Delphi 2

M. W. Roberts

Abstract

An optical communication system is described. The system provides a unique operational capability that allows rapid communications over long, even astronomical distances.

1. Introduction

The system uses cascaded spontaneous parametric down-conversion similar to that described in [1]. Also, the system employs nonlocal interference like that described in [2].

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 Transmitter is adjusted to be somewhat less than the optical path length from the Source to the Receiver. 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:

$$P[D2;(\Delta_1),(\Delta_2)] = \left|pa[D2;(\Delta_1),(\Delta_2)]\right|^2$$

In the above, $pa[D2;(\Delta_1),(\Delta_2)]$ is the probability amplitude of a three photon detection: the detection of a photon in detector D2 in the Transmitter followed by the detection of associated photons in both detectors D4 and D5 in the Receiver.

The time parameter (Δ_1) is the time between the detection in D2 and the detection in D4. The time parameter (Δ_2) is the time between the detection in D2 and the detection in D5.

$P[D2;(\Delta_1),(\Delta_2)]$ 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:

$R_1 = |r_1|^2$, $T_1 = |t_1|^2$ 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 50 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.

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.

The long 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 Receiver (Rx). The V polarized idler photons are reflected by PBS1 and travel to the Transmitter (Tx).

3b. Transmitter

The Transmitter (Tx) contains a Pockels cell (PC), a polarizing beam splitter (PBS2), two "50/50" amplitude beam splitters (ABS1 and ABS2), two optical mirrors (m1 and m2), and three detectors (D1-D3). The detectors are capable of photon counting.

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

Polarizing beam splitter PBS2 is set to transmit incident H polarized photons to amplitude beam splitter ABS1 and to reflect incident V polarized idler photons to detector D3.

Amplitude beam splitters ABS1 and ABS2 may be partially-silvered plate beam splitters. The characteristics of ABS1 and ABS2 are:

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

The amplitude beam splitters and 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.

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 [3].

The time difference between the time an idler photon may be incident on detector D1 (or D2) via the short path, and the time the idler photon may be incident on detector D1 (or 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. Receiver

The Receiver (Rx) contains two dichroic mirrors (DM2 and DM3), a periodically-poled lithium niobate crystal (PPLN2), a lithium niobite compensating crystal (LiN), a Soleil-Babinet compensator (SBC), a polarizing beam splitter (PBS3), two “50/50” amplitude beam splitters (ABS3 and ABS4), four mirrors (m3-m6), and three detectors (D4-D6). The 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.

Polarizing beam splitter PBS3 is set to transmit incident H polarized photons to detector D4 and to reflect incident V polarized photons to detector D5.

Amplitude beam splitters ABS3 and ABS4 may be partially-silvered plate beam splitters. The characteristics of ABS3 and ABS4 are:

$$R_3 = |r_3|^2 = 0.5 \ ; \ T_3 = |t_3|^2 = 0.5$$
$$R_4 = |r_4|^2 = 0.5 \ ; \ T_4 = |t_4|^2 = 0.5$$

Signal photons from the Source are transmitted through short pass dichroic mirror DM2 and 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. The purpose of detector D6 is to monitor the number of signal photons that reach the Receiver in order to verify proper system operation. Detector D6 is not used in the communication process.

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.

Long pass dichroic mirror DM3 transmits the long wavelength sdc photons which then travel to amplitude beam splitter ABS3. The two sdc photons have (independently) a 50% probability of being transmitted through ABS3, and a 50% probability of being reflected at ABS3.

An sdc photon that is transmitted through ABS3 travels to mirror m3. A photon that is reflected at ABS3 travels to PBS3.

Components in the Transmitter are arranged as a "circulator" to provide two paths for the sdc photons to reach detectors D4 and D5. The circulator is adjusted so that the two paths precisely overlap at the lower output port from ABS3 to PBS3.

The first path in the circulator is from creation of an sdc photon in PPLN2, through DM3, and then reflection at ABS3 to PBS3 and the detectors.

The second path in the circulator contains a feedback path and an internal, balanced Mach-Zehnder interferometer (bMZ). The second path is from creation in PPLN2, through DM3, and then transmission through ABS3. An sdc photon then travels via the three-mirror (m3, m4, m5) feedback path to ABS4.

