Electronic tracking system for quantum cryptography and radio telecommunication

M Mariola[1], Y Ismail[1], A Mirza[1], F Petruccione[1,2]

[1]University of KwaZulu-Natal, Westville Campus, Durban, South Africa
[2]National Institute for Theoretical Physics (KZN), Durban, South Africa

E-mail: Mariolam@ukzn.ac.za

Abstract. In optical and radio communications the transmitter and receiver should be aligned in order to transmit and receive the data. The perfect alignment in optical communication is vital to ensure a low bit error rate and in radio communications, a correct alignment between the antennas maximizes the power received. Quantum cryptography in free-space permits to share an encryption key between a transmitter and receiver, where the bits of the key are sent in the form of polaraised single photons. The electronic system presented below is able to align the transmitter and receiver as well as the polarization bases of the transmitter and receiver using a polarised laser beacon transmitted form the receiver. The electronic system measures the intensity of the laser beacon in order to align the polarization basis and through the knowledge of three geographical coordinates it is possible to adjust the transmitter in the direction of the receiver.

1. Introduction

Quantum cryptography is topical of late due its influences in optical communication. Quantum cryptography is a process of ensuring the security of information between numerous entities. The generic quantum crypto scheme consists of a transmitter and receiver, which are conventionally known as Alice and Bob respectively, as well as some medium to transfer information known as a quantum channel. Information is transferred in the form of quantum carriers or more specifically single photons. In the holistic scheme Alice transmits a string of photons to Bob through a medium that could either be free-space or fibre. This process is followed by a measurement and sifting process which results in the distribution of a raw key. Further privacy amplification performed on the raw key results in the procurement of a final key which can be used to encrypt and decrypt information. The quantum carriers used to generate the key can be encoded through polarisation or phase. For free-space communication it is preferable to encode using the polarisation state of light due to the negligence of the change of state under the influence of turbulence. The advantage quantum cryptography has over classical systems is that it is governed by the laws of quantum mechanics specifically by the Heisenberg Uncertainty principle and the no-cloning theorem [1], hence any external interferences leaves traces in the system which can be traced.

The first quantum cryptography protocol proposed by Bennet and Brassard, known as BB84 [2], utilised single photons encoded in the polarisation state. This protocol makes use of two non-orthogonal polarisation bases, namely the rectilinear and diagonal bases, to prepare and measure the transmitted photons. In the case where the quantum channel is a free-space

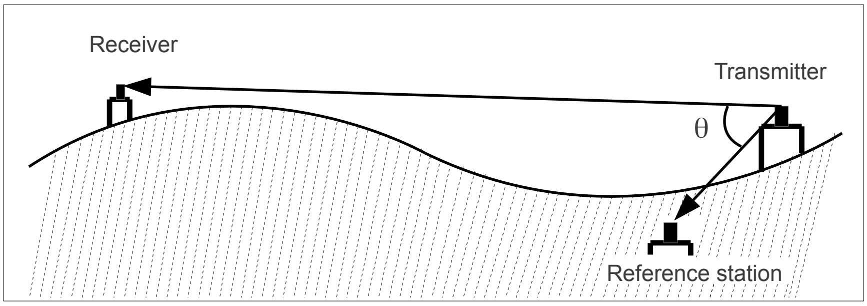


Figure 1. Scheme of the tracking. The coordinates of the receiver and the reference station, are transmitted to the transmitter. The reference station is located near the transmitter. The laser beacon is directed towards the reference station by a manual or automatic control and by processing the coordinates is able to know the direction of rotation and the angle.

medium with a line of sight, the alignment of the polarisation bases of the transmitter and receiver becomes crucial for the successful implementation of the key distribution process. If the polarisation bases of the transmitter and receiver are not aligned, the Quantum Bit Error Rate (QBER) increases. For the procurement of a final key, the QBER should not exceed a threshold percentage dependent on the protocol being implemented. Experimentally if the misalignment angle is lower than 20° the QBER that is obtained is acceptable to identify the presence of interference within the quantum channel [3].

