U.S. DEPARTMENT OF ENERGY | OFFICE OF CYBERSECURITY, ENERGY SECURITY, AND EMERGENCY RESPONSE

Quantum Physics Secured Communications for the Energy Sector

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Cybersecurity for Energy Delivery Systems Peer Review

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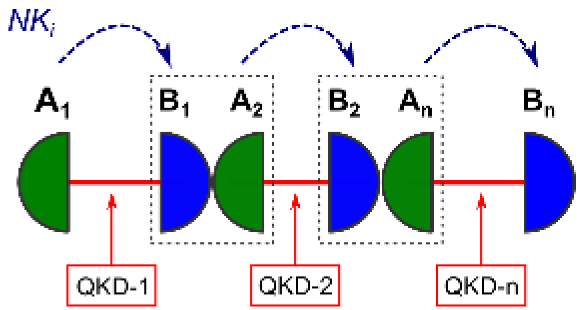
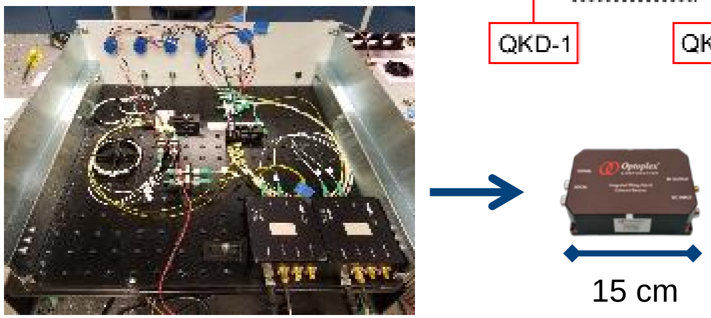
Summary: Quantum Physics Secured Communications for the Energy Sector

Objective

- Decrease cost (Bing Qi), and increase distance (Phil Evans), of Quantum Key Distribution systems that enable real-time detection of adversarial intrusion on control system networks.





Schedule

- **12/05/17-09/30/2020**
- Engage utility and supplier industry partners
- Utility site selected for Y1 demo
- Demonstration at a utility of a trusted node relay between two different types of QKD

Total Value of Award:	**$2,098,640**
Funds Expended to Date:	**23%**
Performer:	**ORNL**
Partners:	**LANL, Electric Power Board of Chattanooga (EPB), Optoplex**

Advancing the State of the Art (SOA)

- **QKD is distance-limited: optical channel loss exponentially reduces secret key rate.**
  - Quantum repeaters are proposed fix but are far away.
- **SOA: Trusted-node QKD extends the distance**
  - Implemented in various research demonstrations
  - Never implemented on an energy grid
- **QKD backbone network (e.g., power transmission)**
  - Delivers keys for authentication and other security tasks
  - Can build more complex local area networks (e.g., power distribution [EPB]).

Advancing the State of the Art (SOA) II—CV-QKD

- **CV-QKD implemented with "classical devices" (lasers and homodyne detectors)**
  - Potentially cost-effective: CV-QKD is resilient against background noise
  - SOA CV-QKD uses specially designed, "home-made" devices → not suitable for large-scale applications
- **Our approach: leverage commercial optical coherent communications system for CV-QKD**
  - If successful, commercial coherent communications system could operate in either a classical or quantum communications mode
- **Feasibility: quantum and classical coherent communication systems are similar but optimized differently**
  - The classical detectors approach the quantum noise limit
  - Classical system has less stringent requirements than quantum system
- **Output: a cost-effective building block for constructing semi-trusted QKD network, which can provide long-term security for energy delivery systems.**

Challenges to Success

Challenge 1: Dark fiber is a start, but there are other requirements

- Collaborate with network engineers to realize quantum link layer

Challenge 2: Disparate QKD systems: operating conditions, key rate, wavelength, etc.,

- Develop QKD-agnostic software layer to handle all key transactions

Challenge 3*: Existing commercial coherent receiver needs improvements to become "quantum grade"*

- We are working with a commercial vendor (Optoplex) to develop a compact, low-noise conjugate homodyne detector based on their existing product

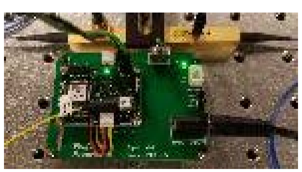
Challenge 4*:* Existing commercial coherent transmitter does not support CV-QKD modulation format

- We are developing a passive CV-QKD scheme with no active modulation.