Beam splitter ABS4 is the entrance component of the internal bMZ. ABS4 equally divides the probability amplitude of an sdc photon. Half of the amplitude of the photon enters the "upper" channel of the internal bMZ and travels through compensating crystal LiN and the SBC and reflects from mirror m6 to the upper input port to ABS3.

The other half of the probability amplitude enters the "lower" channel of the interferometer. This half of the probability amplitude reflects from short pass dichroic mirror DM2 and passes through PPLN2 and DM3 to the lower input port of ABS3.

The LiN and SBC are used to balance the optical path length through the upper channel of the bMZ with the optical path length through the lower channel for both the H and V polarized sdc photons.

The path lengths through the internal bMZ are adjusted so that the net phase difference from input to output for a given channel depends on the reflections at the optical or dichroic mirrors and the reflections (or transmissions) at the beam splitters [3].

The optical path lengths through the two channels are adjusted to be equal (balanced). Also, $(t_4 \bullet t_3)-(r_4 \bullet r_3) = 0$. This results in total destructive interference at the output from ABS3 to mirror m3, and total constructive interference for an sdc photon at the output from ABS3 to PBS3. The sdc photon then travels from ABS3 to PBS3 and the detectors.

The path lengths through the second path in the circulator are adjusted so that the time difference between the time an sdc photon may be incident on detector D4 or D5 via the first path, and the time the sdc photon may be incident on detector D4 or D5 via the second path is equal to X.

The fixed time X should be of sufficient duration to allow the first path and the second path to be temporally distinct. Time X should be much longer than the coherence time of an sdc photon from PPLN2, but should also be much shorter than the coherence time of a pump photon from laser LSR in the Source.

(Note that time X is also the time difference for an idler photon between the long path and the short path through unbalanced Mach-Zehnder interferometer MZ in the Receiver.)

For the system to function properly, the photons detected in detectors D4 and D5 in the Receiver <u>must</u> be created inside the circulator.

4a. Binary Zero

To send a binary zero from the Transmitter to the Receiver, Pockels cell PC in the Transmitter is turned off.

The V polarized idler photon of a down-converted pair travels from the Source to the Transmitter and passes through the PC unchanged. The V polarized idler photon is then reflected by PBS2 and is incident on detector D3. In the binary zero case, the idler photon does not reach the MZ in the Transmitter.

The idler photon follows a single, distinct path from the Source to detector D3 in the Transmitter. Therefore, the time of detection of an idler photon in detector D3 fixes the time of creation of that idler and signal photon pair in PPLN1 in the Source.

The H polarized signal photon of the pair travels from the Source to the Receiver and enters PPLN2. Some of the signal photons produce sdc photon pairs in PPLN2. These sdc photons then travel via either the first path or the second path through the circulator to detectors D4 and D5 in the Receiver.

Because the time of creation of the original signal/idler pair in the Source is known, the time of detection of an sdc photon identifies which of the two paths was followed by that photon in the Receiver.

There is no ambiguity as to which path was followed by either the idler photon in the Transmitter or the two sdc photons in the Receiver. Consequently, nonlocal interference does not occur in the binary zero case [2].

Since there is no nonlocal interference, the probability amplitudes and probabilities that the H and V polarized sdc photons of a pair will be incident on detectors D4 and D5 in the Receiver via the first path through the circulator are:

$pa_H^{(1)}[D4] = ir_3$
$P_H^{(1)}[D4] = |pa_H^{(1)}[D4]|^2 = R_3 = 0.5$

$pa_V^{(1)}[D5] = i^2\ r_3 = -r_3$
$P_V^{()}[D5] = |pa_V^{(1)}[D5]|^2 = R_3 = 0.5$

The probability amplitudes and probabilities that the H and V polarized sdc photons of a pair will be incident on detectors D4 and D5 in the Receiver via the longer second path through the circulator are:

$pa_H^{(2)}[D4] = i^3\ t_3\ [(i^2\ r_4\ t_3)+(i^2\ t_4\ r_3)] = it_3$
$P_H^{(2)}[D4] = |pa_H^{(2)}[D4]|^2 = T_3 = 0.5$

$pa_V^{(2)}[D5] = i^4\ t_3\ [(i^2\ r_4\ t_3)+(i^2\ t_4\ r_3)] = -t_3$
$P_V^{(2)}[D5] = |pa_V^{(2)}[D5]|^2 = T_3 = 0.5$

In the binary zero case, the probability that both sdc photons of a pair reach detectors D4 and D5 at the same time (ST) is:

$P_0[ST] = (P_H^{(1)}[D4] \bullet P_V^{(1)}[D5]) + (P_H^{(2)}[D4] \bullet P_V^{(2)}[D5]) = 0.5$

The probability that the sdc photons of a pair reach detectors D4 and D5 at different times (DT) is:

$P_0[DT] = (P_H^{(1)}[D4] \bullet P_V^{(2)}[D5]) + (P_H^{(2)}[D4] \bullet P_V^{(1)}[D5]) = 0.5$

4b. Binary One

To send a binary one from the Transmitter to the Receiver, Pockels cell PC in the Transmitter is turned on.

The V polarized idler photon of a down-converted pair travels from the Source to the Transmitter and has its polarization direction rotated to H polarized as it passes through the PC. The now H polarized idler photon passes through PBS2 and travels to ABS1, the first component of the MZ in the Transmitter.

The photon then travels via either the short path or the long path through the MZ and is incident on either detector D1 or detector D2.

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

The probability amplitude that an idler photon will reach detector D1 or detector D2 via the short path is:

$$pa^{(S)}[D1] = t_1\ t_2 \exp(i\Phi_I) = \exp(i\Phi_I)/2$$
$$pa^{(S)}[D2] = i\ t_1\ r_2 \exp(i\Phi_I) = [i \exp(i\Phi_I)]/2$$

The probability amplitude that an idler photon will reach detector D1 or detector D2 via the long path is:

$$pa^{(L)}[D1]=(i^4)\ r_1\ r_2 \exp((i\Phi_I)+(i\omega_I X))= \exp((i\Phi_I)+(i\omega_I X))/2$$
$$pa^{(L)}[D2]=(i^3)\ r_1\ t_2 \exp((i\Phi_I)+(i\omega_I X))=[-i \exp((i\Phi_I)+(i\omega_I X))]/2$$

(ω_I is the angular frequency of the idler photon)

with $\omega_I X = 2\pi n$, n a positive integer:

$$pa^{(L)}[D1] = \exp(i\Phi_I)/2$$
$$pa^{(L)}[D2] = [-i \exp(i\Phi_I)]/2$$

The phase angle Φ_I is random, because the location within PPLN1 at which an idler photon is created varies from one photon to the next.

The H polarized signal photon of the pair travels from the Source to the Receiver and passes through short pass dichroic mirror DM2 to PPLN2.

Most signal photons pass through PPLN2, are reflected at DM3, and are incident on detector D6. Some of the signal photons are annihilated within PPLN2 in an SPDC event that creates a pair of orthogonally-polarized, secondary down-converted (sdc) photons [1].

The long wavelength sdc photons exit from PPLN2, pass through long pass dichroic mirror DM3, and travel to ABS3. Each of the two sdc photons has (individually) a 50% probability to reflect from ABS3 and travel to PBS3. The H polarized sdc photon then passes through PBS3 to detector D4; the V polarized sdc photon reflects from PBS3 to detector D5. This is the first path for sdc photons to reach detectors D4 and D5.

The probability amplitude that an H polarized sdc photon will reach detector D4 via the first path is:

$pa_H^{(1)}[D4] = i\ [\exp(i\Phi_S)]/\sqrt{(2)}$

The probability amplitude that a V polarized sdc photon will reach detector D5 via the first path is:

$pa_V^{(1)}[D5] = i^2\ [\exp(i\Phi_S)]/\sqrt{(2)} = -[\exp(i\Phi_S)]/\sqrt{(2)}$

The phase angle Φ_S is random, because the location within PPLN2 at which the sdc photons are created varies from one photon pair to the next.

With 50% probability, an sdc photon may be transmitted through ABS3. The photon enters the feedback path and travels via three mirrors to ABS4, the first component of the internal, balanced Mach-Zehnder interferometer (bMZ)in the Receiver.

