Sidebands modulation scheme with active dispersion compensation for high bit rate QKD

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Abstract

We report a quantum key distribution scheme based on phase coding in frequency domain using standard telecom and RF components. This system operates at 12.5 GHz modulation frequency and includes an active compensation dispersion management and a polarisation insensitive receiver. An Experimental system demonstrated stable quantum bit error rate up to 12 hours on 50 km.

Introduction

The Quantum key distribution (QKD) is a well-known method allowing unconditional secure key generation between legitimate users. Major progress in speed and distance have been realised recently both for free space and fiber impementations [1-3]. For the most advanced QKD systems operating over optical fibers [1,2], the information is encoded in the relative phase between delayed pulses or in polarization. Recently, we proposed an alternate approach where optical pulses are weakly modulated to generate in spectral domain sidebands located aside a central peak. The information is encoded by the relative phase between the sidebands and the central peak [4]. Although this method employs standard integrated optical and RF components, it suffers of limitations in term of stability and bit rate because of 2-GHz frequency modulation used. In what follows, we propose a new architecture based on phase encoding in spectral domain working at 12.5 GHz frequency modulation that potentially allows the use of a high bit rate clock. Active dispersion compensation is demonstrated making the method insensitive to the combination of the high frequency modulation and the transmission distance.

High Frequency modulation quantum key distribution system

The proposed architecture is described in figure 1. The emitter is composed by two single mode lasers (DQ) and (DS) emitting two different wavelength signals, respectively named quantum and synchronisation signals. An electrical signal of 2.5 GHz frequency generated by a voltage control oscillator (VCO) is splitted to drive an integrated intensity modulator (AM) and a QPSK modulator (QPSKM). An I&Q modulator (IQM) and a frequency converter (FC) allow introducing a phase shift and converting the modulation frequency up to 12.5 GHz . In our method, a dc-voltage is applied on DC_1 to set the first section modulator at its null transmission point. The optical signal emerging from this section is composed by two sidebands separated of 25 GHz. None modulation is applied on the RF electrode of the second Mach-Zehnder modulator section. A dc voltage is applied on electrodes DC_2 to set the second modulator at its maximum transmission point. The output of this section is only composed by a central peak. The optical signals issued from the two modulators sections are combined, and a voltage applied on the electrode DC_3 introduces a phase shift between the central peak and the two sidebands. This active control compensates the group-velocity dispersion of the transmission fibre. The quantum and synchronisation signals respectively modulated at 12.5 GHz and 2.5 GHz are then attenuated and launched in a single fibre and transmitted to the receiver. At the receiver, the quantum and synchronisation optical signals are separated with a demultiplexer. An avalanche photodiode (APD) converts the synchronisation optical signal in a 2.5 GHz RF signal. This RF signal is phase shifted and translated at 12.5 GHz by using the method described previously and drives two phase modulators (PM) thus removing the polarization sensitivity of the receiver. This modulation makes interfere the central peak with the two sidebands constituting the optical spectrum of the incoming signal [4]. A Bragg filter (BF) associate to an optical circulator (C), allows separating a single sideband and the central peak. As demonstrated previously, this scheme can be

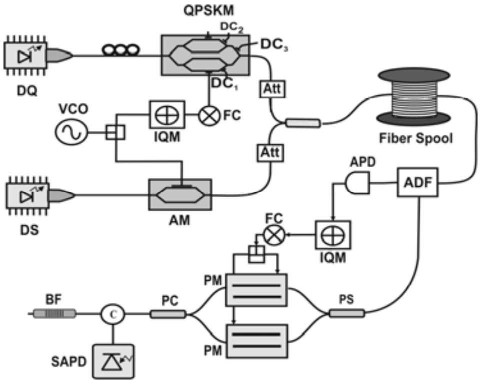

Figure 1: Schematic diagram of the dispersion compensated modulation scheme.

employed to implement a long distance Quantum key distribution [4].