Progress to Date

Major Accomplishments

- TN software demo using hop-by-hop technique
  - Implemented on laptops, moving to Raspberry-pi and MOXA hardware
- Partnership with EPB (subcontract in process)
- Joint ORNL & LANL demo plan for late 2018-early 2019 at EPB



- Collaboration with Optoplex resulted in a compact receiver for CV-QKD.
  - Purchase order issued.
- High-speed FPGA ADC/DAC devices acquired for system control and measurement.
  - Associated software developed
- Automatic bias control for intensity modulator demonstrated.

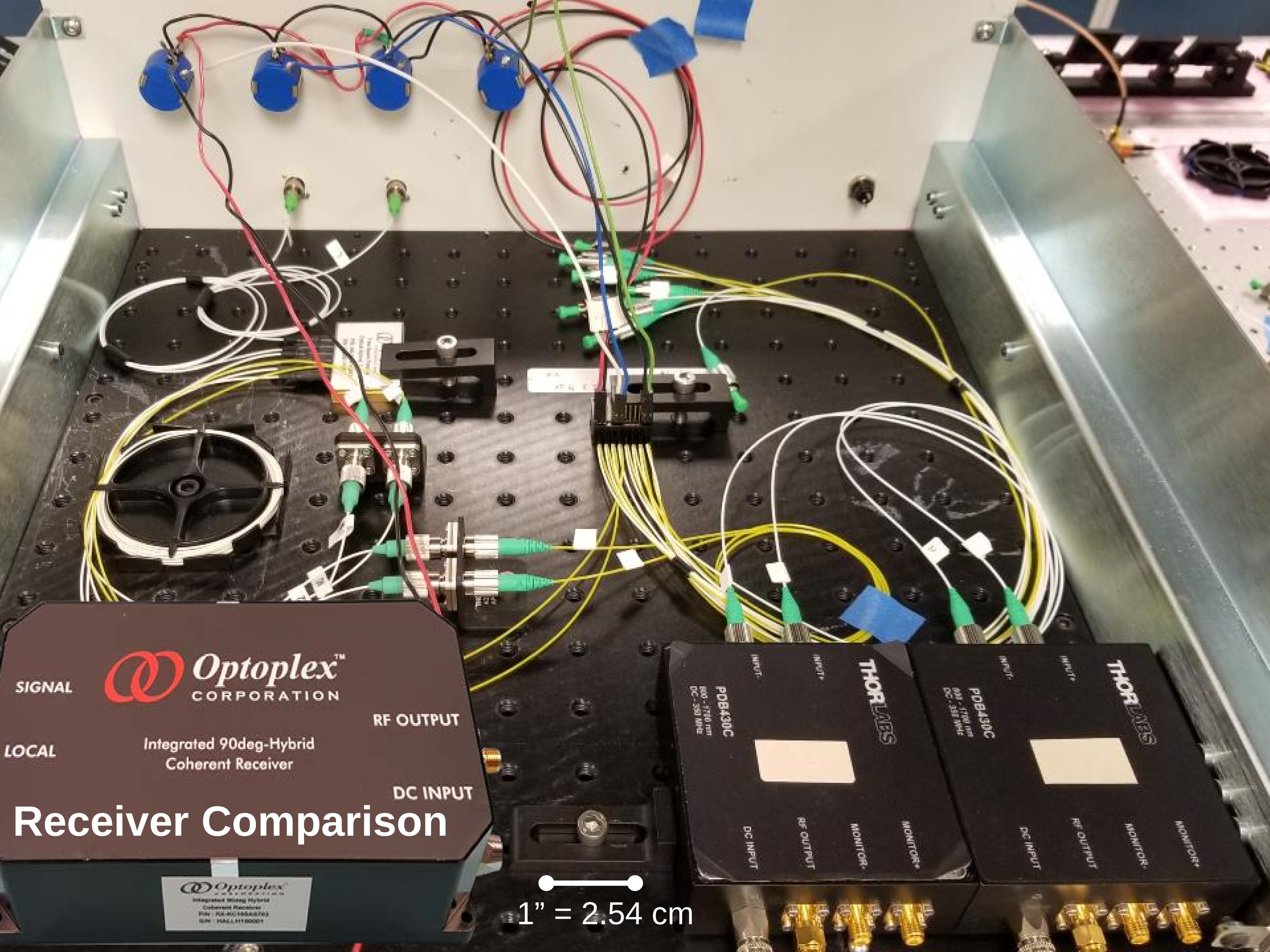
Collaboration/Technology Transfer

- Transferred CV-QKD receiver knowledge to Optoplex (Vendor)
- Transferred quantum-link layer requirements to EPB (electric utility and fiber optic network operator)
- Test plans to gain industry acceptance:
  - 12 months: Trusted node relay demonstration at a utility between two different types of QKD (interoperability)
  - 22 months: Demonstration of end-to-end key generation across two trusted nodes (three QKD systems)