The Electronic system must be able to align the bases with an error lower than 20° since for optical communication it is necessary that the system is able to align the transmitter in the direction of the receiver and vice-versa. In the proposed system a polarised laser beacon directed from the receiver to the transmitter is considered. The laser beacon carries the information about the polarisation bases direction of the receiver and can be exploited to collimate the transmitter and receiver with a minimum error. This system can be used as a coarse alignment for optical communication and fine alignment for radio communication.

2. Tracking

Classical alignment systems use the geographical coordinates of the transmitter and the receiver and include the Hall effect and the direction of the Earth magnetic field to coarsely align two points namely the transmitter and receiver. Unfortunately the terrestrial magnetic field is not homogeneous due to the geology of the Earth, as for example the Reunion Island magnetic field results in a deviation with respect to the north pole greater than 25° [4]. Other systems include exploiting the stars as a reference frame, however in this case it is necessary to know the map of the sky for each geographical position for a particular time.

In our system three geographical positions were used. The first geographical position is indicative of the position of the transmitter. The second position, called the reference station, is located near the transmitter and is used as a reference point. The third and last position is referred to the receiver. The coordinates of the reference station and receiver, are transmitted to the transmitter side. Once the electronic device receives the coordinates, using vectorial calculus, it is possible to determine the angle θ between the line of sight of the transmitter-reference station and that of the transmitter-receiver as shown in Figure 1. A microcontroller is used to calculate the angle θ using single precision from which the errors, due to the approximation is less than 0.5° as shown in Table 1. The microcontroller has a limited number of digital pins to control other external devices such as the controls for the motors of the optics. For the aforementioned reason, a stack of shift registers is used for serial to parallel conversion hence using a limited

Table 1. **Test 1**: Coordinates of the transmitter, receiver and reference station on the south hemisphere; **Test 2**: Coordinates of the transmitter, receiver and reference station on the north hemisphere; λ, μ is the latitude and longitude of the transmitter TX, reference station Rf and the receiver RX; $\theta_{\mathbf{G}}$ angle between the direction transmitter-reference station and transmitter-receiver measured by Google maps; $\theta_{\mathbf{m}}$:angle between the direction transmitter-reference station and transmitter-receiver calculated by the micro-controller; ϵ_θ is the difference between the calculate and the measured angle; **d**: distance between the transmitter and receiver in km.

	Test 1	Test 2
λ_{TX}	-29.060006944	41.43288333
μ_{TX}	27.24506667	12.83350833
λ_{Rf}	-29.05515000	41.43427500
μ_{Rf}	27.23995833	12.83227778
λ_{RX}	-29.00026667	41.48340278
μ_{RX}	27.30960833	13.32911667
θ_G	85.6100	115.6700
θ_m	85.8719	115.7889
ϵ_θ	0.2619	0.1189
$d(km)$	9.1357	41.7860

number of digital pins of the microcontroller. The system is now able to control the motors required to turn the mount of the laser and the optics in order to measure the single photons.

3. Polarisation basis alignment

The laser beacon is polarised with a direction of 45° which respect to the vertical polarisation basis used to receive the single photons. The receiver directs the laser beacon to the transmitter in order to align its vertical polarisation basis with the vertical polarization base used to transmit the single photons. At the transmitter the direction of polarisation of the laser beacon is measured. The vertical polarisation basis of the transmitter should also be tilted by 45° with respect to the direction of polarisation of the laser beacon. The bases are aligned when the transmitter measures 45° with respect to the polarisation of the laser beacon as shown in Figure 2. Once the tilt angle is acquired, the transmitter turns the polarisation bases. The core optics

