Delphi 5

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Abstract

The design of Delphi 4A is changed due to the fact that two of its system requirements were inconsistent. The proposed Delphi 5 quantum optical system is capable of superluminal communication.

1. Introduction

This system uses nonlocal, two-photon interference like that described in [1].

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 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:

$$P[D1,D4,(\Delta)] = \left|pa[D1,D4,(\Delta)]\right|^2$$

In the above, pa[D1,D4,(Δ)] is the probability amplitude for the detection of a signal photon of a down-converted pair in detector D1 in the Transmitter, and the detection of the idler photon of the pair in detector D4 in the Receiver. The time parameter (Δ) is the time between the detection of the signal photon in the Transmitter and the detection of the idler photon in the Receiver.

P[D1,D4,(Δ)] is the probability for the same detection events.

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 (PPLN), one short pass dichroic mirror (SPDM), one long pass dichroic mirror (LPDM), a beam stop (Stp), one polarizing beam splitter (PBS1), one half-wave plate (HWP), two regular amplitude beam splitters (ABS1 and ABS2), one coil of optical fiber (OF1), one compensator (CP), and seven mirrors (m).

Laser LSR has a stable output, and the coherence length of the pump photons from LSR is greater than 400 meters.

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

Optical fiber OF1 is a coil of polarization-preserving optical fiber.

Half-wave plate HWP is set with its “fast” axis 45 degrees above horizontal. A +H polarized photon that passes through the wave plate has its polarization direction rotated, and the photon exits from the wave plate +V polarized.

The regular amplitude beam splitters may be partially-silvered plate beam splitters. The characteristics of the beam splitters (for both H polarized and V polarized photons) are:

$R_1 = |r_1|^2$; $T_1 = |t_1|^2$

$R_2 = |r_2|^2$; $T_2 = |t_2|^2$

$R_1 = T_2$; $T_1 = R_2$

The PPLN crystal is temperature-controlled, and is set to allow collinear, degenerate, type II spontaneous parametric down-conversion (SPDC). On average, one of every 10^6 of the photons from pump laser LSR is annihilated in a SPDC event that creates a signal and idler pair of photons. The signal photon is horizontally (H) polarized, and the idler photon is vertically (V) polarized.

The short wavelength photons from pump laser LSR pass through short pass dichroic mirror SPDM and travel to and pass through the PPLN. Photons from pump laser LSR that are not down-converted in the PPLN are reflected at long pass dichroic mirror LPDM and are incident on beam stop Stp.

The longer wavelength signal and idler photons exit from the PPLN and are transmitted through the LPDM. The V polarized idler photons reflect at PBS1 and travel to the Receiver (Rx). The H polarized signal photons are transmitted through PBS1 and travel to ABS1.

A signal photon may pass through ABS1, or it may reflect at ABS1. If a signal photon reflects at ABS1, it travels to the HWP. As the H polarized signal photon passes through the HWP, its polarization direction is rotated, and it exits from the HWP as a V polarized photon. The now V polarized signal photon then reflects at mirror m1 and travels to the Transmitter (Tx). The probability amplitude for this possible component of the signal photon is:

$$pa(Tx,0,V) = -r_1$$

Alternately at ABS1, the H polarized signal photon may pass through ABS1 and enter a feedback path. The first part of the feedback path is from ABS1 through OF1 and reflection at five mirrors (m) to ABS2. Optical fiber coil OF1 provides the majority of the optical path length of the feedback path.

Beam splitter ABS2 produces two probability amplitude components of the H polarized signal photon that travel by different paths back to ABS1.

The first component reflects at ABS2 and travels through the upper path to ABS1. The upper path is from ABS2, through compensator CP, then reflection at mirror m2 to ABS1. The probability amplitude incident on ABS1 in this case is:

$$pa(ABS1,U) = -it_1r_2$$

The second component passes through ABS2 and travels through the lower path to ABS1. The lower path is from ABS2, reflection at the SPDM, then passage through the PPLN, the LPDM, and PBS1 to ABS1. The SPDM is set so that the feedback path through the PPLN is precisely aligned to follow the original collinear path to ABS1. The probability amplitude incident on ABS1 in this case is:

$$pa(ABS1,L) = -t_1t_2$$

Compensator CP is adjusted so that the optical path lengths through the upper and lower paths are equal, and the two signal photon components arrive at ABS1 at exactly the same time. These are components of the same signal photon, so they are coherent, and one-photon interference occurs at ABS1.

The two component paths are set so that total destructive interference occurs into the output path from ABS1 to OF1, and total constructive interference occurs into the output path from ABS1 to the HWP.

As this possible component of the H polarized signal photon passes through the HWP, its polarization direction is rotated, and it exits from the HWP as a V polarized photon. The now V polarized signal photon then reflects at mirror m1 and travels to the Transmitter (Tx). The probability amplitude in this case is:

$pa(Tx,1,V) = +t_1$

Path lengths are set so that the component of the signal photon with probability amplitude pa(Tx,1,V) will exit from the Source at a time equal to 500 nanoseconds after the component with probability amplitude pa(Tx,0,V) exited the Source. The 500 nanoseconds corresponds to a free-space propagation distance of approximately 150 meters.

Note that, until a given photon is actually detected, all possible components of that photon co-exist.

3b. Transmitter

The Transmitter (Tx) contains a Pockels cell (PC), one polarizing beam splitter (PBS2), one special amplitude beam splitter (PABS3), one coil of optical fiber (OF2), three mirrors (m), and two detectors (D1 and D2). The fast detectors are capable of photon counting.

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

The PC should have a repetition rate of 1 MHz with a rise time and fall time less than 10 nsec. When the PC is turned on, it will operate with a "50/50" duty cycle: a repeating cycle of 500 nsec on, then 500 nsec off.

Polarizing beam splitter PBS2 is set to transmit incident H polarized photons and to reflect incident V polarized photons.

Optical fiber OF2 is a coil of polarization-preserving optical fiber.

Special amplitude beam splitter PABS3 is actually a "lossy" polarizing beam splitter plate. The special beam splitter acts like a polarizing beam splitter for H polarized photons (transmits all H polarized photons), but acts like an amplitude beam splitter for V polarized photons. This is because the wavelength of the down-converted photons is somewhat longer than the design wavelength of the polarizing plate. The characteristics of special beam splitter PABS3 are:

$R_{3H} = |r_{3H}|^2 = 0$; $T_{3H} = |t_{3H}|^2 = 1.0$
$R_{3V} = |r_{3V}|^2 = 0.85$; $T_{3V} = |t_{3V}|^2 = 0.15$

Beam splitter PABS3, three mirrors (m), and optical fiber coil OF2 form an optical circulator (OC). Pockels cell PC is placed in the optical path within the OC.

The time required for a signal photon to make one cycle around through the OC from PABS3, through OF2 and the PC (with the PC turned off), and back to PABS3 is equal to 500 nanoseconds. Optical fiber coil OF2 provides the majority of the optical path length through the OC.

Requirement for proper system operation:

$T_1 = R_1 \bullet R_{3V}$; $R_1 = 1/(1 + R_{3V})$

3c. Receiver

The Receiver (Rx) contains two regular amplitude beam splitters (ABS4 and ABS5), two mirrors (m), one coil of optical fiber (OF3), and two detectors (D3 and D4). The fast detectors are capable of photon counting.

Optical fiber OF3 is a coil of polarization-preserving optical fiber.

The amplitude beam splitters may be partially-silvered plate beam splitters. Beam splitters ABS4 and ABS5 are "50/50" amplitude beam splitters. The characteristics of the beam splitters are:

$R_4 = |r_4|^2 = 0.50$; $T_4 = |t_4|^2 = 0.50$

$R_5 = |r_5|^2 = 0.50$; $T_5 = |t_5|^2 = 0.50$

Amplitude beam splitters ABS4, ABS5, two mirrors (m), and optical fiber coil OF3 form an unbalanced Mach-Zehnder interferometer (MZ). Unbalanced MZ provides a short path and a long path between ABS4 and ABS5 for idler photons.

The path lengths through the MZ are set 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 [2].

The time difference between the time an idler photon may be incident on detector D3 (D4) via the short path through the MZ, and the time the photon may be incident on detector D3 (D4) via the long path is equal to 500 nanoseconds. Optical fiber coil OF3 provides the majority of the optical path length through the long path of the MZ.

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

4a. Binary Zero

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

The idler photon of a down-converted pair that is created in the PPLN exits from the Source and travels to the Receiver. The signal photon of the pair exits from the Source as two possible components and travels to the Transmitter.

The optical path length from the Source to the Transmitter is somewhat less than the optical path length from the Source to the Receiver. This ensures that every signal photon of a down-converted pair will be incident on a detector in the Transmitter before the idler photon of the pair reaches the Receiver.

At the Receiver, the V polarized idler photon travels to the MZ. The idler photon then passes through either the short path or the long path through the MZ and is incident on either detector D3 or detector D4.

At the Transmitter, the first V polarized signal photon component with probability amplitude pa(Tx,0,V) is incident on PABS3 of the OC. The V polarized component may reflect at PABS3, or it may pass through PABS3. If it reflects at PABS3, the component travels to and reflects at PBS2 and is incident on detector D2. The probability amplitude in this case is:

$pa_0(D2,0) = +r_1 r_{3V}$

Instead, if the V polarized component passes through PABS3, it travels around in the OC to the PC. In the binary zero case, the PC is always off, so the component is still V polarized when it exits from the PC. This first component then travels to PABS3.

Path lengths are set so that the first component arrives back at PABS3 at the same time as the second signal photon component with probability amplitude pa(Tx,1,V) arrives at PABS3 from the Source.

These are components of the same signal photon, so they are coherent, and one-photon interference occurs at PABS3. The probability amplitude directed into the OC in this case is:

$pa_0(PABS3,OC,1) = (+t_1t_{3V}) + (-r_1t_{3V}r_{3V})$

With $t_1 = r_1r_{3V}$ (system requirement):

$pa_0(PABS3,OC,1) = 0$

Total destructive interference. No component into the OC.

The probability amplitude directed toward PBS2 in this case is:

$pa_0(PABS3,PBS2,1) = (+it_1r_{3V}) + (+ir_1t_{3V}^2)$

With $t_1 = r_1r_{3V}$ (system requirement):

$pa_0(PABS3,PBS2,1) = +ir_1$

Total constructive interference. This component then travels to and reflects at PBS2 and is incident on detector D2. The probability amplitude in this case is:

$pa_0(D2,1) = -r_1$

The component of the signal photon with probability amplitude $pa_0(D2,1)$ will be incident on detector D2 at a time equal to 500 nanoseconds, after the component with probability amplitude $pa_0(D2,0)$ was incident on detector D2.

This analysis concerns a single signal photon. All of the components are of the same signal photon. All possibilities that can occur (that are not forbidden) do occur. Of course, a given signal photon can only be detected at one event: in one detector, at one time.

If the signal photon of a down-converted pair travels from the Source to the Transmitter and is detected in detector D2 with probability amplitude $pa_0(D2,0)$, and the idler photon of the pair travels to the Receiver, passes through the short path through the MZ, and is detected in either detector D3 or D4, then the time between the detection of the signal photon in the Transmitter and the idler photon in the Receiver is equal to τ. Note that τ >> 500 nanoseconds.

If the time difference between the detection of a signal photon in the Transmitter in detector D2, and the detection in the Receiver of the idler photon of the down-converted pair in either detector D3 or D4 is equal to (τ+500nsec), then there is no ambiguity as to which paths the photons travelled.

The signal photon travelled to the Transmitter and was detected in detector D2 with probability amplitude $pa_0(D2,0)$, and the idler photon travelled to the Receiver and then passed through the long path through the MZ to detector D3 or detector D4.

Because there is no ambiguity, non-local, two-photon interference does not occur. The probability amplitudes and probabilities in this case are:

With $R_1 = 0.540$; $R_{3V} = 0.85$:

$$pa_0[D2,D3,(\tau+500nsec)] = (+r_1r_{3V})(+ir_4r_5) = +i(0.339)$$

$$P_0[D2,D3,(\tau+500nsec)] = \left|pa_0[D2,D3,(\tau+500nsec)]\right|^2$$

$$= \{R_1R_{3V}/4\} = \{0.115\}$$

$$pa_0[D2,D4,(\tau+500nsec)] = (+r_1r_{3V})(+r_4t_5) = +(0.339)$$

$$P_0[D2,D4,(\tau+500nsec)] = \left|pa_0[D2,D4,(\tau+500nsec)]\right|^2$$

$$= \{R_1R_{3V}/4\} = \{0.115\}$$

If the time difference between the detection of a signal photon in the Transmitter in detector D2, and the detection in the Receiver of the idler photon of the down-converted pair in either detector D3 or D4 is equal to τ, then there is an ambiguity as to which paths the photons travelled.

The signal photon may have travelled to the Transmitter and then was detected in detector D2 with probability amplitude $pa_0(D2,0)$, and the idler photon travelled to the Receiver and then passed through the short path through the MZ to detector D3 or detector D4.

Alternately, the signal photon may have travelled to the Transmitter and then was detected in detector D2 with probability amplitude $pa_0(D2,1)$, and the idler photon travelled to the Receiver and then passed through the long path through the MZ to detector D3 or detector D4.

Because of this ambiguity, non-local, two-photon interference occurs [1]. The probability amplitudes of the two possibilities must be combined. The probability amplitudes and probabilities in this case are:

$$pa_0[D2,D3,(\tau)] = (+r_1 r_{3V})(+it_4 t_5) + (-r_1)(+ir_4 r_5)$$

$$= (-ir_1/2)(1 - r_{3V}) = -i(0.055)$$

$$P_0[D2,D3,(\tau)] = |pa_0[D2,D3,(\tau)]|^2 = \{(R_1/4)(1 - r_{3V})^2\} = \{0.001\}$$

$$pa_0[D2,D4,(\tau)] = (+r_1 r_{3V})(-t_4 r_5) + (-r_1)(+r_4 t_5)$$

$$= (-r_1/2)(1 + r_{3V}) = -(0.680)$$

$$P_0[D2,D4,(\tau)] = |pa_0[D2,D4,(\tau)]|^2 = \{(R_1/4)(1 + r_{3V})^2\} = \{0.499\}$$

If the time difference between the detection of a signal photon in the Transmitter in detector D2, and the detection in the Receiver of the idler photon of the down-converted pair in either detector D3 or D4 is equal to (τ-500nsec), then there is no ambiguity as to which paths the photons travelled.

The signal photon travelled to the Transmitter and was detected in detector D2 with probability amplitude $pa_0(D2,1)$, and the idler photon travelled to the Receiver and then passed through the short path through the MZ to detector D3 or detector D4.

Because there is no ambiguity, non-local, two-photon interference does not occur. The probability amplitudes and probabilities in this case are:

$$pa_0[D2,D3,(\tau\text{-500nsec})] = (-r_1)(+it_4 t_5) = -i(0.367)$$

$$P_0[D2,D3,(\tau\text{-500nsec})] = \{R_1/4\} = \{0.135\}$$

$$pa_0[D2,D4,(\tau\text{-500nsec})] = (-r_1)(-t_4 r_5) = +(0.367)$$

$$P_0[D2,D4,(\tau\text{-500nsec})] = \{R_1/4\} = \{0.135\}$$

In the binary zero case, the probabilities for the detection of idler photons in detectors D3 and D4 in the Receiver are:

$$P_0[D3] = \{0.115\} + \{0.001\} + \{0.135\} = \{0.251\}$$

$$P_0[D4] = \{0.115\} + \{0.499\} + \{0.135\} = (0.749\}$$

4b. Binary One

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

The idler photon of a down-converted pair that is created in the PPLN exits from the Source and travels to the Receiver. The signal photon of the pair exits from the Source as two possible components and travels to the Transmitter.

The optical path length from the Source to the Transmitter is somewhat less than the optical path length from the Source to the Receiver. This ensures that every signal photon of a down-converted pair will be incident on a detector in the Transmitter before the idler photon of the pair reaches the Receiver.

At the Receiver, the V polarized idler photon travels to the MZ. The idler photon then passes through either the short path or the long path through the MZ and is incident on either detector D3 or detector D4.

At the Transmitter, the first V polarized signal photon component with probability amplitude pa(Tx,0,V) is incident on PABS3 of the OC. The V polarized component may reflect at PABS3, or it may pass through PABS3. If it reflects at PABS3, the component travels to and reflects at PBS2 and is incident on detector D2. The probability amplitude in this case is:

$pa_1(D2,0) = +r_1 r_{3V}$

Instead, if the V polarized component passes through PABS3, it travels around in the OC to the PC. In the binary one case, the PC is turned on. When turned on, the PC operates on a "50/50" duty cycle: a repetitive cycle of 500 nanoseconds on, then 500 nanoseconds off.

There is no synchronization between the Transmitter and the Source, so the first component of the signal photon that is travelling through the OC may arrive at the PC while the PC is on, or while it is off.

On average in the binary one case, the probability that the first component of the signal photon will pass through the PC during the time that the PC is off is equal to one-half. In this case, the results are the same as in the binary zero case:

$P_0[D3] = \{0.251\}$

$P_0[D4] = (0.749\}$

On average in the binary one case, the probability that the first component of the signal photon will pass through the PC during the time that the PC is on is also equal to one-half. In this case, the polarization direction of the first component will be rotated, and it will exit from the PC as an H polarized component.

The now H polarized first component travels to and passes through PABS3 (T_{3H} = 1.0), then travels to and passes through PBS2, and is incident on detector D1. The probability amplitude in this case is:

$pa_1(D1,1) = +ir_1t_{3V}$

It is assumed that the optical path distance from PABS3 through OF2 to the input of the PC is very much greater than the optical path distance from the output of the PC to PABS3 and then to PBS2 and the detectors.

Because of the short optical path distance from the PC to detector D1, in almost all cases, when the H polarized first component with probability amplitude $pa_1(D1,1)$ reaches detector D1, the PC will still be on.

As the H polarized first component passes through PABS3, the V polarized second component from the Source arrives at PABS3. This V polarized second component may reflect at PABS3, or it may pass through PABS3. If it reflects at PABS3, the component travels to and reflects at PBS2 and is incident on detector D2. The probability amplitude in this case is:

$pa_1(D2,1) = -t_1r_{3V} = -r_1r_{3V}^2$

In almost all cases, if the first component of the signal photon passes through the PC during the time that the PC is on, then the V polarized second component with probability amplitude $pa_1(D2,1)$ will reach detector D2 while the PC is on.

The component of the signal photon with probability amplitude $pa_1(D2,1)$ will be incident on detector D2 at a time equal to 500 nanoseconds, after the component with probability amplitude $pa_1(D2,0)$ was incident on detector D2. In almost all cases, if the first component of the signal photon (that passed through PABS3) passes through the PC during the time that the PC is on, then the V polarized first component (that reflected at PABS3) reached detector D2 with probability amplitude $pa_1(D2,0)$ while the PC was off.

Instead, if the V polarized second component passes through PABS3, it travels around in the OC to the PC. Since the PC was on at the time that the first component arrived at the PC, the PC will be off when this second component arrives 500 nanoseconds later. The second component passes through the PC unchanged and travels to PABS3 still V polarized.

At PABS3, this V polarized second component may pass through PABS3, or it may reflect at PABS3 and re-enter the OC. If the V polarized component passes through PABS3, it travels to and reflects at PBS2, and is incident on detector D2. The probability amplitude in this case is:

$pa_1(D2,2) = +t_1t_{3V}^2 = +r_1r_{3V}t_{3V}^2$

Because of the short optical path distance from the PC to detector D2, in almost all cases, when the V polarized second component with probability amplitude $pa_1(D2,2)$ reaches detector D2, the PC will be off.

The component of the signal photon with probability amplitude $pa_1(D2,2)$ will be incident on detector D2 at a time equal to 500 nanoseconds, after the component with probability amplitude $pa_1(D2,1)$ was incident on detector D2.

Instead of passing through PABS3, the V polarized second component may reflect at PABS3 and again travel around in the OC to the PC. Since the PC was off when the second component reached the PC during the previous cycle, the PC will be on when this V polarized component arrives 500 nanoseconds later.

As it passes through the PC, the polarization direction of the component will be rotated, and it will exit from the PC as an H polarized component. The now H polarized component travels to and passes through PABS3 ($T_{3H} = 1.0$), then travels to and passes through PBS2, and is incident on detector D1. The probability amplitude in this case is:

$pa_1(D1,3) = -it_1t_{3V}r_{3V} = -ir_1t_{3V}r_{3V}^2$

The component of the signal photon with probability amplitude $pa_1(D1,3)$ will be incident on detector D1 at a time equal to 1 microsecond, after the component with probability amplitude $pa_1(D1,1)$ was incident on detector D1.

If the signal photon of a down-converted pair travels from the Source to the Transmitter and is detected in detector D2 with probability amplitude $pa_1(D2,0)$, and the idler photon of the pair travels to the Receiver, passes through the short path through the MZ, and is detected in either detector D3 or D4, then the time between the detection of the signal photon in the Transmitter and the idler photon in the Receiver is equal to τ. Note that $\tau >> 500$ nanoseconds.

The following analysis is for those cases when the PC is on during the time that the first component of the signal photon initially passes through the PC.

If the time difference between the detection of a signal photon in the Transmitter in detector D2, and the detection in the Receiver of the idler photon of the down-converted pair in either detector D3 or D4 is equal to (τ+500nsec), then there is no ambiguity as to which paths the photons travelled.

The signal photon travelled to the Transmitter and was detected in detector D2 with probability amplitude $pa_1(D2,0)$, and the idler photon travelled to the Receiver and then passed through the long path through the MZ to detector D3 or detector D4.

Because there is no ambiguity, non-local, two-photon interference does not occur. The probability amplitudes and probabilities in this case are:

With $R_1 = 0.540$; $R_{3V} = 0.85$:

$$pa_1[D2,D3,(\tau+500nsec)] = (+r_1 r_{3V})(+ir_4 r_5) = +i(0.339)$$

$$P_1[D2,D3,(\tau+500nsec)] = \left|pa_1[D2,D3,(\tau+500nsec)]\right|^2$$

$$= \{R_1 R_{3V}/4\} = \{0.115\}$$

$$pa_1[D2,D4,(\tau+500nsec)] = (+r_1 r_{3V})(+r_4 t_5) = +(0.339)$$

$$P_1[D2,D4,(\tau+500nsec)] = \left|pa_1[D2,D4,(\tau+500nsec)]\right|^2$$

$$= \{R_1 R_{3V}/4\} = \{0.115\}$$

If the time difference between the detection of a signal photon in the Transmitter in detector D2 while the PC is off, and the detection in the Receiver of the idler photon of the down-converted pair in either detector D3 or D4 is equal to τ, then there is no ambiguity as to which paths the photons travelled.

The signal photon travelled to the Transmitter and then was detected in detector D2 with probability amplitude $pa_1(D2,0)$, and the idler photon travelled to the Receiver and then passed through the short path through the MZ to detector D3 or detector D4.

Because there is no ambiguity, non-local, two-photon interference does not occur. The probability amplitudes and probabilities in this case are:

$$pa_1[D2,D3,(\tau),PCoff] = (+r_1 r_{3V})(+it_4 t_5) = +i(0.339)$$

$P_1[D2,D3,(\tau),PCoff] = |pa_1[D2,D3,(\tau),PCoff]|^2 = \{R_1R_{3V}/4\} = \{0.115\}$

$pa_1[D2,D4,(\tau),PCoff] = (+r_1r_{3V})(-t_4r_5) = -(0.339)$

$P_1[D2,D4,(\tau),PCoff] = |pa_1[D2,D4,(\tau),PCoff]|^2 = \{R_1R_{3V}/4\} = \{0.115\}$

If the time difference between the detection of a signal photon in the Transmitter in detector D2 while the PC is on, and the detection in the Receiver of the idler photon of the down-converted pair in either detector D3 or D4 is equal to τ, then there is no ambiguity as to which paths the photons travelled.

The signal photon travelled to the Transmitter and then was detected in detector D2 with probability amplitude $pa_1(D2,1)$, and the idler photon travelled to the Receiver and then passed through the long path through the MZ to detector D3 or detector D4.

Because there is no ambiguity, non-local, two-photon interference does not occur. The probability amplitudes and probabilities in this case are:

$pa_1[D2,D3,(\tau),PCon] = (-r_1r_{3V}^2)(+ir_4r_5) = -i(0.312)$

$P_1[D2,D3,(\tau),PCon] = |pa_1[D2,D3,(\tau),PCon]|^2 = \{R_1R_{3V}^2/4\} = \{0.097\}$

$pa_1[D2,D4,(\tau),PCon] = (-r_1r_{3V}^2)(+r_4t_5) = -(0.312)$

$P_1[D2,D4,(\tau),PCon] = |pa_1[D2,D4,(\tau),PCon]|^2 = \{R_1R_{3V}^2/4\} = \{0.097\}$

If the time difference between the detection of a signal photon in the Transmitter in detector D2 while the PC is on, and the detection in the Receiver of the idler photon of the down-converted pair in either detector D3 or D4 is equal to (τ-500nsec), then there is no ambiguity as to which paths the photons travelled.

The signal photon travelled to the Transmitter and then was detected in detector D2 with probability amplitude $pa_1(D2,1)$, and the idler photon travelled to the Receiver and then passed through the short path through the MZ to detector D3 or detector D4.

Because there is no ambiguity, non-local, two-photon interference does not occur. The probability amplitudes and probabilities in this case are:

$pa_1[D2,D3,(\tau-500nsec),PCon] = (-r_1r_{3V}^2)(+it_4t_5) = -i(0.312)$

$P_1[D2,D3,(\tau-500nsec),PCon] = |pa_1[D2,D3,(\tau-500nsec),PCon]|^2$

$= \{R_1R_{3V}^2/4\} = \{0.097\}$

$pa_1[D2,D4,(\tau\text{-}500nsec),PCon] = (-r_1r_{3V}{}^2)(-t_4r_5) = +(0.312)$

$P_1[D2,D4,(\tau\text{-}500nsec),PCon] = |pa_1[D2,D4,(\tau\text{-}500nsec),PCon]|^2$

$= \{R_1R_{3V}{}^2/4\} = \{0.097\}$

If the time difference between the detection of a signal photon in the Transmitter in detector D2 while the PC is off, and the detection in the Receiver of the idler photon of the down-converted pair in either detector D3 or D4 is equal to (τ-500nsec), then there is no ambiguity as to which paths the photons travelled.

The signal photon travelled to the Transmitter and then was detected in detector D2 with probability amplitude pa_1(D2,2), and the idler photon travelled to the Receiver and then passed through the long path through the MZ to detector D3 or detector D4.

Because there is no ambiguity, non-local, two-photon interference does not occur. The probability amplitudes and probabilities in this case are:

$pa_1[D2,D3,(\tau\text{-}500nsec),PCoff] = (+r_1r_{3V}t_{3V}{}^2)(+ir_4r_5) = +i(0.051)$

$P_1[D2,D3,(\tau\text{-}500nsec),PCoff] = |pa_1[D2,D3,(\tau\text{-}500nsec),PCoff]|^2$

$= \{(R_1R_{3V}T_{3V}{}^2)/4\} = \{0.003\}$

$pa_1[D2,D4,(\tau\text{-}500nsec),PCoff] = (+r_1r_{3V}t_{3V}{}^2)(+r_4t_5) = +(0.051)$

$P_1[D2,D4,(\tau\text{-}500nsec),PCoff] = |pa_1[D2,D4,(\tau\text{-}500nsec),PCoff]|^2$

$= \{(R_1R_{3V}T_{3V}{}^2)/4\} = \{0.003\}$

If the time difference between the detection of a signal photon in the Transmitter in detector D2, and the detection in the Receiver of the idler photon of the down-converted pair in either detector D3 or D4 is equal to (τ-1μsec), then there is no ambiguity as to which paths the photons travelled.

The signal photon travelled to the Transmitter and was detected in detector D2 with probability amplitude pa_1(D2,2), and the idler photon travelled to the Receiver and then passed through the short path through the MZ to detector D3 or detector D4.

Because there is no ambiguity, non-local, two-photon interference does not occur. The probability amplitudes and probabilities in this case are:

$pa_1[D2,D3,(\tau-1\mu sec)] = (+r_1 r_{3V} t_{3V}^2)(+it_4 t_5) = +i(0.051)$

$P_1[D2,D3,(\tau-1\mu sec)] = |pa_1[D2,D3,(\tau-1\mu sec)]|^2$

$= \{R_1 R_{3V} T_{3V}^2/4\} = \{0.003\}$

$pa_1[D2,D4,(\tau-1\mu sec)] = (+r_1 r_{3V} t_{3V}^2)(-t_4 r_5) = -(0.051)$

$P_1[D2,D4,(\tau-1\mu sec)] = |pa_1[D2,D4,(\tau-1\mu sec)]|^2$

$= \{R_1 R_{3V} T_{3V}^2/4\} = \{0.003\}$

If the time difference between the detection of a signal photon in the Transmitter in detector D1, and the detection in the Receiver of the idler photon of the down-converted pair in either detector D3 or D4 is equal to τ, then there is no ambiguity as to which paths the photons travelled.

The signal photon travelled to the Transmitter and was detected in detector D1 with probability amplitude $pa_1(D1,1)$, and the idler photon travelled to the Receiver and then passed through the long path through the MZ to detector D3 or detector D4.

