上海交通大學
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A wideband balanced homodyne detector for high speed continuous variable quantum key distribution systems

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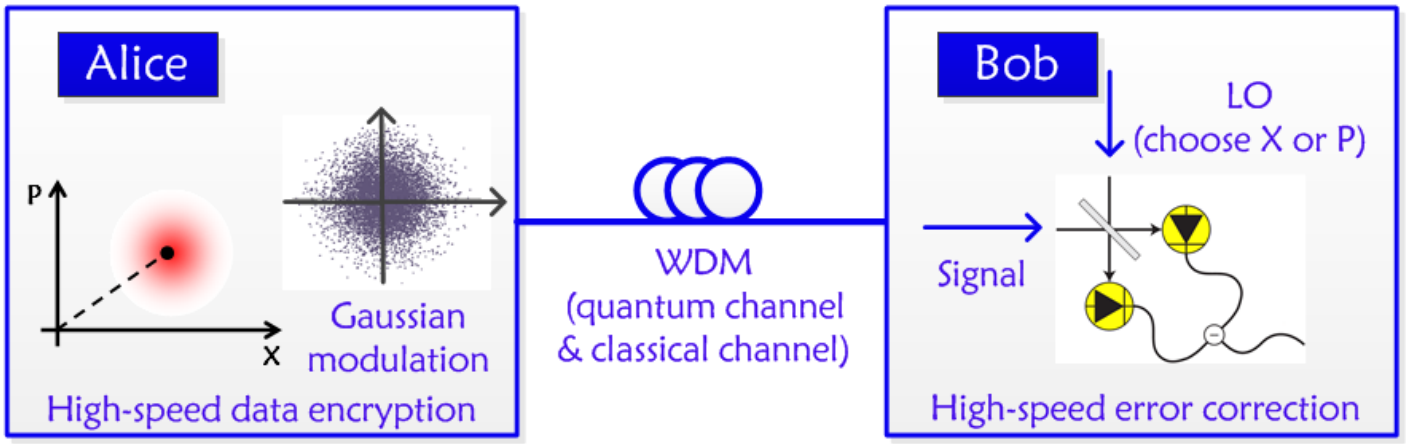
Outline

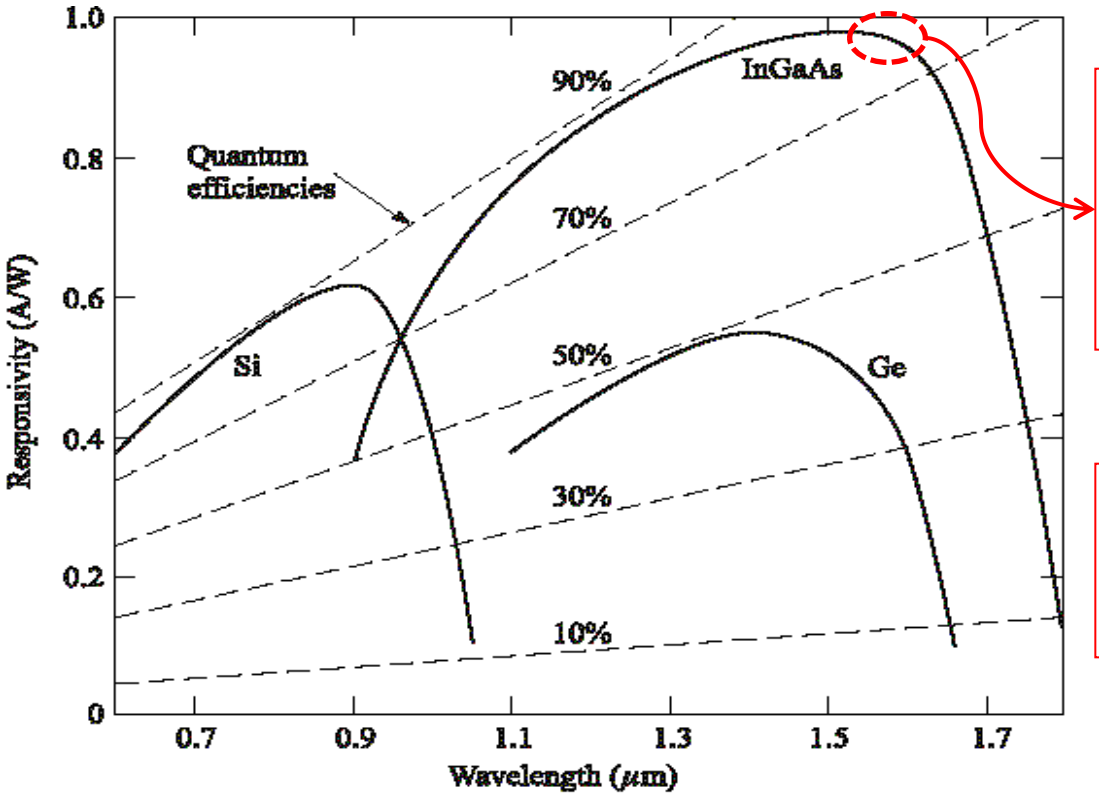
- Introduction
- A new wideband homodyne detector
- Experimental setup and results
- CV-QKD & KCQ systems (Existing work)

Wideband homodyne detector in high-speed CV-QKD system



- Requirements for wideband homodyne detector for high-speed CV-QKD system:
  - ✓ High quantum efficiency
  - ✓ High resolution in time domain (or high Bandwidth)
  - ✓ Shot-noise-limited & low electronic noise

