MCRQ Technology.

A brief introduction to our proprietary optical design and demodulation scheme.

LASER ULTRASONICS FOR NON-DESTRUCTIVE TESTING

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Design

Laser-based ultrasound receivers rely on **interferometry**. This means that two interfering beams are necessary for signal detection. A reference beam carries an ideal phase and amplitude profile, while a sample beam is formed by the reflection of the probe light from the sample surface, the contrast created by the interference of the two beams is where the information lies. An ultrasound signal wave, generally produced by a generation laser, introduces a displacement on the surface of the sample. This signal wave modifies the sample beam which is projected against the sample. The interference between the two beams makes it possible to determine the temporal dependence of vibrational surface displacement.

Common laser-based interferometer designs require both the reference and sample beams to be plane waves. However, **for most LU systems** the random phase distribution of speckles means that only a small portion of the reflected, scattered light can contribute to the amplitude of the measured signal, making the interference inefficient. This is especially true when scanning rough surfaces which tend to scatter the incident light. For most laser-based interferometer designs a highly speckled reflection beam means that most of the power of the probe beam reflected from the surface is unusable and as a result the detection sensitivity of the instrument drops sharply. Due to the limitations of their optical architecture most laser-based interferometers only collect a single or a few speckle in order to maintain phase coherence, which leads to a significant reduction of sensitivity on optically challenging surfaces.

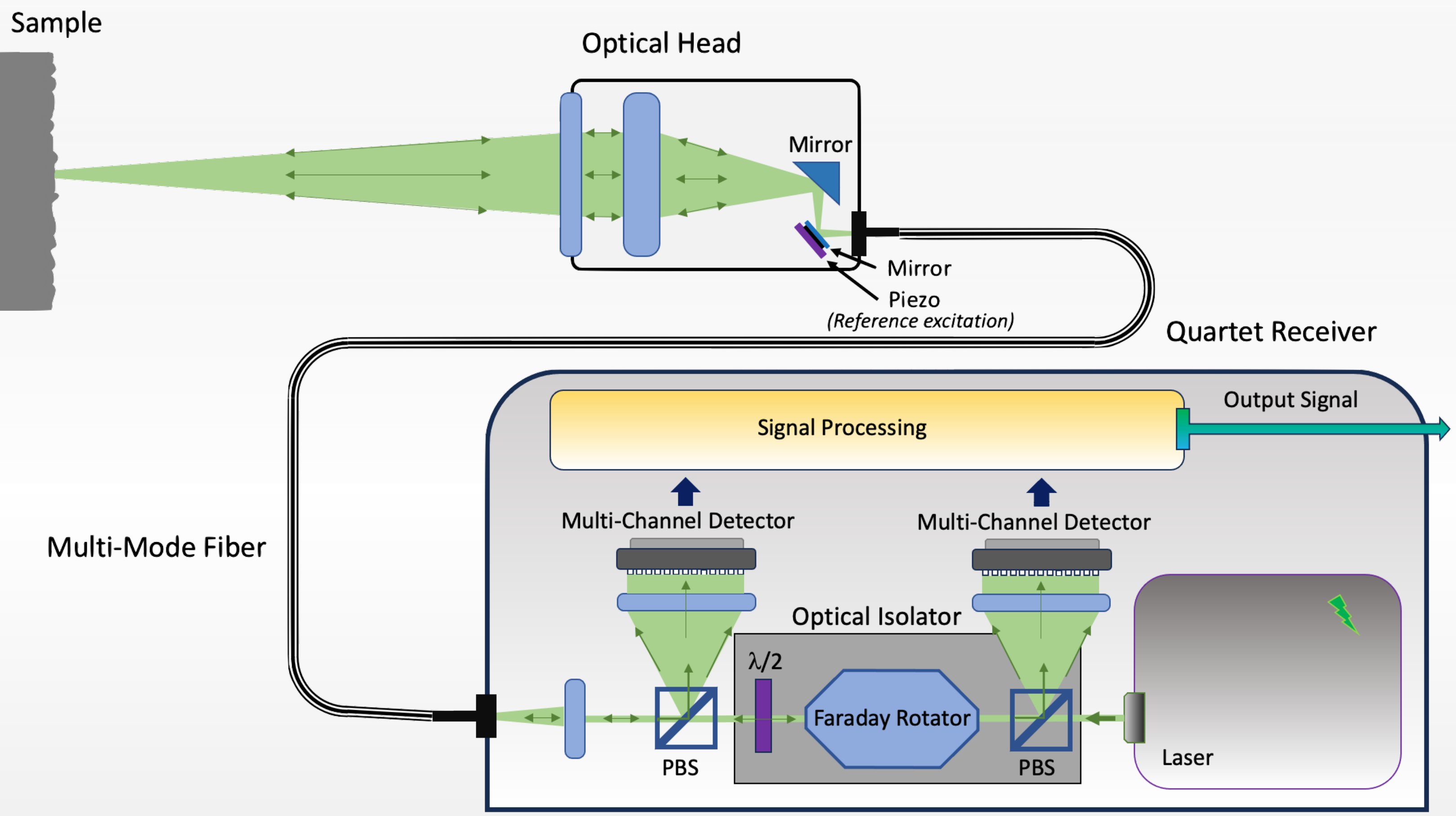
To remedy the problem, the detection aperture size can be enlarged and an array of photodetectors used instead of a single detector such that the instrument collects multiple speckles. The sample beam, composed of multiple speckles, is mixed with the expanded reference beam and then projected onto arrays of photodetectors.