An sdc photon that reaches ABS4 then passes through the two channels of the bMZ and (due to constructive interference) exits from the lower output port of ABS3 to PBS3. This is the second path for an sdc photon to reach detector D4 or D5.

The probability amplitude that an H polarized sdc photon will reach detector D4 via the second path is:

$pa_H^{(2)}[D4] = i\ [\exp((i\Phi_S)+(i\omega_H X))]/\sqrt{(2)}$

(ω_H is the angular frequency of the H polarized sdc photon)

with $\omega_H X = 2\pi m$, m a positive integer:

$pa_H^{(2)}[D4] = i\ [\exp(i\Phi_S)]/\sqrt{(2)}$

The probability amplitude that a V polarized sdc photon will reach detector D5 via the second path is:

$pa_V^{(2)}[D5] = i^2\ [\exp((i\Phi_S)+(i\omega_V X))]/\sqrt{(2)}$

(ω_V is the angular frequency of the V polarized sdc photon; $\omega_V=\omega_H$)

with $\omega_V X = 2\pi m$, m a positive integer:

$pa_V^{(2)}[D5] = -[\exp(i\Phi_S)]/\sqrt{(2)}$

The time difference between the time an sdc photon may be incident on detector D4 or D5 via the first path, and the time the sdc photon may be incident on detector D4 or D5 via the longer second path through the circulator in the Receiver is set equal to X.

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

The optical path length from the Source to the Transmitter is less than the optical path length from the Source to the Receiver. The idler photon will be incident on either detector D1 or D2 in the Transmitter, before the signal photon of the pair reaches the Receiver.

If an idler photon is detected in detector D1 or D2 after travelling through the short path of the MZ in the Transmitter, and an associated sdc photon is detected in detector D4 or D5 after travelling through the first path in the circulator in the Receiver, then the time difference between these detections is equal to τ.

If an idler photon is detected in detector D1 or D2 after travelling through the long path of the MZ in the Transmitter, and an associated sdc photon is detected in detector D4 or D5 after travelling through the second path in the circulator in the Receiver, then the time difference between these detections is also equal to τ.

If an idler photon is detected in detector D1 or D2 after travelling through the short path of the MZ, and an associated sdc photon is detected in detector D4 or D5 after travelling through the second path in the circulator, then the time difference between these detections is equal to $(\tau + X)$.

If an idler photon is detected in detector D1 or D2 after travelling through the long path of the MZ in the Transmitter, and an associated sdc photon is detected in detector D4 or D5 after travelling through the first path in the circulator, then the time difference between these detections is equal to $(\tau - X)$.

When the time between the detection of the idler photon in the Transmitter and <u>both</u> of its associated sdc photons in the Receiver is equal to τ, there is an ambiguity as to "which path" the photons travelled. This causes nonlocal, three-photon interference between the idler photon in the Transmitter and the two sdc photons in the Receiver [2].

For detection of the idler photon in detector D1 in the Transmitter, and the detection of both the H polarized sdc photon in detector D4 and the V polarized sdc photon in detector D5 with time difference equal to τ:

$pa_1[D1;(\tau),(\tau)] =$

$\{pa^{(S)}[D1]\bullet pa_H^{(1)}[D4]\bullet pa_v^{(1)}[D5]\}+\{pa^{(L)}[D1]\bullet pa_H^{(2)}[D4]\bullet pa_v^{(2)}[D5]\} =$

$\{\exp(i\Phi_I)/2\}\{i[\exp(i\Phi_S)]/\surd(2)\}\{-[\exp(i\Phi_S)]/\surd(2)\}$
$+ \{\exp(i\Phi_I)/2\}\{i[\exp(i\Phi_S)]/\surd(2)\}\{-[\exp(i\Phi_S)]/\surd(2)\} =$

$[\exp(i(\Phi_I + 2\Phi_S))]/2$

$P_1[D1;(\tau),(\tau)] = |pa_1[D1;(\tau),(\tau)]|^2 = 0.25$

For detection of the idler photon in detector D2 in the Transmitter, and the detection of both the H polarized sdc photon in detector D4 and the V polarized sdc photon in detector D5 with time difference equal to τ:

$pa_1[D2;(\tau),(\tau)] =$

$\{pa^{(S)}[D2]\bullet pa_H^{(1)}[D4]\bullet pa_v^{(1)}[D5]\}+\{pa^{(L)}[D2]\bullet pa_H^{(2)}[D4]\bullet pa_v^{(2)}[D5]\} =$