Quantum efficiency



Typical value at 1550 nm

Responsivity:1 A/W

(quantum efficiency: 80%)

Focus on:

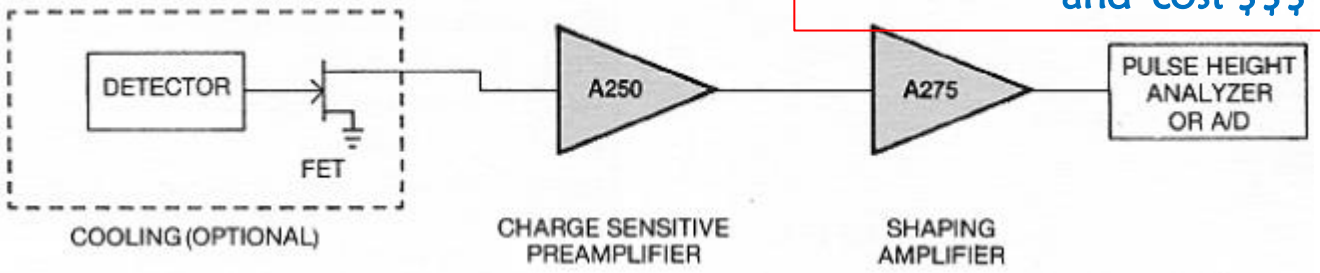
Electronic design

InGaAs Analog Photodiode: Limited quantum efficiency

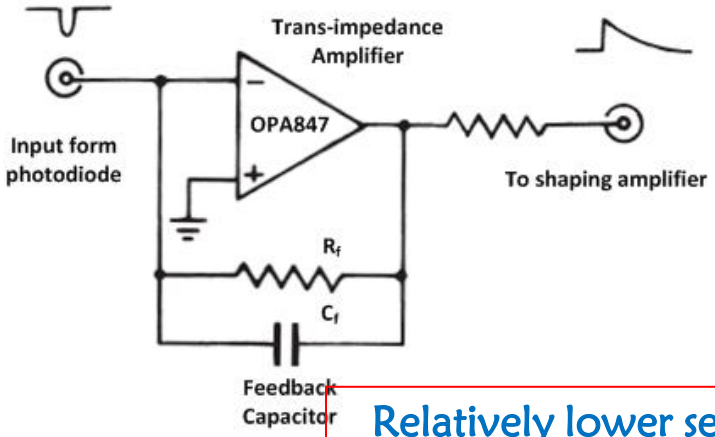
Electronic design for homodyne detector

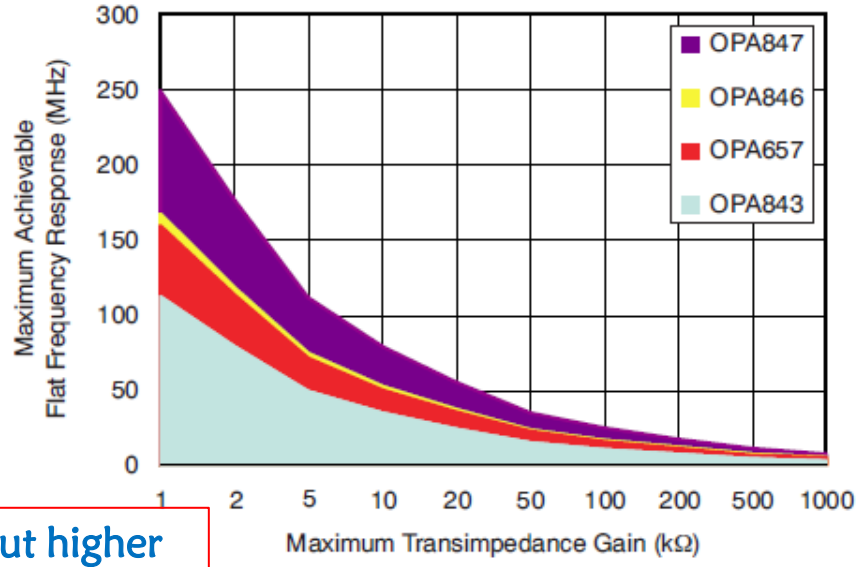
- Charge-sensitive preamplifier

High sensitivity but Limited bandwidth and cost $$$



- Voltage-feedback operational amplifier





Maximum Achievable Bandwidth for Selected Op Amps (10pF Source Capacitance)