  - 24 months: Trusted node relay demonstration at a utility yielding a higher secret bit rate than a single QKD system over the same distance
  - 36 months: Demonstration of end-to-end key generation across four trusted nodes (five QKD systems) at a partner utility site
  - 36 months: Demonstrations of CV-QKD and raw-key based authentication scheme at a partner utility site

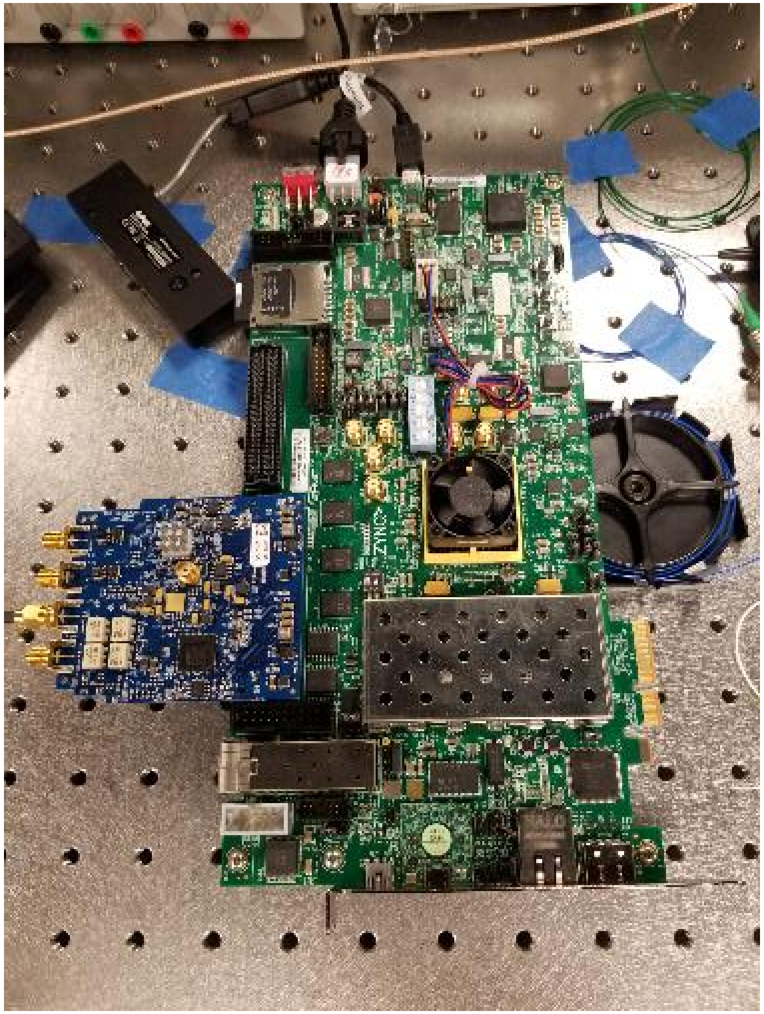
Next Steps for this Project

Approach for the next year

- Demonstrate trusted relays at increasing levels of complexity
- Experimental confirmation of Optoplex “quantum grade” receiver performance leading to construction of cost-effective coherent communication system to demonstrate classical communication and CV-QKD on same hardware
- Feasibility study of chip-size integration of CV-QKD
- Explore authentication protocols using shared imperfect randomness (rather than secure key)


Receiver Comparison
1” = 2.54 cm
Optoplex
CORPORATION
SIGNAL
LOCAL
RF OUTPUT
DC INPUT
Integrated 90deg-Hybrid
Coherent Receiver
THORLABS
PDB430C
INPUT-
INPUT+
DC INPUT
RF OUTPUT
MONITOR-
MONITOR+