Experiments

The experimental set-up described in figure 1 was implemented on a benchtop with a fiber spool of 50km. At the emitter, two temperature stabilized DFB Laser diodes operating at 1547.7 nm and 1552.7 nm were used respectively as quantum and synchronization signal sources. A RF switch (not shown on the figure 1) curved RF pulses of 5 ns on the 2.5 GHz electric signal before the frequency converter. The pulses were triggered by a 100 kHz-clock signal that controlled any phase changes introduced by the I&Q modulator. The 12.5 GHz pulsed RF signal drove an LiNb03 integrated QPSK modulator. The amplitude modulation was chosen to weakly modulate the quantum signal (10% of the intensity of the central peak). An adjustable attenuator (Att) set the mean photon number to 0.2 photon per 5ns gate in each sideband at the output of the emitter. A second RF switch (not shown on the figure 1) curved square envelope on the 2.5 GHz RF signal driving the $LiNbO_3$ integrated intensity modulator (AM). The amplitude modulation was chosen to strongly modulate the synchronization optical signal. The average optical power of the synchronization signal launched in the fiber was set to -10 dBm. At the receiver, a 2.2 dB-loss tunable add-drop filter separated the optical signals, avoiding any crosstalk between them. The optical synchronization signal was converted in RF signal using high sensitivity avalanche photodiode (sensitivity -33 dBm). A clock recovery circuit (not shown in the figure 1) was used to extract a clock signal allowing i) the synchronization of any phase change between emitter and receiver ii) to gate a single photon avalanche photodiode (SAPD). The second part of RF signal was phase shifted and converted at 12.5 GHz to drive the $LiNbO_3$ phase modulators. A Bragg filters and a circulator were used to separate the single sideband from the central peak. Bandwidth and isolation of the combined filters were respectively equal 0.1 nm and 30dB. The global loss of the receiver was measured to be 7dB. After filtering, the photon were recorded by a cooled avalanche photodiode (Princeton Lightwave) gated by 5ns pulses. The quantum efficiency and the dark count of the photodiode were 10% and 1.10^{-5} respectively. First experiment was performed without attenuating the quantum signal by using a classical detector. The figure 2 represents the visibility of one sideband using the active compensation for different distances. As expected, the phase introduced between the central peak and the sidebands allows correcting perfectly the effect of the dispersion and ensures a visibility around 99 % on several kilometers [5]. A second experiment was carried by turn on the attenuation. Random phase changes necessary to estimate the QBER with single detector were controlled by two computers communicating through a local area network. The figure 3 shows the measured QBER recorded during 12 hours, demonstrating the stability long period of time.

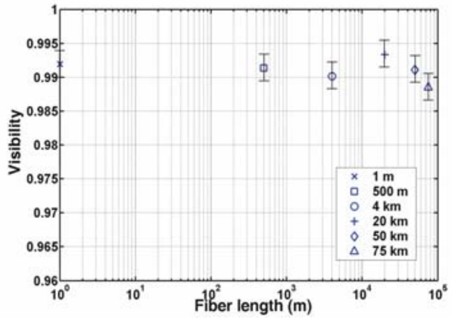

Figure 2: Visibility for different fibre lengths.

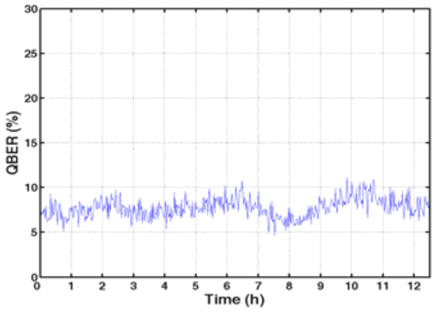

Figure 3: QBER recorded on 50 km (0.2 photon per pulse, 5ns gate, 5ns pulse, APD darkcount: 1.10^{-5} ,APD efficiency: 10%).

Conclusions

In summary, we proposed a new architecture based on phase-coding in frequency domain combining chromatic dispersion management and polarization insensitive receiver. First results demonstrated stable QBER of 7.5% up to 12 hours. Even if the rate is low compared with the most advanced system, we believe the performances can be improved by using high clock rate and single photon up-converter. This work is supported by the Agence National de la Recherche under the HQNET project.

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