^2(R_3{}^{(M+1)})/2$

For integer $M \geq 0$

    If the time difference between the detection of an idler photon in the Receiver in detector D2, and the detection of the associated V polarized sdc photon in the Transmitter in detector D5 is equal to $(\partial-X)$, and the detection of the associated H polarized sdc photon in detector D4 is equal to ∂, then there is no ambiguity as to which paths the photons travelled.

    The idler photon travelled via the long path through the MZ to detector D2 in the Receiver, and the V polarized sdc photon immediately passed through ABS3 without entering the feedback path and then travelled to and was detected in detector D5 in the Transmitter, and the H polarized sdc photon reflected from ABS3, travelled one cycle around through the feedback path, then passed through ABS3, and travelled to and was detected in detector D4. The probability amplitude and probability for this are:

$pa_1[D2;D4,(\partial);D5,(\partial-X)] = [r_1t_2][it_3r_3][it_3] = -r_1t_3{}^2r_3/(\sqrt{}(2))$

$P_1[D2;D4,(\partial);D5,(\partial-X)] = R_1T_3{}^2R_3/2$

    In general, in this $(\partial-X)$ case, there is no ambiguity:

$pa_1[D2;D4,(\partial+NX);D5,(\partial-X)] = pa_1[D2;D4,(\partial);D5,(\partial-X)] \cdot r_3{}^N$

$P_1[D2;D4,(\partial+NX);D5,(\partial-X)] = R_1T_3{}^2(R_3{}^{(N+1)})/2$

For integer $N \geq 0$

    The probability for the detection of an idler photon in detector D2 in the Receiver is:

$P_1[D2] = [R_1T_3{}^2/2] + [R_1T_3{}^2R_3/(2(1 - R_3))] + [R_1T_3{}^2R_3/(2(1 - R_3))]$

$= [R_1T_3{}^2/2] + [R_1T_3R_3]$

    If the time difference between the detection of an idler photon in the Receiver in detector D1, and the detection of both of the associated sdc photons in the Transmitter in detectors D4 and D5 is equal to ∂, then there is an ambiguity as to which paths the photons travelled.

    The idler photon may have travelled via the short path through the MZ to detector D1 in the Receiver, and the sdc photons may have both immediately passed through ABS3 without entering the

feedback path and then travelled to and were detected in detectors D4 and D5 in the Transmitter.

Alternately, the idler photon may have travelled via the long path through the MZ to detector D1 in the Receiver, and the associated sdc photons may have both reflected at ABS3 and travelled one cycle around through the feedback path, then passed through ABS3 and travelled to and were detected in detectors D4 and D5 in the Transmitter.

Because of this ambiguity, nonlocal, two-photon interference occurs and the probability amplitudes for the two possibilities must be added together [5]:

$pa_1[D1;D4,(\partial);D5,(\partial)] = [it_1t_2][it_3][it_3] + [ir_1r_2][it_3r_3][it_3r_3]$

With $t_1 = r_1r_3{}^2$:

$pa_1[D1;D4,(\partial);D5,(\partial)] = -i(\sqrt{(2)})r_1t_3{}^2r_3{}^2$

$P_1[D1;D4,(\partial);D5,(\partial)] = \left|pa_1[D1;D4,(\partial);D5,(\partial)]\right|^2 = 2R_1T_3{}^2R_3{}^2$

If the time difference between the detection of an idler photon in the Receiver in detector D1, and the detection of both of the associated sdc photons in the Transmitter in detectors D4 and D5 is equal to $(\partial+X)$, then there is an ambiguity as to which paths the photons travelled.

The idler photon may have travelled via the short path through the MZ to detector D1 in the Receiver, and the sdc photons may have both reflected at ABS3 and travelled one cycle around through the feedback path, then passed through ABS3 and travelled to and were detected in detectors D4 and D5 in the Transmitter.

Alternately, the idler photon may have travelled via the long path through the MZ to detector D1 in the Receiver, and the associated sdc photons may have both reflected at ABS3 and travelled two cycles around through the feedback path, then passed through ABS3 and travelled to and were detected in detectors D4 and D5 in the Transmitter.