That’s where we come in with our proprietary **Multi-Channel Random Quadrature (MCRQ)** technology.

Our system does not rely on a standard quadrature **detection scheme** (which requires the detection of two complimentary signals with a 90° phase difference). MCRQ takes advantage of the random optical phase distribution, assuming that statistically half of signals registered by the photodetectors are in-quadrature and half are out-of-quadrature. The signals from multiple photodetectors (a detector array) are demodulated separately then summed together. This way the overall sensitivity of the measured signal remains high without the need for stabilization as the out-of-quadrature signals will not contribute to the resulting signal. To obtain exceptionally high sensitivity, our Quartet relies on two arrays of 25 photodetectors. Each signal recorded by the array is individually demodulated and processed. Relying on statistical speckle distribution to perform quadratic demodulation makes our MCRQ interferometers (the Quartet and Modulo series) highly sensitive, while forgoing the need for strict optical alignment protocol.

To further improve our systems' flexibility, our MCRQ interferometers are fitted with a multimode optical fiber and optical head. The sample beam is projected through the fiber and then focused onto the surface being measured using the optical head's lens system. A portion of the beam then reflects off the surface of the object before being collected by the same optical head and sent back through the fiber. The reference beam is made up of a small part (about 4–5 %) of the incident laser beam that is reflected by the end of the optical fiber. A small piezoelectric actuator is also attached to the end of the fiber, inside the optical head to vary the object path between the lens and the end of the fiber, such that a known Doppler shift based pilot signal is added to the sample beam. We use this pilot signal during processing to perform the sign correction. During backpropagation, the reference and sample beams interfere in the optical fiber.

