PDV Workshop at Sandia National Laboratories

October 22, 2012

New Dimensions in PDV

Polarization Controlled and Short Wavelength Photonic Doppler Interferometry

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Defense Experimentation and Stockpile Stewardship
National Security Technologies

New Dimensions in Photonics Doppler Interferometry

- Interferometer configurations
- Polarization control
- Signal-to-Noise Ratio (SNR) as a primary performance measure
- Balanced heterodyne detection
- Post-interferometer modulation
- New multiplexing possibilities
- Short wavelength PDV
- A new research team at UNLV

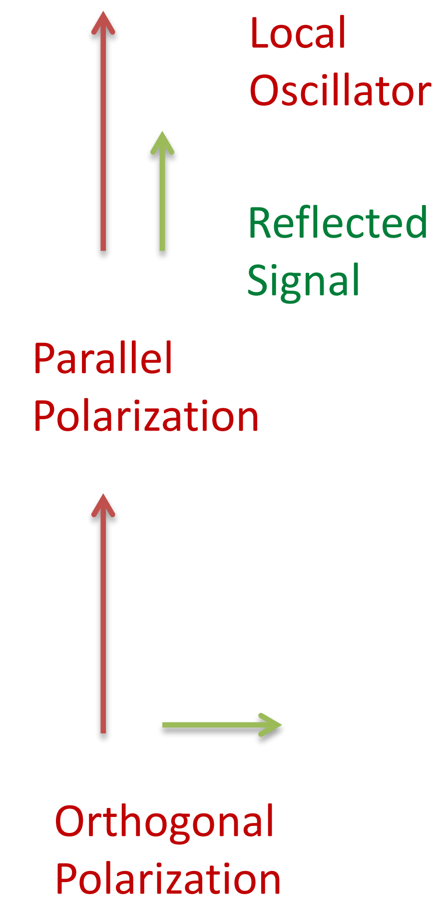
Polarization: A New Dimension to Enhance PDV Performance

- Higher heterodyning efficiency

$$\vec{E}_{LO} \bullet \vec{E}_{signal} = E_{LO} E_{signal} \cos(\theta) =$$

$$= \begin{cases} 0, & \text{for orthogonal polarization} \\ E_{LO} E_{signal}, & \text{for parallel polarization} \end{cases}$$

- Higher signal
- Lower noise
- Higher SNR: Higher precision!



Sagnac Interferometer for High Precision Displacement Measurement

- Loop interferometer topology
- Polarization based signal extraction scheme

VOLUME 76, NUMBER 17 PHYSICAL REVIEW LETTERS 22 APRIL 1996

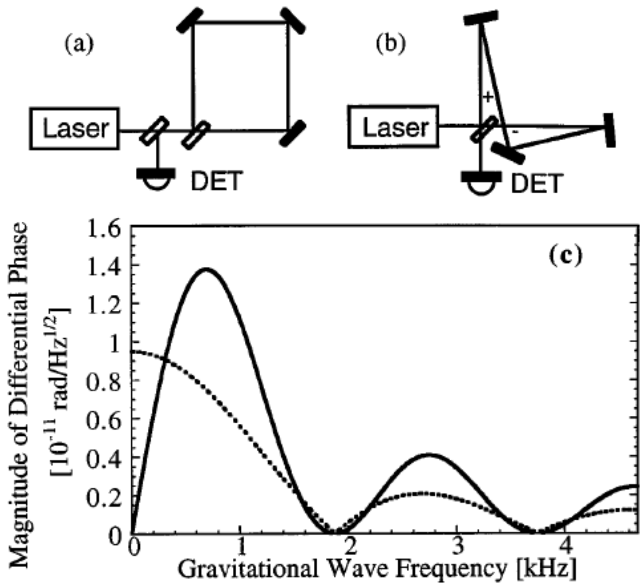
Sagnac Interferometer for Gravitational-Wave Detection