Because there is no ambiguity, non-local, two-photon interference does not occur. The probability amplitudes and probabilities in this case are:

$pa_1[D1,D3,(\tau)] = (+ir_1 t_{3V})(+ir_4 r_5) = -(0.142)$

$P_1[D1,D3,(\tau)] = |pa_1[D1,D3,(\tau)]|^2 = \{R_1 T_{3V}/4\} = \{0.020\}$

$pa_1[D1,D4,(\tau)] = (+ir_1 t_{3V})(+r_4 t_5) = +i(0.142)$

$P_1[D1,D4,(\tau)] = |pa_1[D1,D4,(\tau)]|^2 = \{R_1 T_{3V}/4\} = \{0.020\}$

If the time difference between the detection of a signal photon in the Transmitter in detector D1, and the detection in the Receiver of the idler photon of the down-converted pair in either detector D3 or D4 is equal to (τ-500nsec), then there is no ambiguity as to which paths the photons travelled.

The signal photon travelled to the Transmitter and was detected in detector D1 with probability amplitude $pa_1(D1,1)$, and the idler photon travelled to the Receiver and then passed through the short path through the MZ to detector D3 or detector D4.

Because there is no ambiguity, non-local, two-photon interference does not occur. The probability amplitudes and probabilities in this case are:

$pa_1[D1,D3,(\tau\text{-}500nsec)] = (+ir_1t_{3V})(+it_4t_5) = -(0.142)$

$P_1[D1,D3,(\tau\text{-}500nsec)] = |pa_1[D1,D3,(\tau\text{-}500nsec)]|^2$

$= \{R_1T_{3V}/4\} = \{0.020\}$

$pa_1[D1,D4,(\tau\text{-}500nsec)] = (+ir_1t_{3V})(-t_4r_5) = -i(0.142)$

$P_1[D1,D4,(\tau\text{-}500nsec)] = |pa_1[D1,D4,(\tau\text{-}500nsec)]|^2$

$= \{R_1T_{3V}/4\} = \{0.020\}$

If the time difference between the detection of a signal photon in the Transmitter in detector D1, and the detection in the Receiver of the idler photon of the down-converted pair in either detector D3 or D4 is equal to (τ-1µsec), then there is no ambiguity as to which paths the photons travelled.

The signal photon travelled to the Transmitter and was detected in detector D1 with probability amplitude $pa_1(D1,3)$, and the idler photon travelled to the Receiver and then passed through the long path through the MZ to detector D3 or detector D4.

Because there is no ambiguity, non-local, two-photon interference does not occur. The probability amplitudes and probabilities in this case are:

$pa_1[D1,D3,(\tau\text{-}1\mu sec)] = (-ir_1t_{3V}r_{3V}^2)(+ir_4r_5) = +(0.121)$

$P_1[D1,D3,(\tau\text{-}1\mu sec)] = |pa_1[D1,D3,(\tau\text{-}1\mu sec)]|^2$

$= \{R_1T_{3V}R_{3V}^2/4\} = \{0.015\}$

$pa_1[D1,D4,(\tau\text{-}1\mu sec)] = (-ir_1t_{3V}r_{3V}^2)(+r_4t_5) = -i(0.121)$

$P_1[D1,D4,(\tau\text{-}1\mu sec)] = |pa_1[D1,D4,(\tau\text{-}1\mu sec)]|^2$

$= \{R_1T_{3V}R_{3V}^2/4\} = \{0.015\}$

If the time difference between the detection of a signal photon in the Transmitter in detector D1, and the detection in the Receiver of the idler photon of the down-converted pair in either detector D3 or D4 is equal to (τ-1.5μsec), then there is no ambiguity as to which paths the photons travelled.

The signal photon travelled to the Transmitter and was detected in detector D1 with probability amplitude pa_1(D1,3), and the idler photon travelled to the Receiver and then passed through the short path through the MZ to detector D3 or detector D4.

Because there is no ambiguity, non-local, two-photon interference does not occur. The probability amplitudes and probabilities in this case are:

$$pa_1[D1,D3,(\tau-1.5\mu sec)] = (-ir_1t_{3V}r_{3V}^2)(+it_4t_5) = +(0.121)$$

$$P_1[D1,D3,(\tau-1.5\mu sec)] = \left|pa_1[D1,D3,(\tau-1.5\mu sec)]\right|^2$$

$$= \{R_1T_{3V}R_{3V}^2/4\} = \{0.015\}$$

$$pa_1[D1,D4,(\tau-1.5\mu sec)] = (-ir_1t_{3V}r_{3V}^2)(-t_4r_5) = +i(0.121)$$

$$P_1[D1,D4,(\tau-1.5\mu sec)] = \left|pa_1[D1,D4,(\tau-1.5\mu sec)]\right|^2$$

$$= \{R_1T_{3V}R_{3V}^2/4\} = \{0.015\}$$

This analysis concerns a single signal photon. All of the components are of the same signal photon. All possible components that can exist (that are not forbidden) do exist. A given signal photon can only be detected at one event: in one detector, at one time.

