Quantum Applications

1. Introduction

Optoplex Corporation, a leading technology company specializing in free-space optics based micro-interferometry, has developed a wide range of optical products for applications from commercial optical communications, satellite laser communications, Lidar, fiber optic sensing (such as DAS), to quantum applications (Quantum Entanglement Light sources, QKD, QRANG, Quantum Cryptography, Quantum computing, etc.).

1.1 DPSK DLIs (Delay-Line-Interferometers) in QKD Quantum Communications

In Quantum Key Distribution (QKD), delay-line interferometers (DLIs) play a crucial role in **detecting differentially phase-shifted keying (DPSK) signals**.

Here's how:

- **DPSK in QKD:** In some QKD protocols, information is encoded in the phase difference between consecutive photons.
- **DLI for DPSK Detection:**
  - A DLI splits the incoming optical signal into two paths.
  - One path introduces a time delay equal to the duration of one bit.
  - The two paths are then recombined.
  - The interference pattern at the output of the DLI depends on the phase difference between the delayed and undelayed signals.
  - This effectively converts phase shifts into intensity variations, which can be easily detected by photodetectors.

Advantages of using DLIs in QKD:

- **Robustness to Phase Noise:** DLIs are relatively insensitive to slow phase fluctuations (phase noise) in the optical channel. This is because the phase comparison is made between consecutive bits, effectively canceling out common-mode phase drifts.
- **Simplicity:** Compared to some other demodulation techniques, DLIs can be relatively simple to implement.

1.2 90deg Optical Hybrids in QKD Quantum Communications

In Quantum Key Distribution (QKD), 90-degree optical hybrids can be employed in certain scenarios, particularly those involving **coherent detection techniques**.

Here's how:

- **Coherent Detection in QKD:** Some advanced QKD protocols utilize coherent detection to improve sensitivity and data rates. This involves mixing the incoming weak quantum signal with a strong local oscillator signal.
- **Role of 90-degree Hybrids:**
  - **Phase and Amplitude Information:** 90-degree hybrids are crucial for extracting both the phase and amplitude information of the weak quantum signal. This is achieved by combining the signal with the local oscillator with a 90-degree phase shift.
  - **Balanced Detection:** By combining the outputs of the 90-degree hybrid with balanced photodetectors, common-mode noise can be effectively suppressed. This is essential for detecting the extremely weak signals typical in QKD systems.

Key Considerations:

- **Technical Challenges:** Implementing coherent detection in QKD systems presents significant technical challenges, such as minimizing noise and ensuring high stability of the local oscillator.

- **Not Always Essential:** 90-degree hybrids are not essential for all QKD protocols. Many QKD systems utilize simpler detection schemes that do not require coherent detection.

In summary:

While not always necessary, 90-degree optical hybrids can play a role in certain advanced QKD systems that employ coherent detection techniques. Their ability to extract both phase and amplitude information with high sensitivity is crucial for achieving improved performance in these systems.

1.3 90deg Optical Hybrids in QRNG

90-degree optical hybrids can be used in certain types of Quantum Random Number Generators (QRNGs).

Here's how:

- **Phase Noise-Based QRNGs:** Some QRNGs exploit the inherent randomness of phase noise in laser light.
  - 90-degree hybrids are crucial for **homodyne detection**, a technique used to precisely measure the phase fluctuations of the laser light.
  - By combining the laser signal with a strong local oscillator signal with a 90-degree phase shift at the 90-degree hybrid, both the in-phase and quadrature components of the laser's phase noise can be extracted.
  - These phase fluctuations are then digitized and processed to generate random numbers.

Key Advantages:

- **High-Speed Generation:** Phase noise-based QRNGs using 90-degree hybrids can potentially achieve very high random number generation rates.

In Summary:

While not the only approach to QRNGs, 90-degree optical hybrids play a vital role in phase noise-based QRNGs by enabling precise measurement of the laser's phase fluctuations, a crucial step in extracting true randomness from the system.

2. Optoplex's Products in Quantum Applications

2.1 Quantum Communications

Systems	Protocol	Functions in the Quantum System	Optoplex Products
DV-QPKD:	BB84 protocol	DLI-based receiver for the Quantum Channel	DPSK DLIs
	Polarization-Based,	Homodyne-coherent detection	90deg optical hybrids and Integrated Receivers (Rx) Dual-Polarization 90deg hybrid & Rx
CV-QKD	Single-Polarization	Coherent detection	90deg optical hybrids & Rx
	Dual-Polarizations	Dual-polarization coherent detection	Dual-Polarization 90deg hybrid & Rx
DPR-QKD	differential phase shift (DPS) QKD and	DLI Receiver at both Alice and Bob sides	DPSK DLIs
	coherent one-way (COW) QKD.	DLI receivers	DPSK DLIs 90deg optical hybrid & Rx
Quantum Entangled Light Source based on Time-Bin Qbit QKD		Quantum entanglement light source	DPSK DLI