Because of this ambiguity, nonlocal, two-photon interference occurs and the probability amplitudes for the two possibilities must be added together [5]:

$pa_1[D1;D4,(\partial+X);D5,(\partial+X)] = [it_1t_2][(it_3r_3)^2] + [ir_1r_2][(it_3r_3{}^2)^2]$

$pa_1[D1;D4,(\partial+X);D5,(\partial+X)] = pa_1[D1;D4,(\partial);D5,(\partial)] \cdot r_3{}^2$

$$= -i(\sqrt{(2)})r_1t_3{}^2r_3{}^4$$

$P_1[D1;D4,(\partial+X);D5,(\partial+X)] = 2R_1T_3{}^2R_3{}^4$

In general, there is an ambiguity, so nonlocal, two-photon interference occurs producing:

$$P_1[D1;D4,(\partial+NX);D5,(\partial+NX)] = 2R_1T_3{}^2(R_3{}^{(2N+2)})$$

For integer $N \geq 0$

If the time difference between the detection of an idler photon in the Receiver in detector D1, and the detection of the H polarized sdc photon in detector D4 in the Transmitter is equal to ∂, and the detection of the V polarized sdc photon in detector D5 is equal to $(\partial+X)$, then there is also an ambiguity as to which paths the photons travelled.

The idler photon may have travelled via the short path through the MZ to detector D1 in the Receiver, and the H polarized sdc photon may have immediately passed through ABS3 without entering the feedback path and was then detected in detector D4, and the V polarized sdc photon reflected at ABS3 and travelled one cycle around through the feedback path, then passed through ABS3 and travelled to and was detected in detector D5 in the Transmitter.

Alternately, the idler photon may have travelled via the long path through the MZ to detector D1 in the Receiver, and the associated H polarized sdc photon may have reflected at ABS3 and travelled one cycle around through the feedback path, then passed through ABS3 and travelled to and was detected in detector D4, and the associated V polarized sdc photon may have reflected at ABS3 and travelled two cycles around through the feedback path, then passed through ABS3 and travelled to and was detected in detector D5 in the Transmitter.

Because of this ambiguity, nonlocal, two-photon interference occurs and the probability amplitudes for the two possibilities must be added together [5]:

$$pa_1[D1;D4,(\partial);D5,(\partial+X)] = [it_1t_2][it_3][it_3r_3] + [ir_1r_2][it_3r_3][it_3r_3{}^2]$$

$$pa_1[D1;D4,(\partial);D5,(\partial+X)] = pa_1[D1;D4,(\partial);D5,(\partial)] \bullet r_3$$

$$= -i(\sqrt{(2)})r_1t_3{}^2r_3{}^3$$

$$P_1[D1;D4,(\partial);D5,(\partial+X)] = 2R_1T_3{}^2R_3{}^3$$

In general, there is an ambiguity, so nonlocal, two-photon interference occurs producing:

$$pa_1[D1;D4,(\partial+NX);D5,(\partial+MX)] = pa_1[D1;D4,(\partial);D5,(\partial)] \bullet r_3{}^{(N+M)}$$

With $t_1 = r_1r_3{}^2$:

$$pa_1[D1;D4,(\partial+NX);D5,(\partial+MX)] = -i(\sqrt{2})r_1t_3{}^2(r_3{}^{(N+M+2)})$$

$$P_1[D1;D4,(\partial+NX);D5,(\partial+MX)] = \left|pa_1[D1;D4,(\partial+NX);D5,(\partial+MX)]\right|^2$$

$$= 2R_1T_3{}^2R_3{}^{(N+M+2)}$$

For integer $N \geq 0$, integer $M \geq 0$, N not necessarily equal to M

If the time difference between the detection of an idler photon in the Receiver in detector D1, and the detection of both of the associated sdc photons in the Transmitter in detectors D4 and D5 is equal to $(\partial-X)$, then there is no ambiguity as to which paths the photons travelled.

The idler photon travelled via the long path through the MZ to detector D1 in the Receiver, and the sdc photons both immediately passed through ABS3 without entering the feedback path and then travelled to and were detected in detectors D4 and D5 in the Transmitter. The probability amplitude and probability for this are:

$$pa_1[D1;D4,(\partial-X);D5,(\partial-X)] = [ir_1r_2][it_3][it_3] = -ir_1t_3{}^2/(\sqrt{2})$$

$$P_1[D1;D4,(\partial-X);D5,(\partial-X)] = \left|pa_1[D1;D4,(\partial-X);D5,(\partial-X)]\right|^2 = R_1T_3{}^2/2$$

If the time difference between the detection of an idler photon in the Receiver in detector D1, and the detection of the associated H polarized sdc photon in the Transmitter in detector D4 is equal to $(\partial-X)$, and the detection of the associated V polarized sdc photon in detector D5 is equal to ∂, then there is no ambiguity as to which paths the photons travelled.