$\{i\exp(i\Phi_I)/2\}\{i[\exp(i\Phi_S)]/\surd(2)\}\{-[\exp(i\Phi_S)]/\surd(2)\}$
$+ \{-i\exp(i\Phi_I)/2\}\{i[\exp(i\Phi_S)]/\surd(2)\}\{-[\exp(i\Phi_S)]/\surd(2)\} = 0$

$P_1[D2;(\tau),(\tau)] = |pa_1[D2;(\tau),(\tau)]|^2 = 0$

When the time difference between the detection of the idler photon in detector D1 in the Transmitter and both of its associated sdc photons in the Receiver is not equal to τ, then there is no ambiguity as to which path the photons travelled. Consequently, nonlocal interference does not occur:

$P_1[D1;(\tau),(\tau+X)]=|pa^{(S)}[D1]\bullet pa_H^{(1)}[D4]\bullet pa_v^{(2)}[D5]\}|^2 = (1/16) = 0.0625$

$P_1[D1;(\tau+X),(\tau)] = |pa^{(S)}[D1]\bullet pa_H^{(2)}[D4]\bullet pa_v^{(1)}[D5]\}|^2 = 0.0625$

$P_1[D1;(\tau+X),(\tau+X)] = |pa^{(S)}[D1]\bullet pa_H^{(2)}[D4]\bullet pa_v^{(2)}[D5]\}|^2 = 0.0625$

$P_1[D1;(\tau-X),(\tau-X)] = |pa^{(L)}[D1]\bullet pa_H^{(1)}[D4]\bullet pa_v^{(1)}[D5]\}|^2 = 0.0625$

$P_1[D1;(\tau-X),(\tau)] = |pa^{(L)}[D1]\bullet pa_H^{(1)}[D4]\bullet pa_v^{(2)}[D5]\}|^2 = 0.0625$

$P_1[D1;(\tau),(\tau-X)] = |pa^{(L)}[D1]\bullet pa_H^{(2)}[D4]\bullet pa_v^{(1)}[D5]\}|^2 = 0.0625$

When the time difference between the detection of the idler photon in detector D2 in the Transmitter and both of its associated sdc photons in the Receiver is not equal to τ, then there is no ambiguity as to which path the photons travelled. Again, nonlocal interference does not occur:

$P_1[D2;(\tau),(\tau+X)] = |pa^{(S)}[D2] \bullet pa_H{}^{(1)}[D4] \bullet pa_v{}^{(2)}[D5]\}|^2 = (1/16) = 0.0625$

$P_1[D2;(\tau+X),(\tau)] = |pa^{(S)}[D2] \bullet pa_H{}^{(2)}[D4] \bullet pa_v{}^{(1)}[D5]\}|^2 = 0.0625$

$P_1[D2;(\tau+X),(\tau+X)] = |pa^{(S)}[D2] \bullet pa_H{}^{(2)}[D4] \bullet pa_v{}^{(2)}[D5]\}|^2 = 0.0625$

$P_1[D2;(\tau-X),(\tau-X)] = |pa^{(L)}[D2] \bullet pa_H{}^{(1)}[D4] \bullet pa_v{}^{(1)}[D5]\}|^2 = 0.0625$

$P_1[D2;(\tau-X),(\tau)] = |pa^{(L)}[D2] \bullet pa_H{}^{(1)}[D4] \bullet pa_v{}^{(2)}[D5]\}|^2 = 0.0625$

$P_1[D2;(\tau),(\tau-X)] = |pa^{(L)}[D2] \bullet pa_H{}^{(2)}[D4] \bullet pa_v{}^{(1)}[D5]\}|^2 = 0.0625$

Summing the above, the probabilities that an idler photon will be incident on detector D1 or detector D2 in the Transmitter are:

$P_1[D1] = (0.25) + [6 \bullet (0.0625)] = (5/8) = 0.625$

$P_1[D2] = 0 + [6 \bullet (0.0625)] = (3/8) = 0.375$

Note, these probabilities cannot be correct, because the distance from Source to Transmitter is less than the distance from Source to Receiver. Consequently, the idler photon reaches the Transmitter and is incident on detector D1 or D2, before the signal photon of the pair reaches the Receiver.