Relatively lower sensitivity but higher bandwidth and lower cost $$$

Reported homodyne detector

➢ Existing homodyne detector

◆ Based on charge-sensitive preamplifier

Shot noise to electronic noise ratio: 14 dB at 3×10^8 photons per pulse

Bandwidth : ~1 MHz

Test laser repetition rate : 204 kHz , can be up to 1 MHz

H. Hansen, et al., OPTICS LETTERS, 26, 001714 (2001)

◆ Based on voltage-feedback operational amplifiers

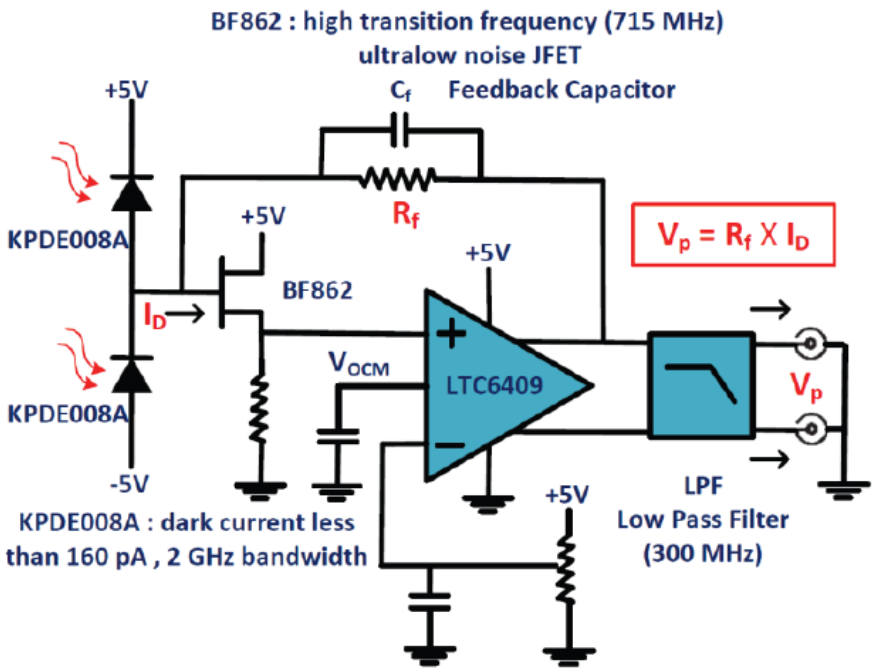
Shot noise to electronic noise ratio: 13 dB at 8.5×10^8 photons per pulse

Bandwidth : ~100 MHz

Test laser repetition rate : 32 MHz (optimal repetition rate in consideration of excess noise)

Yue-Meng Chi, et al., New J. Phys. 13, 013003 (2011)

A 300 MHz bandwidth shot-noise-limited homodyne detector



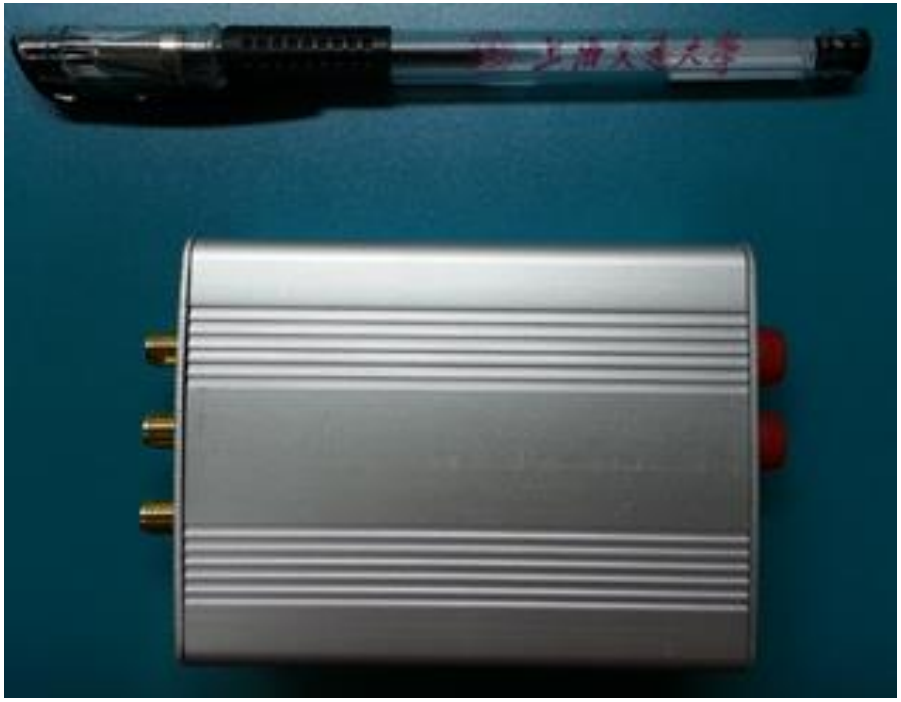
Simplified electronic circuit of homodyne detector

- Improvements in electronic structure
  - ✓ FET :reduce current noise
  - ✓ New type of amplifier :LTC6409

	OPA847	LTC6409
Gain-Bandwidth Product (GHz)	3.9	10
Slew rate (V/ns)	0.95	3.3
Input voltage noise density ($nV/\sqrt{Hz}$)	0.85	1.1