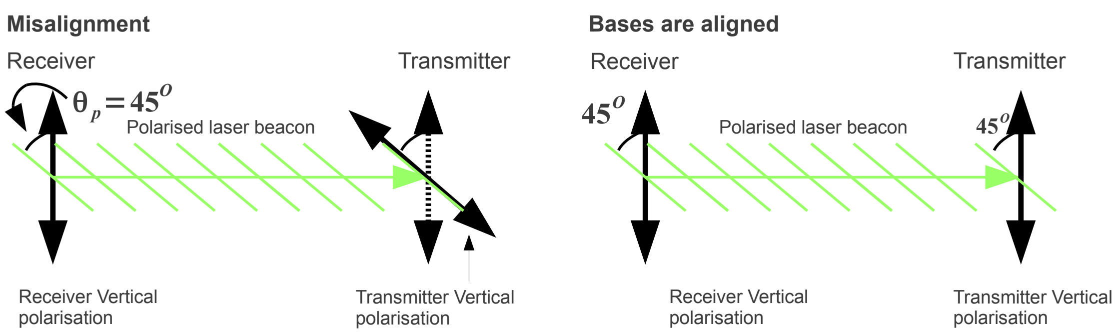


Figure 2. The receiver transmits the polarised laser beacon to the transmitter. The transmitter turns its bases when the polarisation of the laser beacon is 45° which respect to vertical polarisation bases.

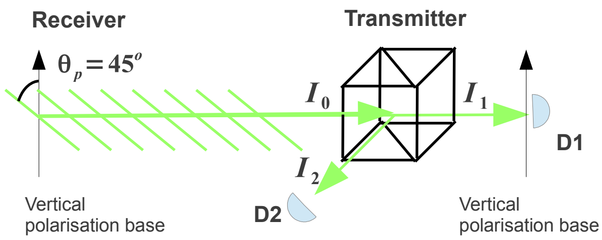


Figure 3. The PBS splits the laser beacon into two paths with the intensity I_1 and I_2 respectively. When the system measures $I_1 = I_2$ the polarisation bases are aligned.

used to measure the tilt angle of the polarisation alignment is a Polarising Beam Splitter (PBS) [5]. As shown in Figure 3, the intensity received by the transmitter is I_o. The PBS splits the intensity I_0 into two paths according to the following equation:

$$I_1 = I_0 \cos^2(\theta_p), \tag{1}$$

$$I_2 = I_0 \sin^2(\theta_p). \tag{2}$$

The tilt angle θ_p can be calculated using the equation:

$$\theta_p = \arctan \sqrt{\frac{I_2}{I_1}}. \tag{3}$$

Equations (1), (2) and (3) follow the ideal behavior of the PBS. Since the PBS is optimized for an angle $\theta_p = 45°$, it is necessary to characterize the PBS to find an error function $\Delta\theta_p(I_1, I_2)$ calculated form the normalized values of I_1 and I_2. The tilt angle θ_p is calculated by Equation (4).

$$\theta_p = \arctan \sqrt{\frac{I_2}{I_1}} + \Delta\theta_p(I_1, I_2). \tag{4}$$

The signals I_1 and I_2 are measured using an electronic device that amplifies the signal from the photodiodes D1 and D2 that subsequently are used in a microcontroller unit that calculates the tilt angle using the Equation (4). To simulate the electronic circuits, the intensities I_1 and I_2 were measured for a total power $I_{tot} = I_1 + I_2 = 1.95mW$ and for an angle $0° \leq \theta_p \leq 90°$. The results are shown in Figure 4.

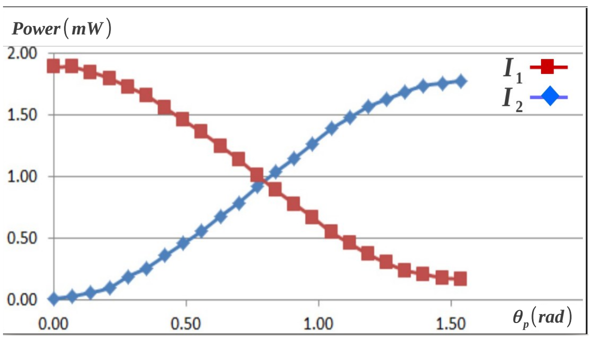


Figure 4. Measurement collected for the electronic simulation for a tilt angle $0° \leq \theta_p \leq 90°$ for a total power of $1.95mW$.