The idler photon travelled via the long path through the MZ to detector D1 in the Receiver, and the H polarized sdc photon immediately passed through ABS3 without entering the feedback path and then travelled to and was detected in detector D4 in the Transmitter, and the associated V polarized sdc photon reflected from ABS3, travelled one cycle around through the feedback path, then passed through ABS3, and travelled to and was detected in detector D5. The probability amplitude and probability for this are:

$$pa_1[D1;D4,(\partial-X);D5,(\partial)] = [ir_1r_2][it_3][it_3r_3] = -ir_1t_3{}^2r_3/(\sqrt{2})$$

$$P_1[D1;D4,(\partial-X);D5,(\partial)] = R_1T_3{}^2R_3/2$$

In general, in this $(\partial-X)$ case, there is no ambiguity:

$pa_1[D1;D4,(\partial-X);D5,(\partial+MX)] = pa_1[D1;D4,(\partial-X);D5,(\partial)] \cdot r_3^M$

$P_1[D1;D4,(\partial-X);D5,(\partial+MX)] = R_1T_3^2(R_3^{(M+1)})/2$

For integer $M \geq 0$

    If the time difference between the detection of an idler photon in the Receiver in detector D1, and the detection of the associated V polarized sdc photon in the Transmitter in detector D5 is equal to $(\partial-X)$, and the detection of the associated H polarized sdc photon in detector D4 is equal to ∂, then there is no ambiguity as to which paths the photons travelled.
    The idler photon travelled via the long path through the MZ to detector D1 in the Receiver, and the V polarized sdc photon immediately passed through ABS3 without entering the feedback path and then travelled to and was detected in detector D5 in the Transmitter, and the associated H polarized sdc photon reflected from ABS3, travelled one cycle around through the feedback path, then passed through ABS3, and travelled to and was detected in detector D4. The probability amplitude and probability for this are:

$pa_1[D1;D4,(\partial);D5,(\partial-X)] = [ir_1r_2][it_3r_3][it_3] = -ir_1t_3^2r_3/(\sqrt{2})$

$P_1[D1;D4,(\partial);D5,(\partial-X)] = R_1T_3^2R_3/2$

    In general, in this $(\partial-X)$ case, there is no ambiguity:

$pa_1[D1;D4,(\partial+NX);D5,(\partial-X)] = pa_1[D1;D4,(\partial);D5,(\partial-X)] \cdot r_3^N$

$P_1[D1;D4,(\partial+NX);D5,(\partial-X)] = R_1T_3^2(R_3^{(N+1)})/2$

For integer $N \geq 0$

    The probability for the detection of an idler photon in detector D1 in the Receiver is:

$P_1[D1] = [2R_1T_3^2R_3^2/((1 - R_3)^2)] + [R_1T_3^2/2]$

$$+ [R_1T_3^2R_3/(2(1 - R_3))] + [R_1T_3^2R_3/(2(1 - R_3))]$$

$$= [2R_1R_3^2] + [R_1T_3^2/2] + [R_1T_3R_3]$$

    In the binary one case, the probabilities for the detection of idler photons in detectors D1 and D2 in the Receiver are:

$P_1[D1] = [2R_1R_3{}^2] + [R_1T_3{}^2/2] + [R_1T_3R_3]$

$P_1[D2] = [R_1T_3{}^2/2] + [R_1T_3R_3]$

Subject to the constraint: $T_1 = R_1R_3{}^2$

Example: For $R_3 = 0.8$, $T_3 = 0.2$

      $R_1 = 1/(1+R_3{}^2) = 0.61$, $T_1 = R_3{}^2/(1 + R_3{}^2) = 0.39$

      $P_1[D1] = 0.78 + 0.11 = 0.89$, $P_1[D2] = 0.11$

    Note that these are the probabilities at the Receiver when sdc photons are detected at the Transmitter. If a signal photon is detected in detector D6 in the Transmitter, then the probabilities at the Receiver are the same as those for binary zero. There are far fewer sdc photons than signal photons at the Transmitter. Therefore, a substantial integration time is required per transmitted bit of information.
    The set integration time required per bit must be of adequate duration to guarantee that a sufficient number of sdc photons will be detected at the Transmitter to ensure that the operator at the Receiver can make a statistically sound decision as to whether a binary one or a binary zero is being transmitted.