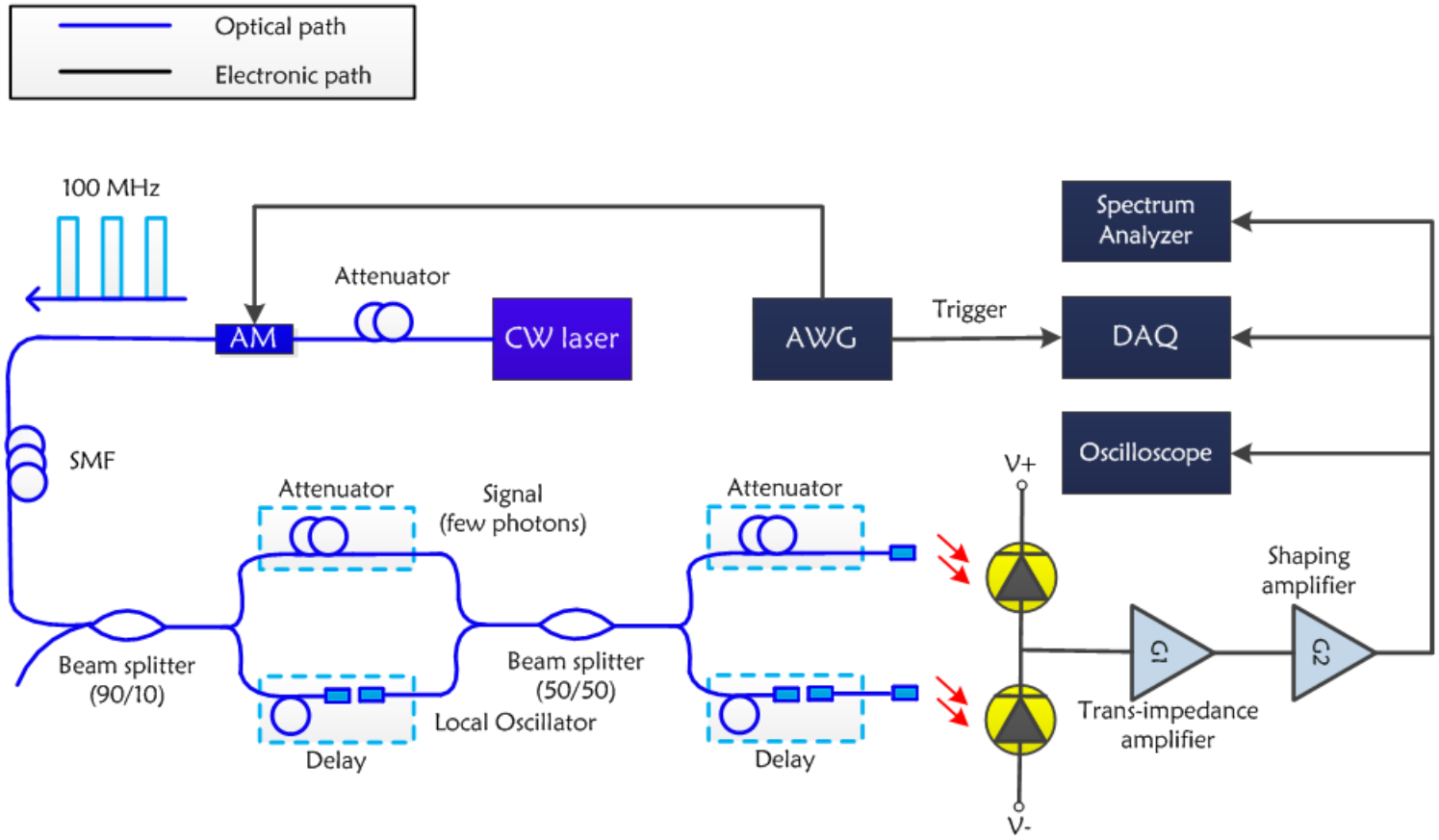
Yue-Meng Chi, et al., New J. Phys. 13, 013003 (2011)
Ryuhi Okubo et al., Optics Letters 33, 001458 (2008)
R. Kumar et al.Optics Communications 285, 5259 (2012)

A 300 MHz bandwidth shot-noise-limited homodyne detector



Small size & Low $$$

Experimental setup



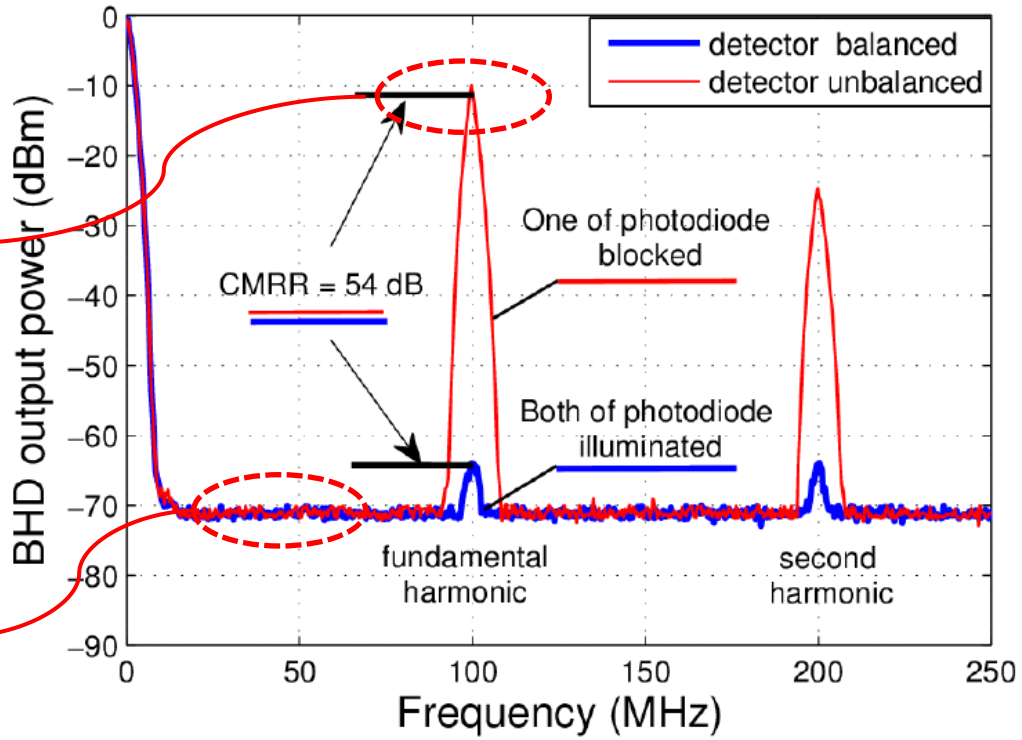
Experimental results

Maximum value of CMRR :