		DLI receivers	DPSK DLIs
QRNG		Quantum random noise generators	90deg optical hybrids & Rx
Quantum Cryptography		Quantum Key Generations	DPSK DLIs 90deg optical hybrids & Rx
General Purpose		Signal Synchronization	Fixed or Variable Delay lines
		Signal filtering	Narrow BW filters Tunable filters F-P etalon filters Flat-top comb filters

2.2 Quantum Computing

Systems	Remarks	Optoplex Products	Note
QKD Communications	See above sections	DPSK DLI, 90deg optical hybrid & Rx, etc.	
Coherent Optical Communications		90deg optical hybrids	
Quadrature Amplitude Modulation (QAM) Signal Generation		90deg optical hybrids	
Coherent Detections		90deg optical hybrids	
Signal Processing	MZI Interferometry	90deg optical hybrids	
Optical Computing Architecture	Beam splitting, combining, and phase shifting, which are essential for implementing optical logic gates and circuits	90deg optical hybrids	
Quantum Signal Synchronization		Fixed or Variable Delay-Lines	
Signal Filtering		Narrow BW Filters F-P etalon filters Flat-top comb filters	

2.3 Quantum Sensors

A quantum sensor is a device that utilizes the principles of quantum mechanics to measure physical quantities with unprecedented sensitivity and accuracy.

Here's a breakdown:

- **Key Concepts:**
  - **Quantum Phenomena:** Quantum sensors leverage unique quantum phenomena like superposition, entanglement, and squeezing to enhance their measurement capabilities.

- **Extreme Sensitivity:** They can detect incredibly weak signals or minute changes in physical properties that are beyond the reach of classical sensors.

- **Examples:**
    - **Atomic Clocks:** Utilize the precise energy levels of atoms to define time with extraordinary accuracy.
    - **Magnetometers:** Employ quantum effects like the precession of atomic spins to measure extremely weak magnetic fields.
    - **Gravitational Wave Detectors:** Utilize laser interferometry with quantum enhancements to detect minuscule ripples in spacetime caused by gravitational waves.
    - **Quantum Gyroscopes:** Measure rotation with unprecedented sensitivity, crucial for navigation and inertial guidance systems.
- **Potential Applications:**
    - **Fundamental Physics Research:** Investigating dark matter, exploring gravity, and testing fundamental laws of physics.
    - **Navigation & Positioning:** Developing highly accurate GPS alternatives and improving inertial navigation systems.
    - **Biomedical Imaging:** Enhancing medical imaging techniques like MRI and developing new diagnostic tools.
    - **Materials Science:** Characterizing novel materials with unprecedented precision.
    - **Environmental Monitoring:** Detecting pollutants and monitoring environmental changes with high sensitivity.

In essence: Quantum sensors represent a cutting-edge frontier in measurement science, offering the potential to revolutionize various fields with their unparalleled sensitivity and accuracy.

Applications	Description	Optoplex Products
Characterizing quantum states	DLIs can be used to characterize the temporal and spectral properties of quantum states, such as those generated by single-photon sources or entangled photon pairs. This information is crucial for optimizing quantum sensing systems and understanding their performance limitations.	DLIs
Measuring Quantum Correlations	In some cases, DLIs can be used to measure temporal correlations between quantum events, which can provide insights into the entanglement properties of quantum systems.	DLIs
Characterizing Single-Photon Sources	DLIs can be used to measure the coherence time and spectral properties of single-photon sources, which are essential components in many quantum sensing applications.	DLIs
Quantum Key Distribution (QKD)	While not a core component of every QKD system, DLIs can be used to characterize the properties of the optical channels used for transmitting quantum information, which is crucial for ensuring secure and reliable QKD operation.	DLIs
Coherent Detection in Quantum Sensing:	Some quantum sensors, such as those based on **interferometry** (like gravitational wave detectors) or **atomic clocks**, rely on precise measurements of the phase and amplitude of optical signals. Coherent detection, which employs 90-degree hybrids, is a crucial technique for achieving this high level of sensitivity.	90deg optical hybrids and Rx

Phase and Amplitude Extraction: 90-degree hybrids are used to combine the incoming optical signal with a local oscillator signal with a 90-degree phase shift. This allows for the simultaneous extraction of both the amplitude and phase information of the received signal.

Balanced Detection: By combining the outputs of the 90-degree hybrid with balanced photodetectors, common-mode noise can be effectively suppressed, significantly improving the signal-to-noise ratio of the measurement.

3. Applications Notes

Download below application notes:

1) Quantum Communications (QKD)_Optoplex DPSK DLIs & 90deg Hybrids.
2) Quantum Entanglement Source… _Optoplex DPSK DLIs
3) Quantum Random Noise Generation (QRANG)_Optoplex 90deg Optical Hybrids