Alice (Transmit) and Bob (Receive) Electronics



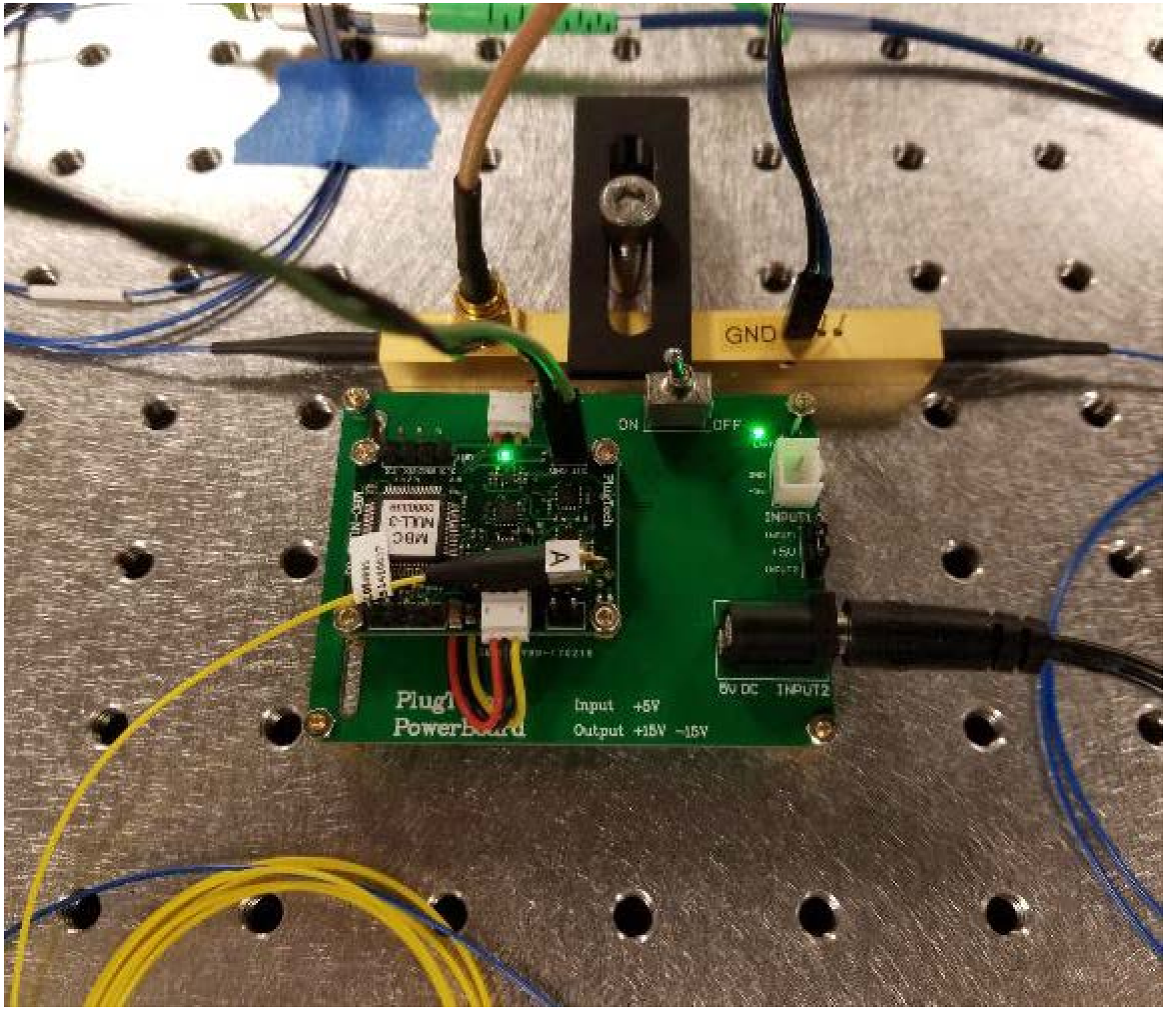
Alice's electronics:

- Sample the random noise from a quantum random number generator
- Transform the random noise into Gaussian random numbers
- Calculate amplitude and phase modulation voltages corresponding to random numbers
- Output the modulator drive signals

Bob's electronics:

- Sample the conjugate homodyne detector
- Perform data processing including synchronization and quadrature value calculation
- Implement polarization feedback control

Modulator Bias Controller



Provides a control voltage to compensate modulator bias-point drifts.

Two are needed at Alice's side to maximize the extinction ratio in pulse generation and amplitude modulation.