Detector is well balanced

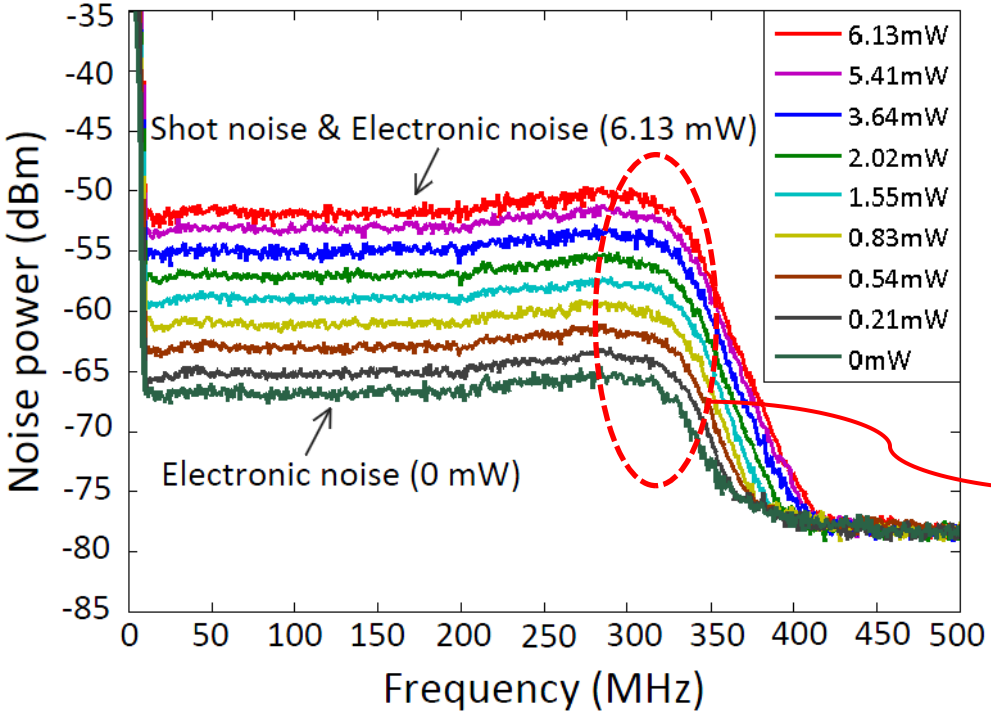
the first stage amplifier output noise:

Less than -70 dBm



Common-mode rejection ratio (CMRR) test
(Spectrum Analyzer output in frequency domain)

Experimental results



Bandwidth: 300 MHz

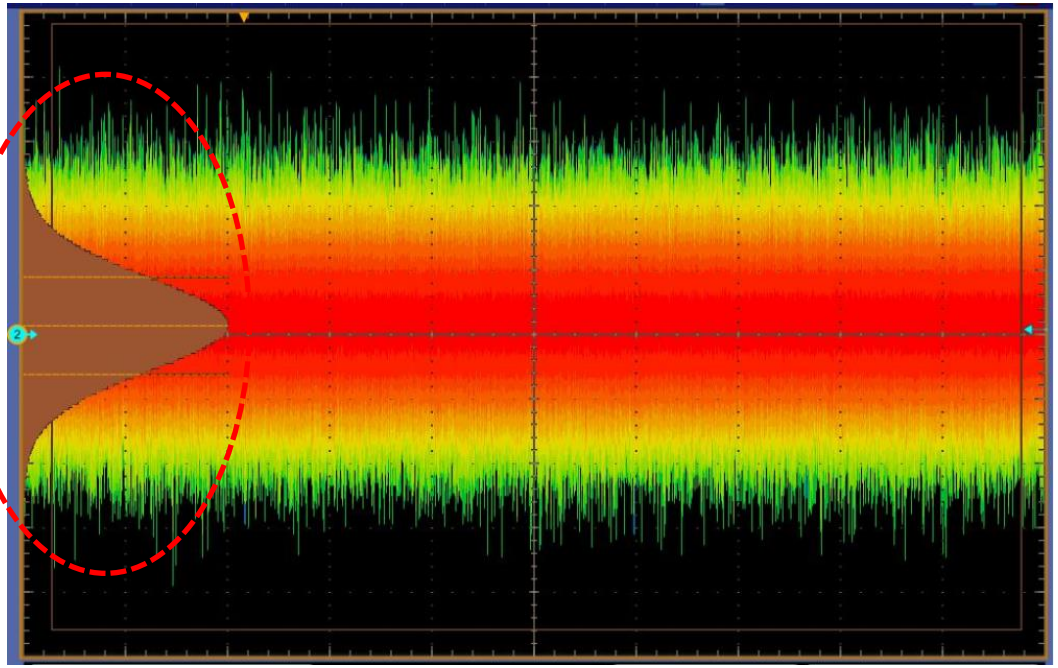
Shot noise power increases with the LO power

Bandwidth test
(Spectrum Analyzer output in frequency domain)