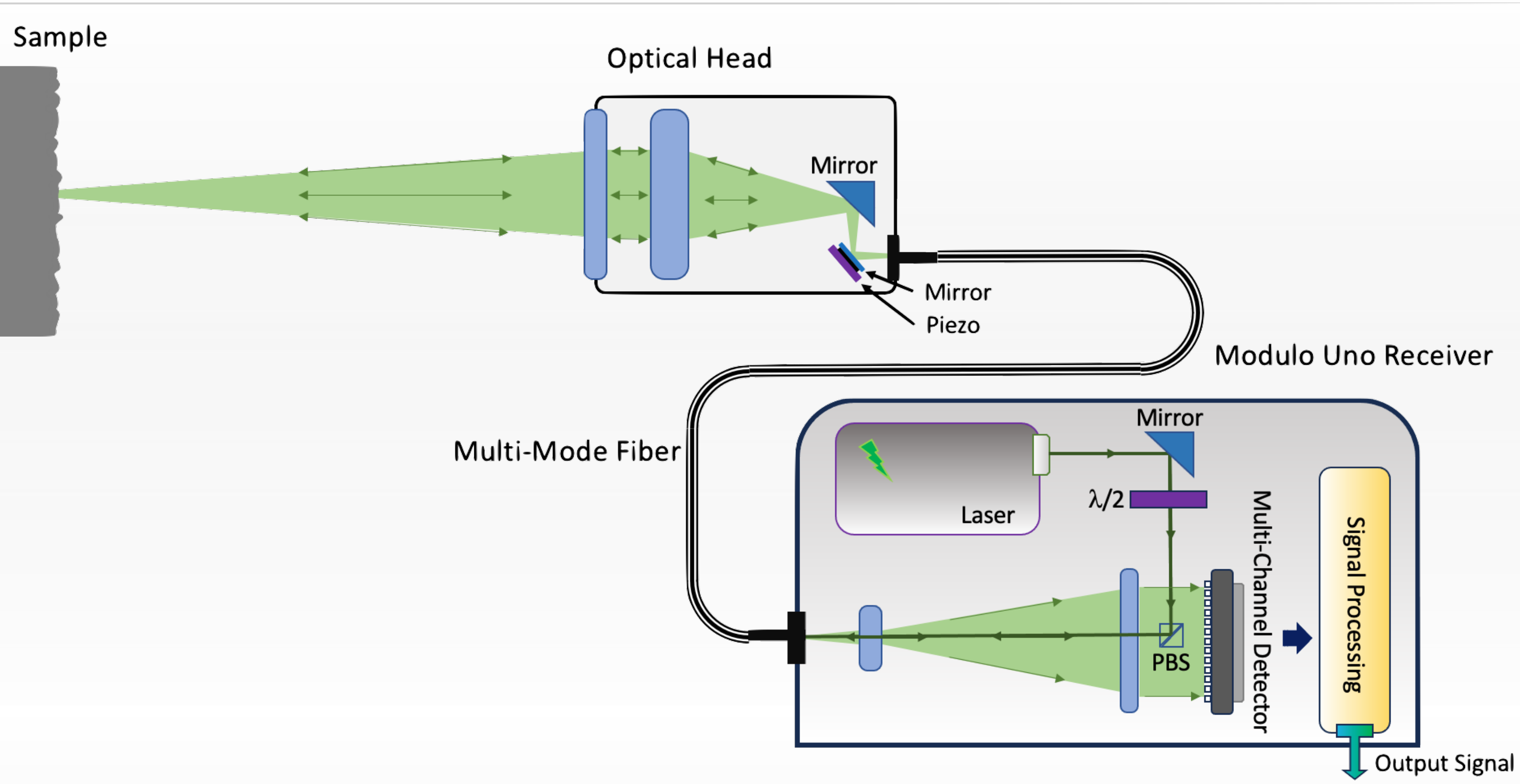
Quartet Optical Architecture:



In **the Quartet**, this mixed beam then travels through a first polarization beam splitter, which directs the vertically polarized components onto one of two detector arrays. The rest of the beam passes through a Faraday rotator serving as an optical isolator, a halfwave plate and a second polarization beam splitter, before being directed onto the second detector array as the vertically polarized component. This architecture also protects the laser from any possible back-reflections.