For the case when the first component of the signal photon enters the OC and passes through the PC while the PC is on, the probabilities for the detection of idler photons in detectors D3 and D4 in the Receiver are:

$$P_1'[D3] = \{0.115\} + \{0.115\} + \{0.097\} + \{0.097\} + \{0.003\} + \{0.003\}$$

$$+ \{0.020\} + \{0.020\} + \{0.015\} + \{0.015\} = \{0.500\}$$

$$P_1'[D4] = \{0.115\} + \{0.115\} + \{0.097\} + \{0.097\} + \{0.003\} + \{0.003\}$$

$$+ \{0.020\} + \{0.020\} + \{0.015\} + \{0.015\} = \{0.500\}$$

In the binary one case, on average, the probability that the first component of the signal photon will pass through the PC while the PC is on is equal to the probability that the first component of the signal photon will pass through the PC while the PC is off.

Overall, in the binary one case, the probabilities for the detection of idler photons in detectors D3 and D4 in the Receiver are:

$P_1[D3] = [(0.5)\{0.500\}] + [(0.5)\{0.251\}] = \{0.375\}$

$P_1[D4] = [(0.5)\{0.500\}] + [(0.5)\{0.749\}] = \{0.625\}$

An integration time is required for proper system operation. The set integration time (I) required per bit must be of adequate duration to guarantee that a sufficient number of signal and idler photon pairs will be detected, signal photons at the Transmitter and idler photons at the Receiver, 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. Integration time I must also take into account all system losses.

5. Conclusion

The binary zero and binary one messages produce different detection probabilities at the Receiver. The difference between the detection probabilities in detectors D3 and D4 is greater in the binary zero case than in the binary one case:

$\Delta_0 = (P_0[D4] - P_0[D3]) = 0.749 - 0.251 = 0.498$

$\Delta_1 = (P_1[D4] - P_1[D3]) = 0.625 - 0.325 = 0.250$

$\Delta_0 > \Delta_1$

The operator at the Receiver notes whether the detections in detectors D3 and D4 correspond to a binary zero or a binary one message.

Communication may begin once signal photons from the Source reach the Transmitter and idler photons reach the Receiver. The transfer of information from the Transmitter to the Receiver is almost instantaneous (independent of distance), limited only by the required integration time per bit (I).

The time required to transmit one bit of information from the Transmitter to the Receiver is equal to I. The distance (D) associated with the integration time is:

$D = c \bullet I$

If the distance between the Transmitter and the Receiver is greater than D, then, using this system, the speed of transmission of information from Transmitter to Receiver can be faster than the speed of light.

Delphi 5 is a superluminal communication system.

In this paper, the variable designation “pa” is used, rather than “Ψ”, to emphasize that the probability amplitude is a unitless complex number (only). Probability amplitude is the square root of a probability. It is not energy, matter, or field, but probability amplitude controls the Universe.

It seems unlikely that the “communication” that occurs during quantum entanglement is due to any of the four currently-known forces of Nature. Perhaps some as yet unidentified “dark force” is responsible for this phenomenon.

References

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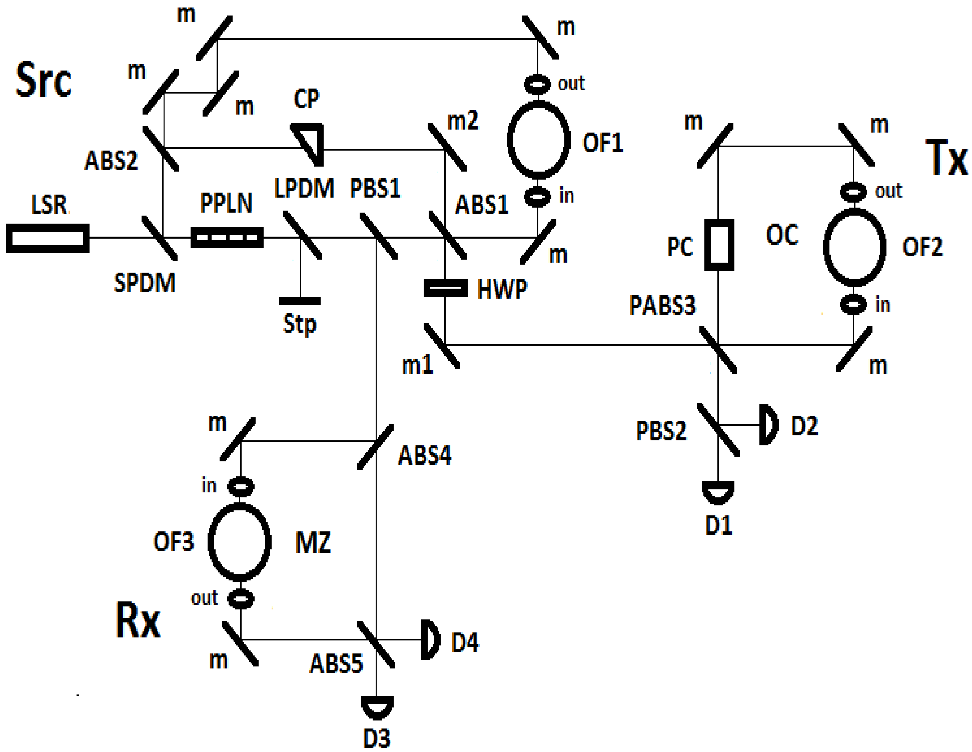

Figure 1: System Design