Experimental results

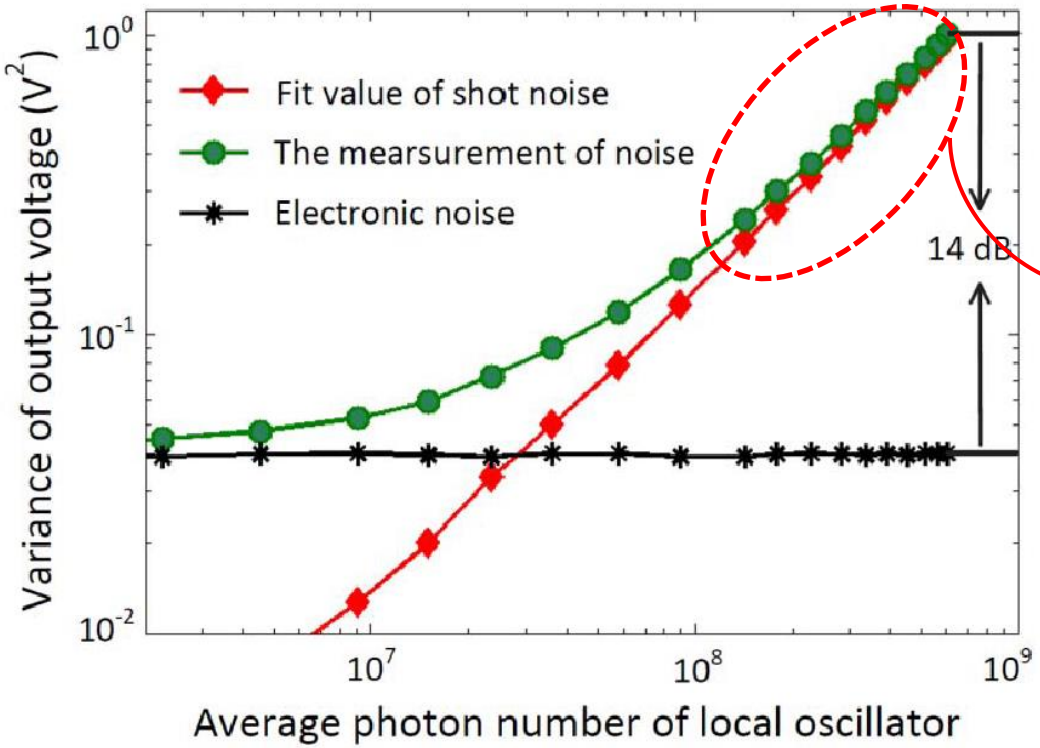
Make sure the collected data is correct:

Electrical noise and shot noise follow Gaussian distribution



Shot noise estimation
(Oscilloscope output in time domain)

Experimental results



Linear range:

$1 \times 10^8 \sim 6 \times 10^8$

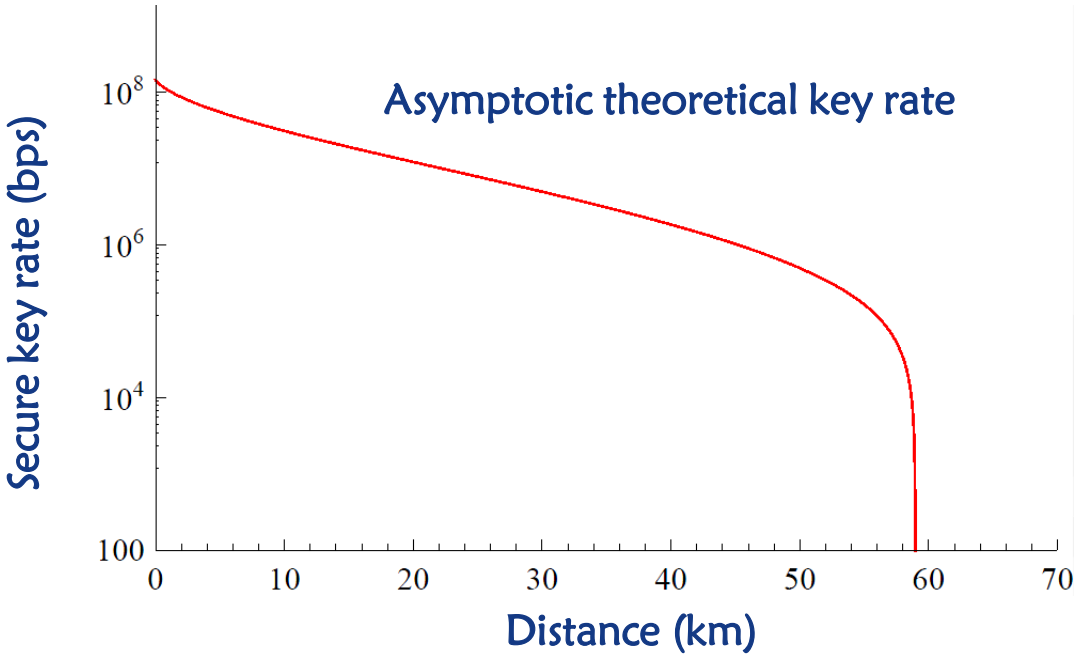
Shot noise to electronic noise ratio:

14 dB at 8.5×10^8 photons per pulse

Shot noise & Electronic noise measurement

Theoretical high-speed QKD system

- Parameters related to detector
  - ✓ Repetition rate
  - ✓ quantum efficiency：η
  - ✓ Electronic noise (in shot noise unit)：V_{elec}
  - ◆ Alice modulation variance：V_A (system optimal process, minimum variance is determined by the detector)