   5. Conclusion

The results of the "before-before" experiment lead to the conclusion that nonlocal influences are not time-ordered [1,2,3]. There is no before or after with respect to nonlocal influences.
    "Quantum correlations are directly caused by the quantum state, such that one event cannot be considered as causing the other"[1]. Nonlocality "reveals a domain of existence, which cannot be described with notions of space and time. In the nonlocal quantum realm, there is dependence without time."[2]
    When the idler photon of a down-converted pair arrives at the Receiver, the signal photon of the pair is still in transit between the Source and the Transmitter. The signal photon will arrive at the Transmitter in what seems to be the "future" of the arrival of the idler photon at the Receiver.
    Upon arrival at the Receiver, the idler photon cannot suspend being detected in order to wait for the detection of the signal photon in the Transmitter. The idler photon detection must follow the probabilities of either binary zero or binary one (which are different), whichever is experienced by its associated signal

photon. There is no "future" with respect to nonlocal quantum interactions. They "arise without the flow of time."[2]

The operator at the Transmitter and the operator at the Receiver decide on an event of interest (such as a potential natural disaster) that is to be monitored. So long as the event does not occur, the operator at the Transmitter continually sends a binary zero message. When the event occurs, the operator at the Transmitter begins continually sending a binary one message.

The binary zero and binary one messages produce different detection probabilities at the Receiver. The operator at the Receiver notes whether the detections in detectors D1 and D2 correspond to a binary zero or a binary one message.

So long as the detections correspond to binary zero, the operator at the Receiver knows that the event of interest has not occurred. When the detections in detectors D1 and D2 correspond to binary one, the operator at the Receiver knows that the event of interest has occurred.

This system can be used as an advanced warning for the event of interest. The length of the advanced warning is determined by the time required by the signal photon to travel the distance between the Source and the Transmitter. (The Receiver is very close to the Source.) This distance may be free space, or it may be through a spool of polarization-preserving optical fiber. Some form of "slow" light may also be employed. However, it should be noted that this system uses pairs of photons, not optical pulses.

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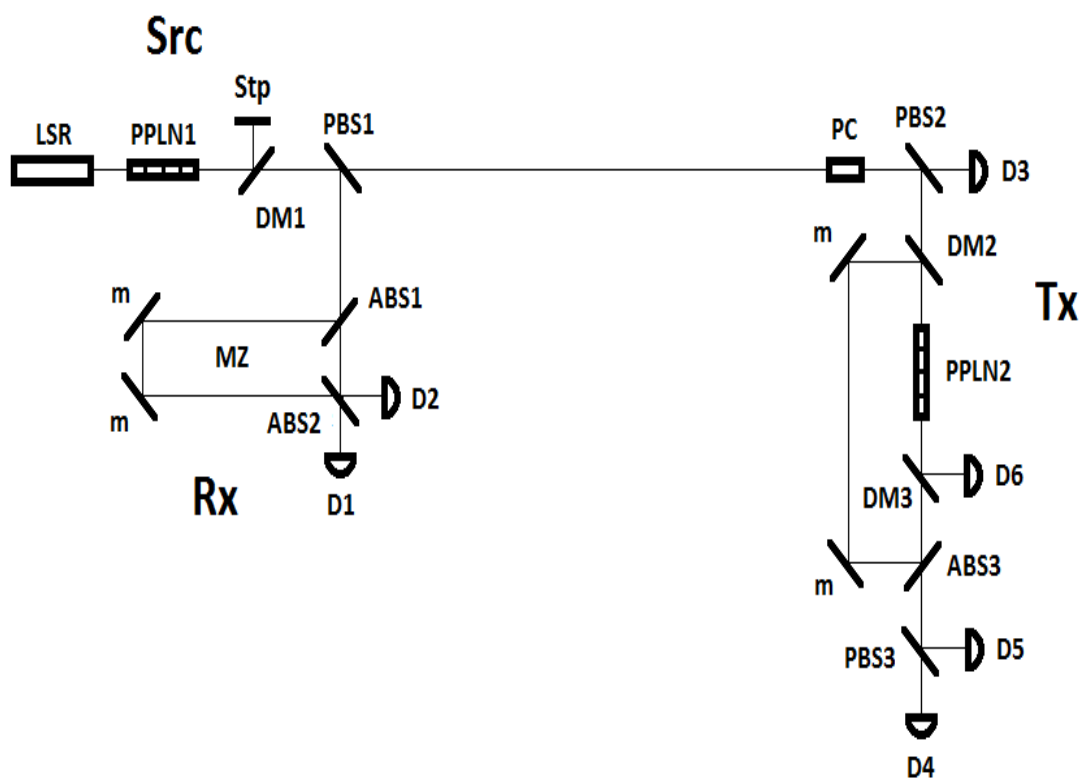   J. Perina (ed.), John Wiley & Sons, Inc. (2001).

Figure 1: System Design