After the idler photon is incident on detector D1 or D2, its associated signal photon could be blocked before it even reaches the Receiver. Consequently, no sdc photons would be created, and nonlocal interference would not occur. Therefore, $P_1[D1]$ and $P_1[D2]$ must both equal 0.5 in the binary one case.

A correction factor must be applied to the probabilities yielding $P_1[D1]$. The physical rationale for this correction factor is that, due to nonlocal interference, the detection of an idler photon in detector D1 in the Transmitter causes a (small) decrease in the probability that the signal photon will be down-converted to create a pair of sdc photons in the Receiver.

The correction factor is x:

$0.625 \bullet x = 0.5$
$x = 4/5 = 0.8$

$P_1^{(Cor)}[D1;(\tau),(\tau)] = P_1[D1;(\tau),(\tau)] \bullet 0.8 = 0.25 \bullet 0.8 = (1/5) = 0.2$

$P_1^{(Cor)}[D1;(\tau),(\tau+X)] = P_1[D1;(\tau),(\tau+X)] \bullet 0.8 = 0.0625 \bullet 0.8 = 0.05$

$P_1^{(Cor)}[D1;(\tau+X),(\tau)] = (1/20) = 0.05$

$P_1^{(Cor)}[D1;(\tau+X),(\tau+X)] = 0.05$

$P_1^{(Cor)}[D1;(\tau-X),(\tau-X)] = 0.05$

$P_1^{(Cor)}[D1;(\tau-X),(\tau)] = 0.05$

$P_1^{(Cor)}[D1;(\tau),(\tau-X)] = 0.05$

$P_1^{(Cor)}[D1] = (0.2) + [6 \bullet (0.05)] = 0.5$

A different correction factor must be applied to the probabilities yielding $P_1[D2]$. The physical rationale for this correction factor is that, due to nonlocal interference, the detection of an idler photon in detector D2 in the Transmitter causes a (small) increase in the probability that the signal photon will be down-converted to create a pair of sdc photons in the Receiver.

The correction factor is y:

$0.375 \bullet y = 0.5$
$y = 4/3 = 1.333$

$P_1^{(Cor)}[D2;(\tau),(\tau)] = P_1[D2;(\tau),(\tau)] \bullet (4/3) = 0$

$P_1^{(Cor)}[D2;(\tau),(\tau+X)] = P_1[D2;(\tau),(\tau+X)] \bullet (4/3) = (1/12) = 0.0833$

$P_1^{(Cor)}[D2;(\tau+X),(\tau)] = 0.0833$

$P_1^{(Cor)}[D2;(\tau+X),(\tau+X)] = 0.0833$

$P_1^{(Cor)}[D2;(\tau-X),(\tau-X)] = 0.0833$

$P_1^{(Cor)}[D2;(\tau-X),(\tau)] = 0.0833$

$P_1^{(Cor)}[D2;(\tau),(\tau-X)] = 0.0833$

$P_1^{(Cor)}[D2] = 0 + [6 \bullet (0.0833)] = 0.5$

Using the corrected probabilities, in the binary one case, the probability that both sdc photons of a pair reach detectors D4 and D5 at the same time (ST) is:

$$P_1^{(Cor)}[ST] = P_1^{(Cor)}[D1;(\tau),(\tau)] + P_1^{(Cor)}[D1;(\tau+X),(\tau+X)] + P_1^{(Cor)}[D1;(\tau-X),(\tau-X)] + P_1^{(Cor)}[D2;(\tau),(\tau)] + P_1^{(Cor)}[D2;(\tau+X),(\tau+X)] + P_1^{(Cor)}[D2;(\tau-X),(\tau-X)] = (1/5)+(1/20)+(1/20)+0+(1/12)+(1/12) = (7/15) = 0.467$$