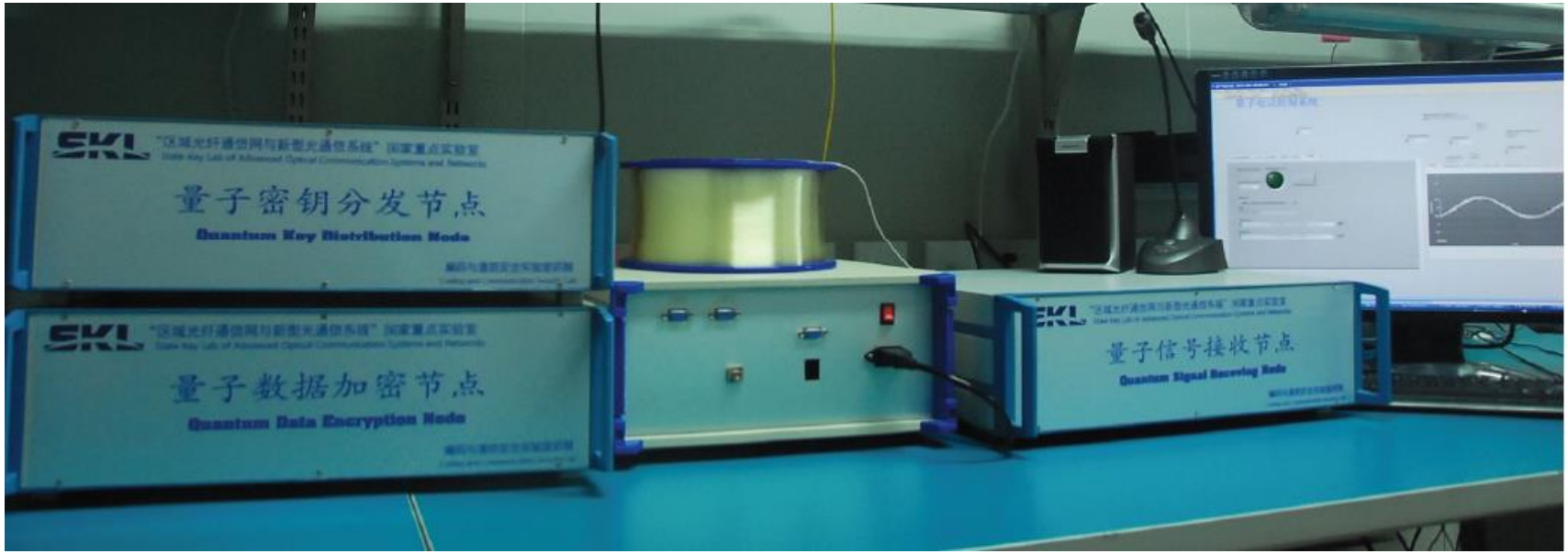
Repetition rate: 100 MHz
Parameters: $\varepsilon = 0.01,\ \eta = 0.6,\ V_{elec} = 0.04,\ V_A = 20,\ \beta = 0.94$
Collective attack: Secure key rate at 50 km will reach ~ 1 Mbps (theoretical)
Practical system: Secure key rate at 50 km will reach 1~100 kbps (considering estimation loss)

Practical high-speed QKD system

➢ Main limitations

- ✓ High performance homodyne detector
- ✓ High speed DAQ & control system
- ◆ High speed & high efficiency error correction

CV-QKD & KCQ system (Existing work)

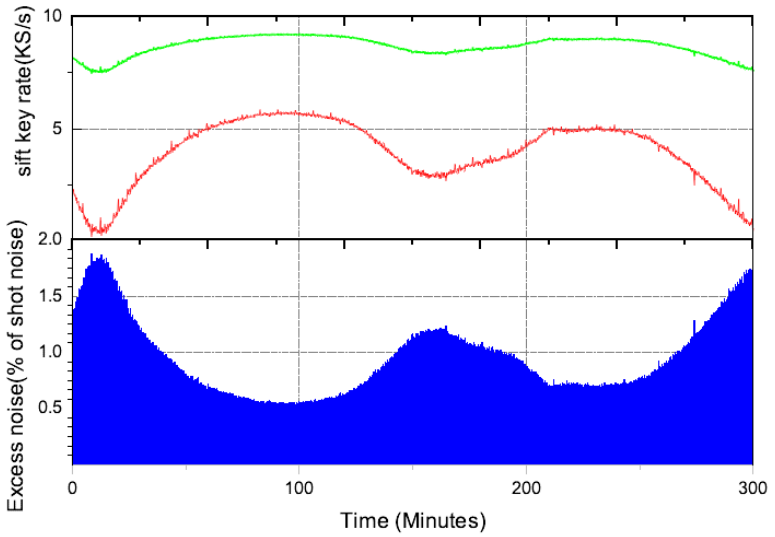


Our group:

repetition rate: 500 KHz

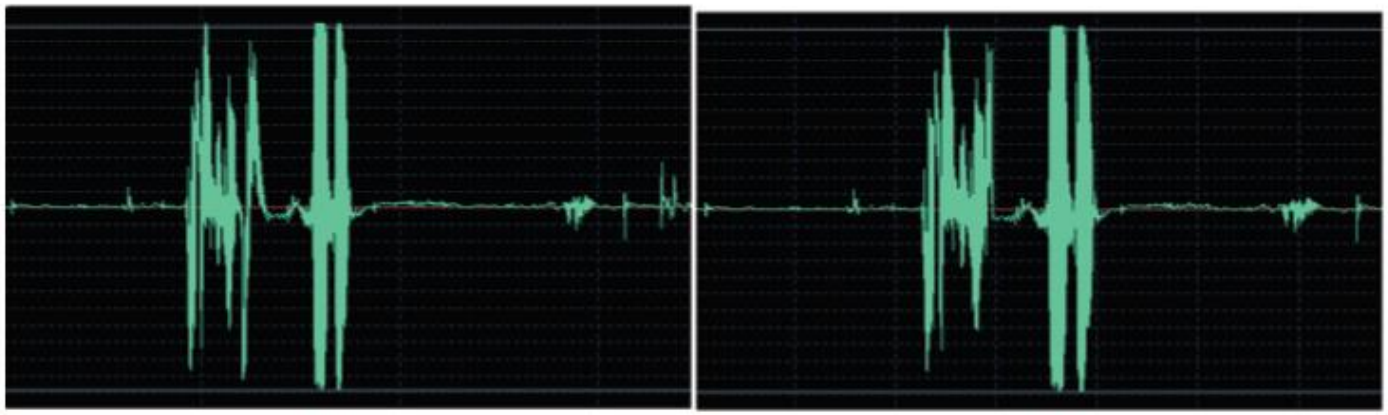
Secure key rate at 27.2 km: 2 kbps

CV-QKD & KCQ system (Existing work)



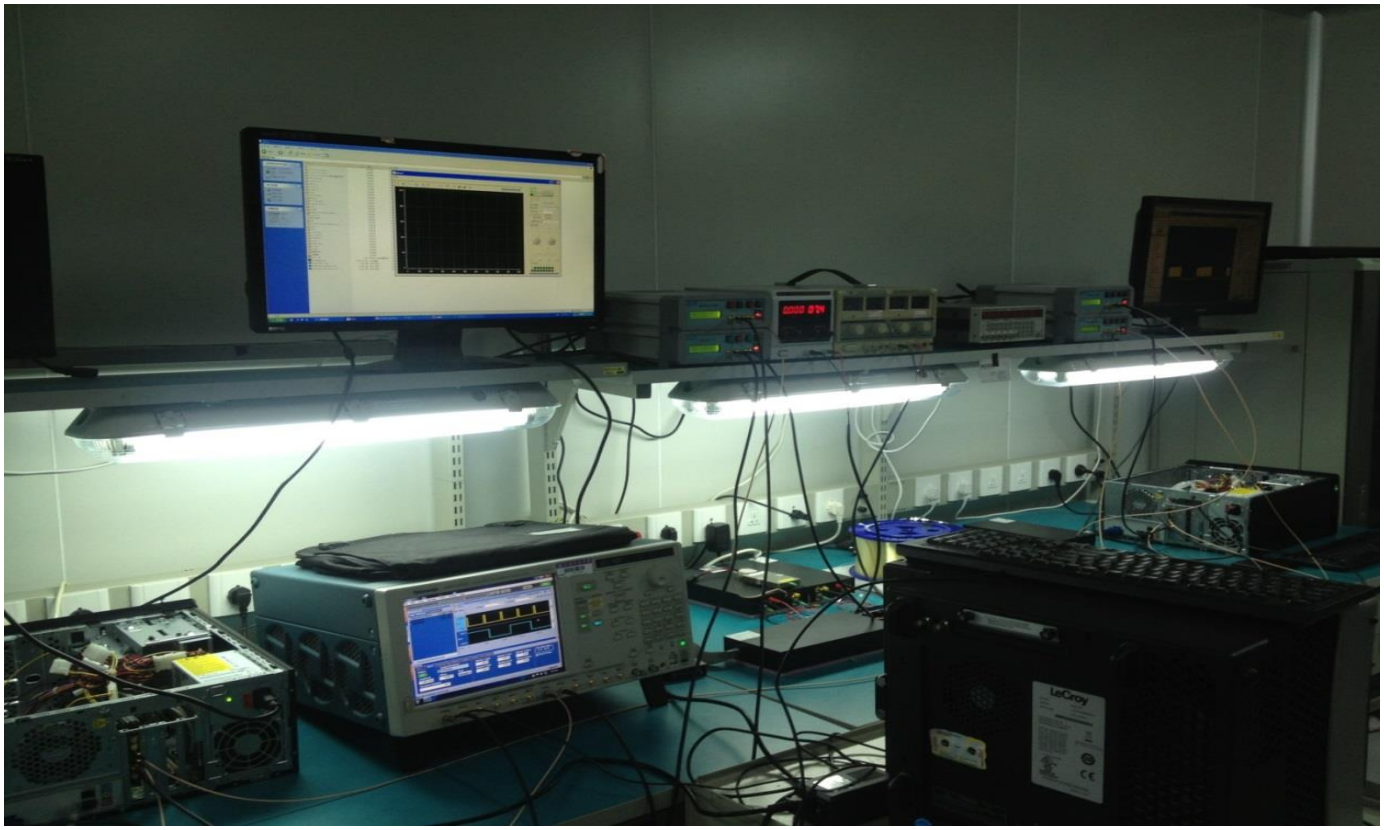
Real-time secure key rate

The measurement of excess noise as a function of time



The real-time compressed voice communication

Practical high-speed CV-QKD system



A new high-speed stable continuous variable QKD system has been finished

Practical tested distance: 25 km

Repetition rate: 25 MHz

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Thank you !