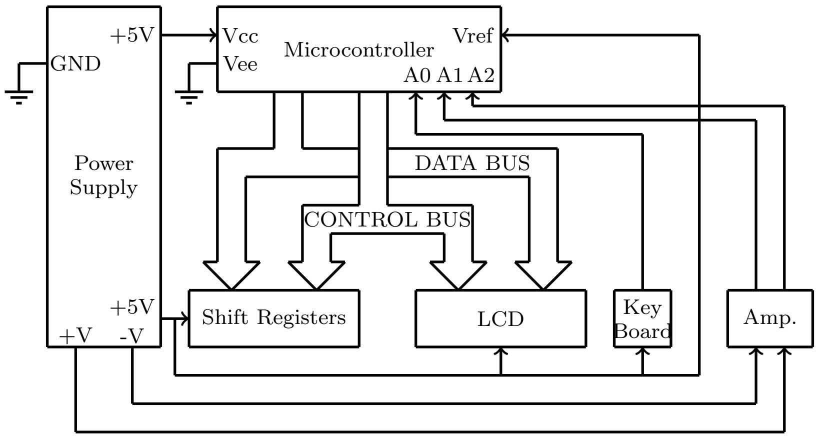
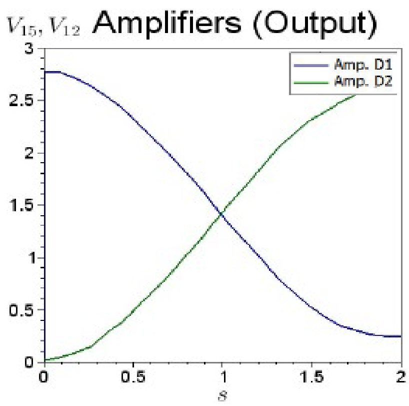


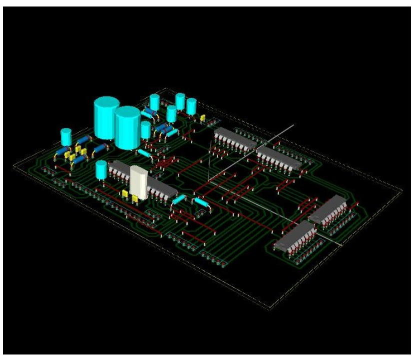
Figure 5. Scheme block of the portable tracking system. The microcontroller has an independent power source of $5V$. The CONTROL BUS and the DATA BUS are unidirectional and are used for the Shift register and for the LCD.

4. The electronics

The electronic devices as shown in Figure 5, consist of a Power supply with two 5 V outputs to supply the microcontroller unit, the shift register stack to control the mechanics of alignment and the LCD display. Two outputs (+V and -V) are used to supply the amplifiers. The signals I_1 and I_2 are amplified through the amplifier block (Amp.) and the amplified signals are sent to the analog to digital converter of the microcontroller indicated with the letter A. These signals are used to calculate the tilt angle of the polarisation bases. The keyboard is used to input the geographical coordinates of the transmitter, receiver and the reference station to the microcontroller Atmel Atmega328-P [6] in order to align the direction of the transmitter and the receiver. To simulate the dynamics of the system, the data are collected for a total power $I_{tot} = 1.95mW$ and for $0° \leq \theta_p \leq 90°$, as explained in section 3. For the simulation the software Ngspice [7] was used and the rotation velocity of polarisation was $45°/s$. The simulation in Figure 6(a) shows that the amplification follows the of the intensity collected from the photodiode D1 and D2. The electronic system proposed in this manuscript was also built



(a) Amplified signals at 1.95mW



(b) 3D rendering of the PCB

Figure 6. (a) Amplifier response for the signal collected from the photodiode D1 and D2. (b) PCB of the elecronic tracking system without the amplifiers.

and tested for a line of sight between the transmitter and receiver. The 3D rendering of the Printed Circuit Board (PCB) is shown in Figure 6(b).

5. Conclusion

In this paper, we presented a tracking system for quantum cryptography and radio telecommunication. Using this system, the transmitter is able to be directed towards the receiver and vice versa. The error of alignment is less than one degree and this fact permits to say that the system can be considered as a fine alignment system for radio telecommunication. In optical communication more accuracy is required and for that reason the system proposed should be used in cooperation with another fine alignment subsystem. The alignment of the polarisation bases used for quantum cryptography does not require future improvement.

Acknowledgments

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