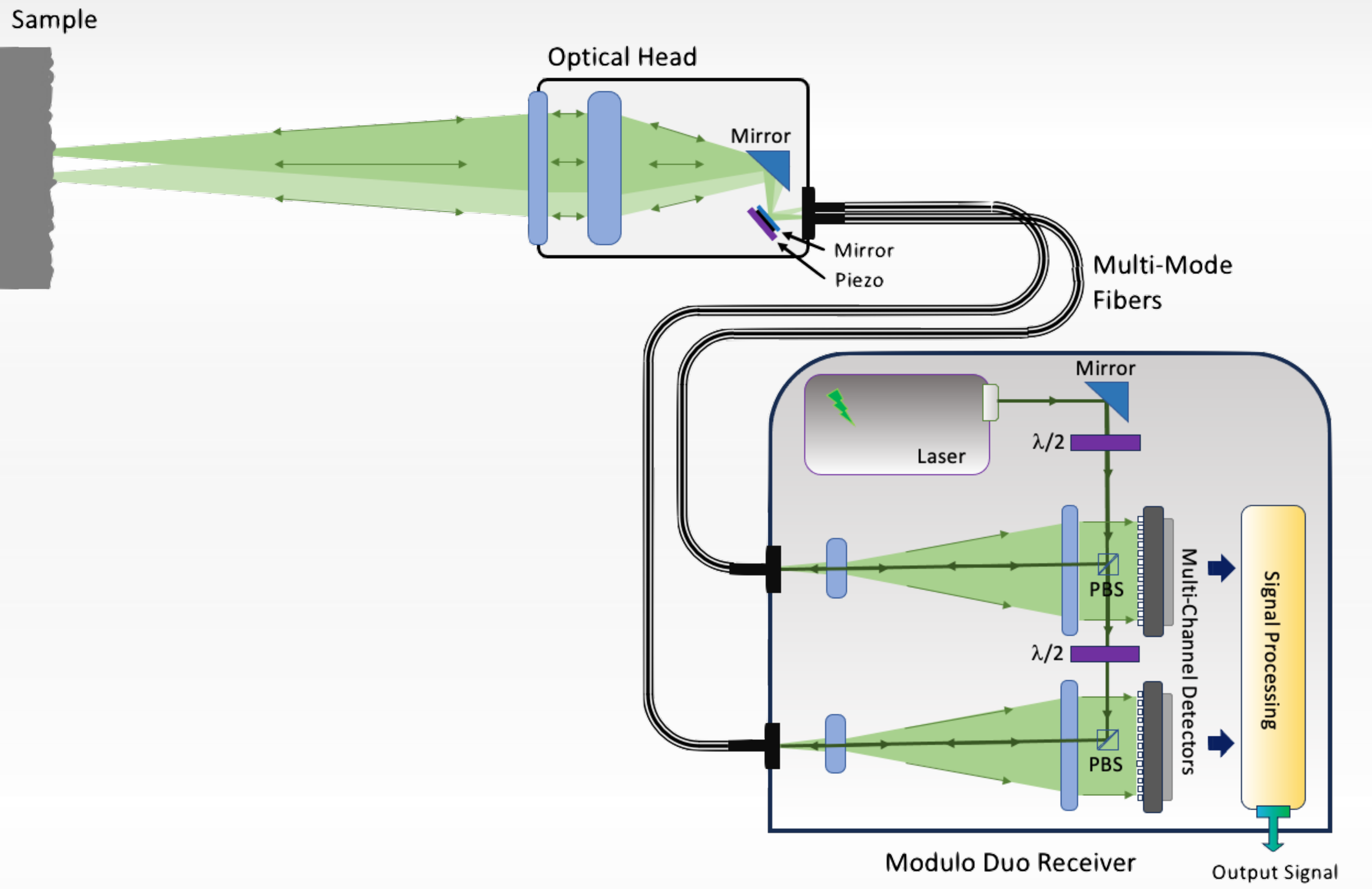
In **the Modulo** series (soon to be released), the mixed beam is directed straight onto a single detector array which collects both the vertically and horizontally polarized components. The noise equivalent surface displacement (NESD) is slightly higher than in the Quartet but the design allows us to make a line of instruments that is more compact and less expensive per detection point. It is also makes for a notably modulable detection scheme; the laser beam can be split into independent optical pathways each with their own detector, allowing us to tailor the receiver to specific applications.

Modulo Uno Optical Architecture:

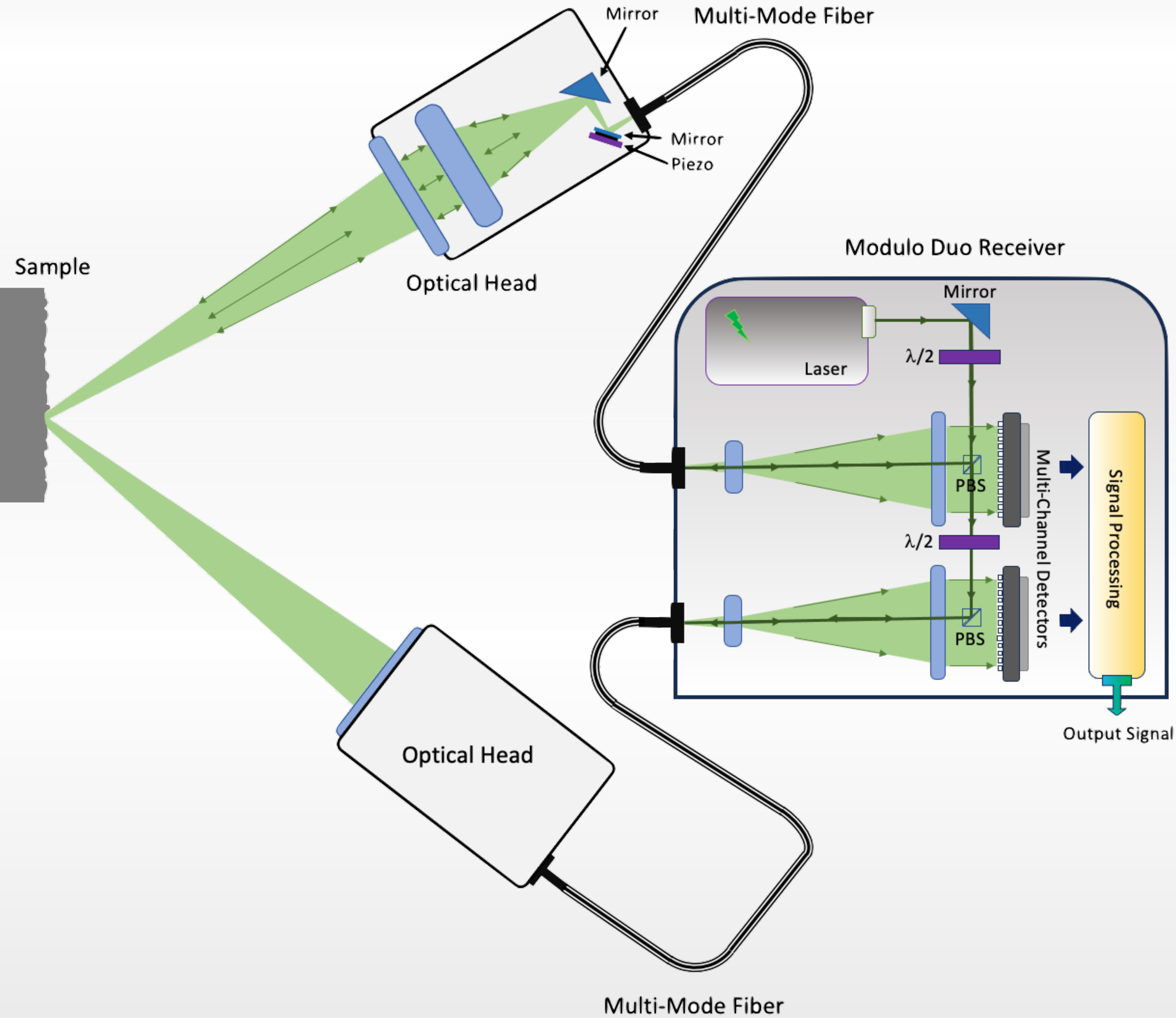


Thanks to the Modulo's novel optical platform we can create a single instrument with two (or three) optical heads to detect the in-plane and out of plane components by measuring a single point from different angles, simultaneously measure different points on a sample, or run multiple closely spaced measurement points through a single head to perform rapid scans. And because the detection scheme is based on the MCRQ, the Modulo line is as robust and low-maintenance as the Quartet. It is also available with digital output.

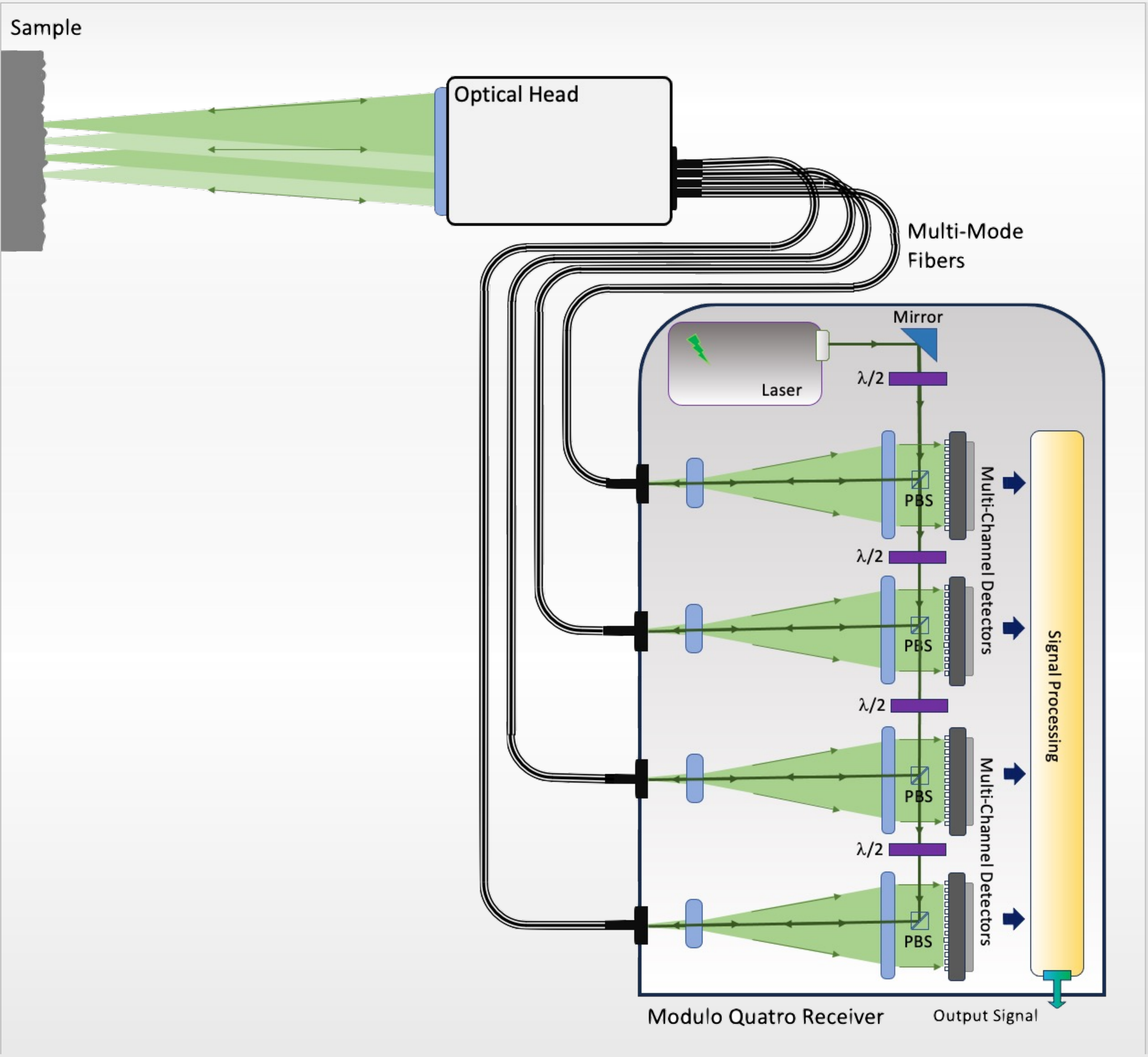
Modulo Duo Single Head Optical Architecture:



Modulo Duo Double Head Optical Architecture:



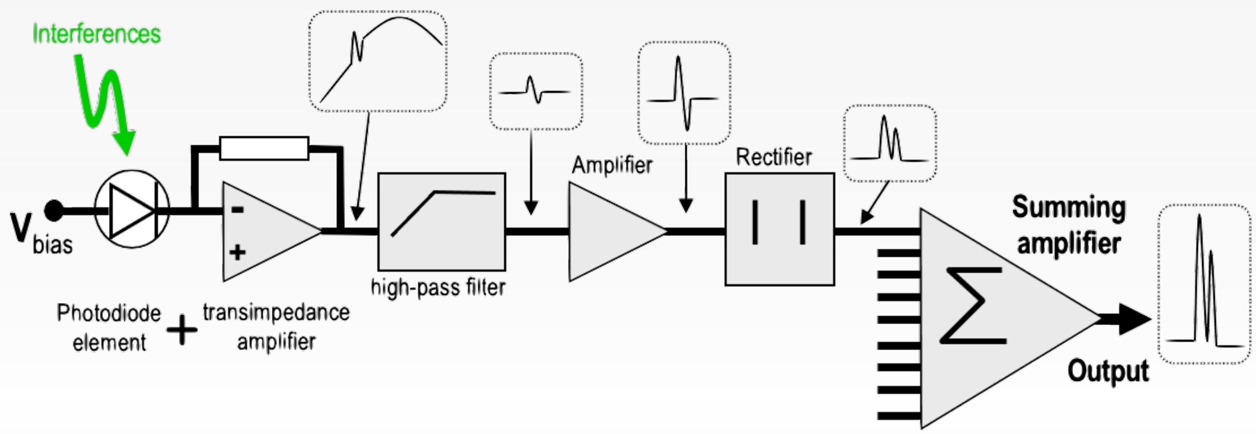
Modulo Quattro Optical Architecture:



Demodulation

Our MCRQ interferometers use two possible **demodulation schemes**: a rectified demodulation, and a linear demodulation. The rectified demodulation involves high-pass filtering to remove low-frequency perturbations, followed by the amplification and rectification of the signal. All the individual signals are summed together to obtain the resulting signal. This first scheme efficiently rejects background noise, but the information on the direction of displacement is lost. The second demodulation scheme, or linear demodulation, involves a logic control which detects the signal phase by monitoring the pilot signal. Depending on whether the signal is in-phase or out-of-phase, the logic switches between the two, summing amplifiers to add the appropriate signals constructively. The switch is based on the previously mentioned low-frequency Doppler shift introduced by the piezo-ring attached to the fiber. The low-frequency signal is separated from the high-frequency signal and used to switch the summation logic circuit based on the low-frequency sign. In this way, the displacement direction of the signal is accurately recovered.

Rectified demodulation:



Linear demodulation: