10386 Experimental Techniques in Quantum Technology

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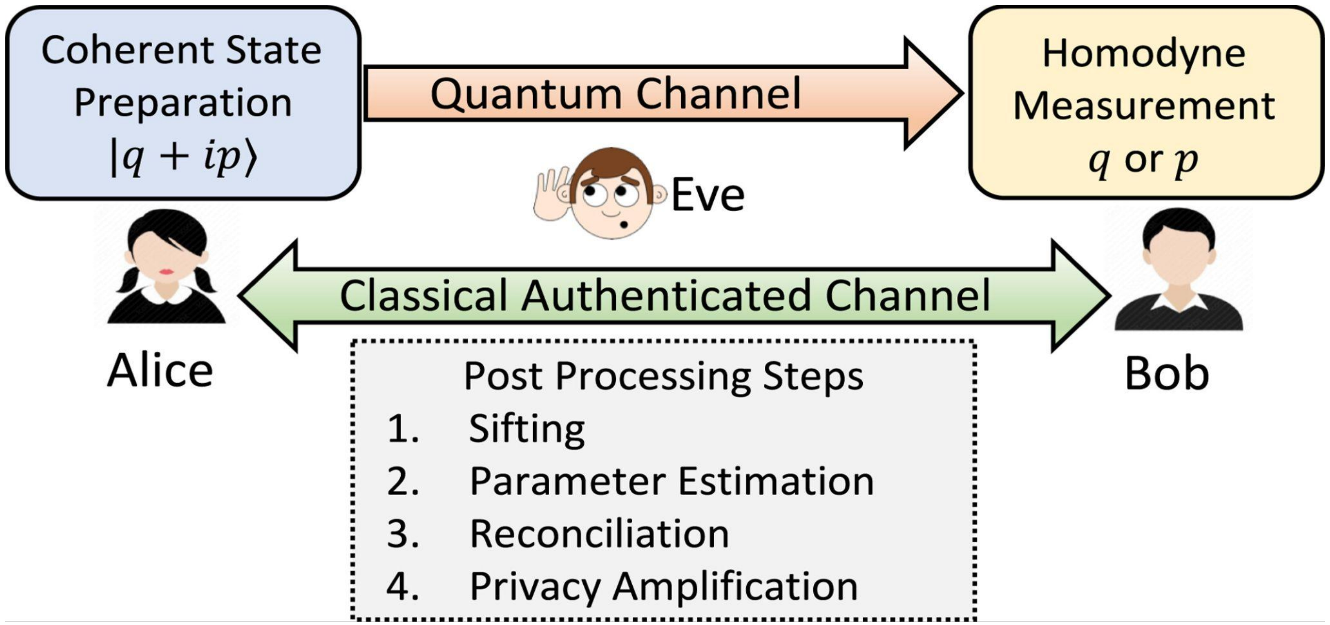
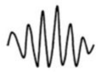
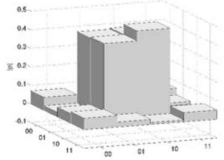
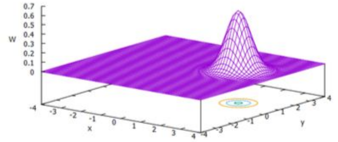
Continuous variable Quantum Key Distribution

Introduction



- Information coded in Continuous variable properties such as the amplitude and phase quadratures
- Coherent Communication: Common phase referencing using a local oscillator (LO)
- CVQKD transmitter: Encode random bits by modulation.
- CVQKD receiver: Decode either amplitude or phase quadrature only (Homodyne)

Comparison to DV-QKD

	DV-QKD	CV-QKD
Year	2019	2019
Light	Discrete Photon 	Continuous Wave 
Information carrier	Photon polarization/phase	Field phase or amplitude
State representation	Density matrix 	Wigner function 
Detector	single-photon detector	Homodyne/Heterodyne
Practical maximum range	104 km (307 km)	202.81 km
Output key rate	12.7 kbps (3.18 bps)	6.24 bps

Initial Implementation

- Choice of states: **Single mode Coherent states**
- Choice of modulation: **Gaussian modulation of Coherent states (GMCS)**
- Choice of detection: **Homodyne Detection**
- Type of Error Correction/Post processing: **Reverse Reconciliation (RR)**
- As usual with QKD, a given protocol has two possible implementations, **prepare and measure (PM) or entanglement based (EB)**, which are known to be equivalent in the case of Gaussian protocols

Why CV-QKD?

Advantages

- Compatibility with classical telecom infrastructure (coherent states and homodyne detection).
- Avoid single-photon detectors (very challenging to produce).
- Higher Key Rate in medium distances (50-100 km) due to high speed modulation and detection.
- No need for single photon sources - use lasers with gaussian modulation instead.

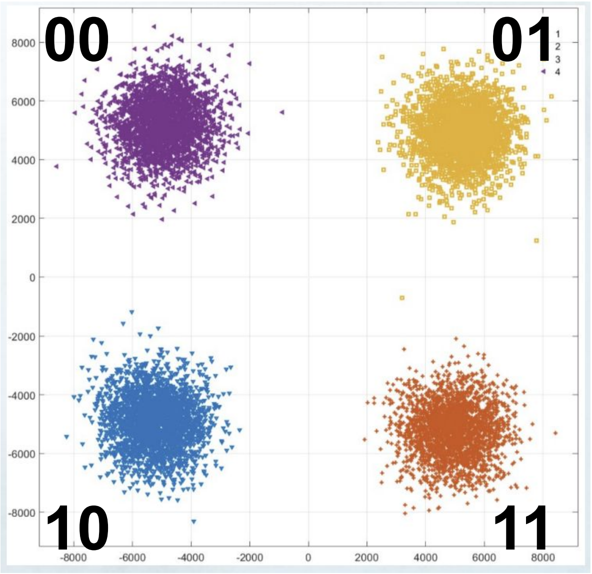
Disadvantages

- Excess noise and channel loss.
- High sensitivity to excess noise.
- Limited security proofs.
- Less intuitive and theoretically complex than DV.

Overview of protocol

Encoding

- Alice encodes information in amplitude (x) and phase (p) quadratures of coherent states.
- Their quadratures are continuous variables.
- **Note:** Alice agrees with Bob on a way of encoding bits into coherent states.



Decoding

- **Homodyne detection:** Bob measures randomly one of the two quadratures.
- He discretizes the measurement into bits.

Sifting

- Bob shares which quadratures he has measured.
- Alice only keeps the bits corresponding to Bob's chosen quadrature.

Post-processing

Reconciliation

- **Goal**: Convert noisy, continuous data into identical binary strings
- Different strategies:
    1. Forward reconciliation (***FR***): Bob corrects his data according to Alice's data
    2. Reverse reconciliation (***RR***): Alice corrects her data to estimate Bob's data

Note: Generally speaking *RR* performs better!

Parameter estimation

- **Goal:** Upper bound Eve's information
- Key rate: $R = \beta I(A:B) - I(A:E)$

Privacy amplification

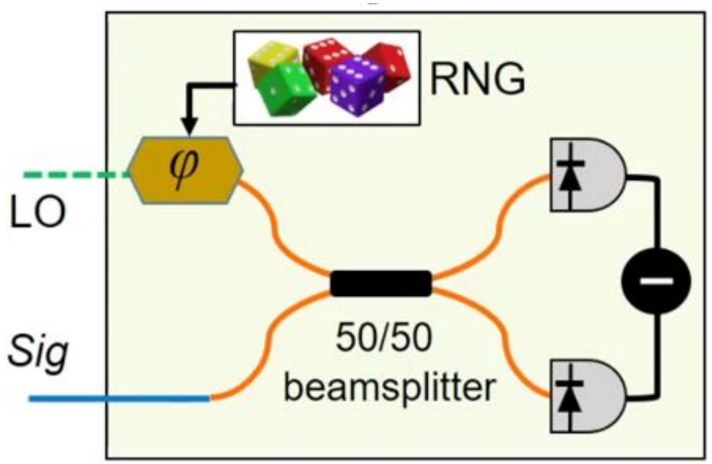
- Alice & Bob share a bit string, but some of these bits might be know to Eve
- **Solution:** Apply hashfunction to sections of the string

Homodyne detection

- Randomly measure **amplitude** or **phase** quadrature, depending on **phase difference φ = {0,π/2}**

- **Advantage:**
    - Higher precision in measurements, i.e. higher SNR.
    - Simpler post-processing techniques
    - Less complex post-processing

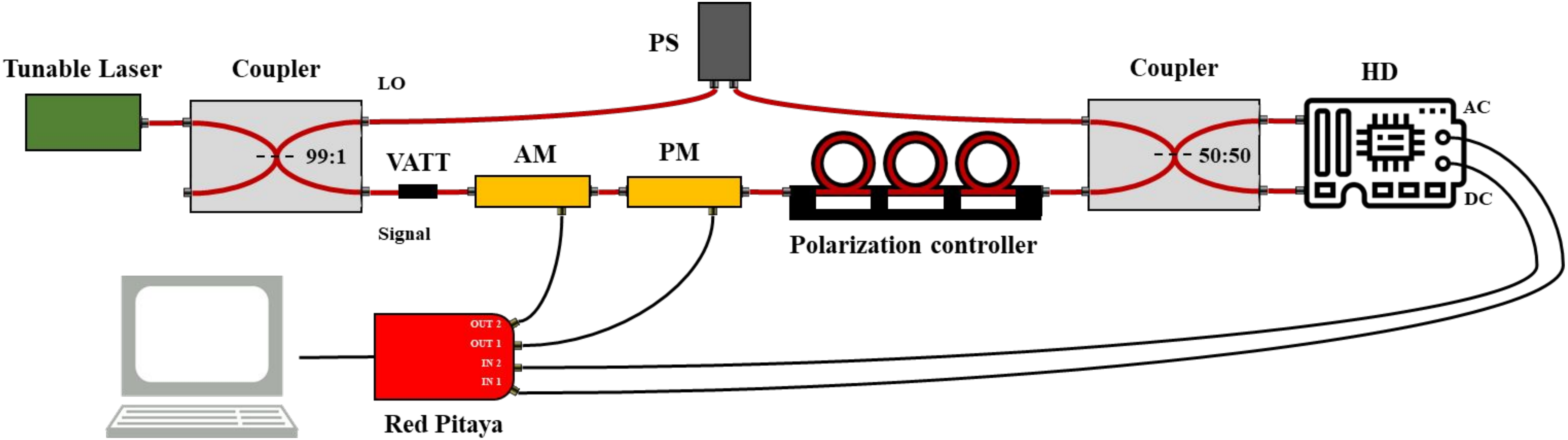
- **Disadvantage:**
    - Lower key rate due to basis switching



- In general, better for **longer distances**/lower noise QKD, but worse for scenarios that require a **higher key rate**.

Experimental setup

- CV QKD setup
  - Tunable Laser → strong local oscillator (LO) and signal
    - Signal: attenuated, modulated in amplitude (AM) and phase (PM) and polarization matched
    - Local oscillator: phase shift (PS)
  - LO and signal interfered and AC/DC currents measured using Homodyne detector (HD)



Measurement strategy

- Component characterization
    - Power measurements from couplers and variable attenuator (VATT)
    - Amplitude and phase modulators investigated on oscilloscope
    - Homodyne detection performed without modulation