The probability that the sdc photons of a pair reach detectors D4 and D5 at different times (DT) is:

$$P_1^{(Cor)}[DT] = P_1^{(Cor)}[D1;(\tau),(\tau+X)] + P_1^{(Cor)}[D1;(\tau+X),(\tau)] + P_1^{(Cor)}[D1;(\tau-X),(\tau)] + P_1^{(Cor)}[D1;(\tau),(\tau-X)] + P_1^{(Cor)}[D2;(\tau),(\tau+X)] + P_1^{(Cor)}[D2;(\tau+X),(\tau)] + P_1^{(Cor)}[D2;(\tau-X),(\tau)] + P_1^{(Cor)}[D2;(\tau),(\tau-X)] = [4 \bullet (1/20)] + [4 \bullet (1/12)] = (8/15) = 0.533$$

These probabilities in the binary one case are different from the probabilities in the binary zero case. As a reminder:

$P_0[ST] = 0.5$

$P_0[DT] = 0.5$

This difference in probabilities allows the operator at the Receiver to determine whether a binary one or a binary zero is being transmitted.

Note that it is only necessary for the operator at the Receiver to observe the detections of the sdc photons. However, there are far fewer sdc photons than signal photons at the Receiver. 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 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 probability amplitude is a purely mathematical function. The tangible, physical mechanism that allows nonlocal interactions to occur is unknown. (Which of the standard "Four Forces of Nature" is responsible for nonlocal interference?) Since nonlocal interference does not appear to be related in any way to electromagnetism, it should not necessarily be subject to the constraints of Special Relativity.

The communication system described in this paper is unique, because the speed of information transfer is limited only by the required length of the integration time per bit.

The actual transfer of information from the Transmitter to the Receiver is virtually instantaneous, independent of the distance between the Transmitter and the Receiver. This is true, even if the distance is so large that the detection of an idler photon in the Transmitter, and the detection of its associated sdc photons in the Receiver are space-like separated events.

References

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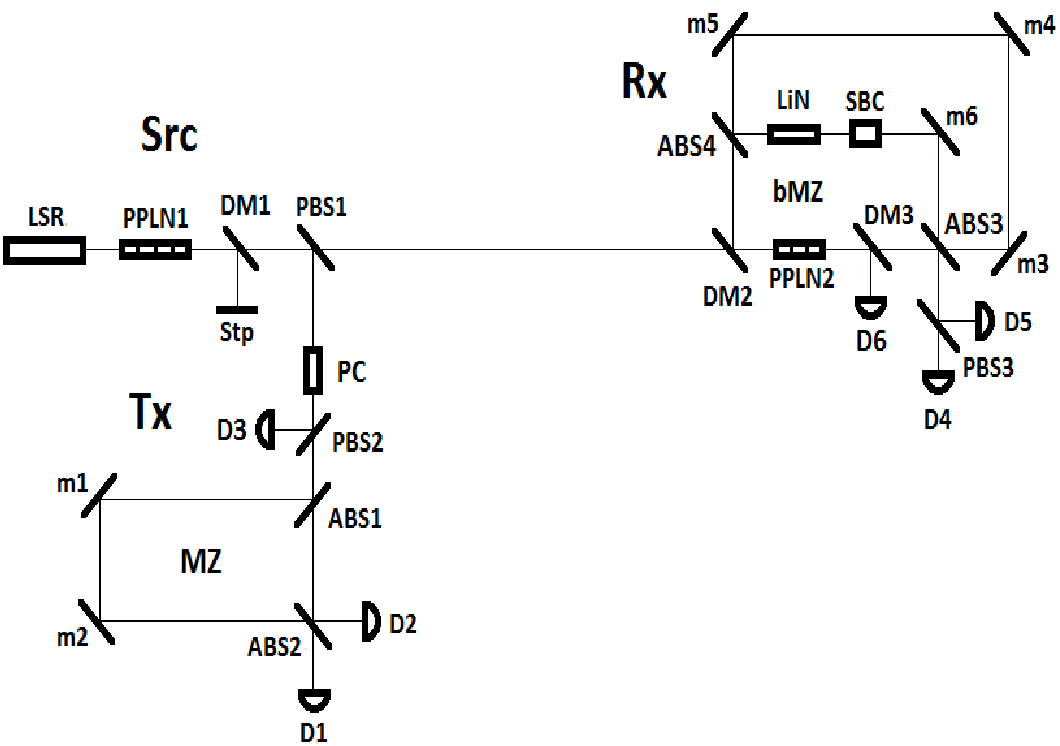

Figure 1: System Design