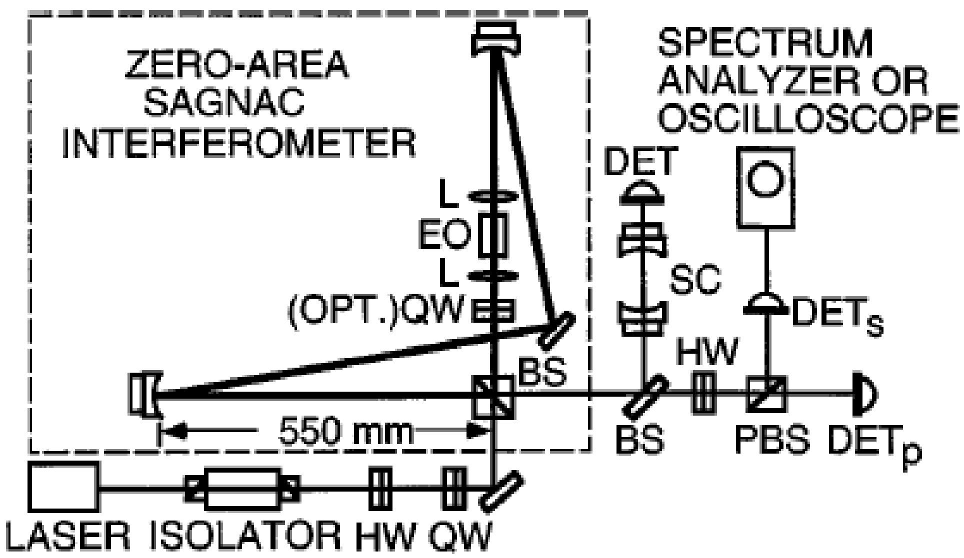
Ke-Xun Sun, M. M. Fejer, Eric Gustafson, and Robert L. Byer
Edward L. Ginzton Laboratory, Stanford University, Stanford, California 94305-4085
(Received 21 August 1995)

We have investigated a zero-area Sagnac interferometer as a broad band gravitational-wave detector. Frequency response measurements of a laboratory-scale interferometer are in excellent agreement with

Zero-Area Loop Interferometer

- Non sensitive to rotation
- Sensitive to displacement at certain locations





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Shot Noise Limited Interferometry Sensitivity

- SNR factors
  - Signals
    - Power
    - Wavelength
  - Noises
    - Imperfect contrast ratio
    - Detector quantum efficiency

The shot-noise-limited phase sensitivity of a Sagnac interferometer, which equivalent to a Michelson interferometer, assuming an optimal homodyne detection scheme at the dark port and coherent states for all inputs, is

$$|\Delta\phi| \approx \sqrt{2(P_{\mathrm{LO}} + P_{\mathrm{min}})2\pi\hbar f_l / P_{\mathrm{LO}} P_{\mathrm{in}} \eta C^2}\,, \qquad (6)$$

where P_{LO} is the local oscillator power, P_{min} is the leakage power from the dark port, $\hbar$ is the reduced Planck constant, P_{in} is the interferometer input power, η is the quantum efficiency of the photodetector, and the contrast ratio $C \equiv (P_{\mathrm{max}} - P_{\mathrm{min}})/(P_{\mathrm{max}} + P_{\mathrm{min}})$, where P_{max} is the maximum power out of the bright port. For less-than-unity contrast ratio, the power incident onto the detector is given by $P + P_{\mathrm{min}}$. A near-unity contrast ratio is desirable in an interferometer for two reasons; first, the phase sensitivity reaches the quantum limit only if the contrast ratio approaches unity; second, the photodetector saturates if illuminated with too much leakage power.

Polarization Controlled Based Balanced Heterodyne Detection

September 1, 1997 / Vol. 22, No. 17 / OPTICS LETTERS 1359

Polarization-based balanced heterodyne detection method in a Sagnac interferometer for precision phase measurement

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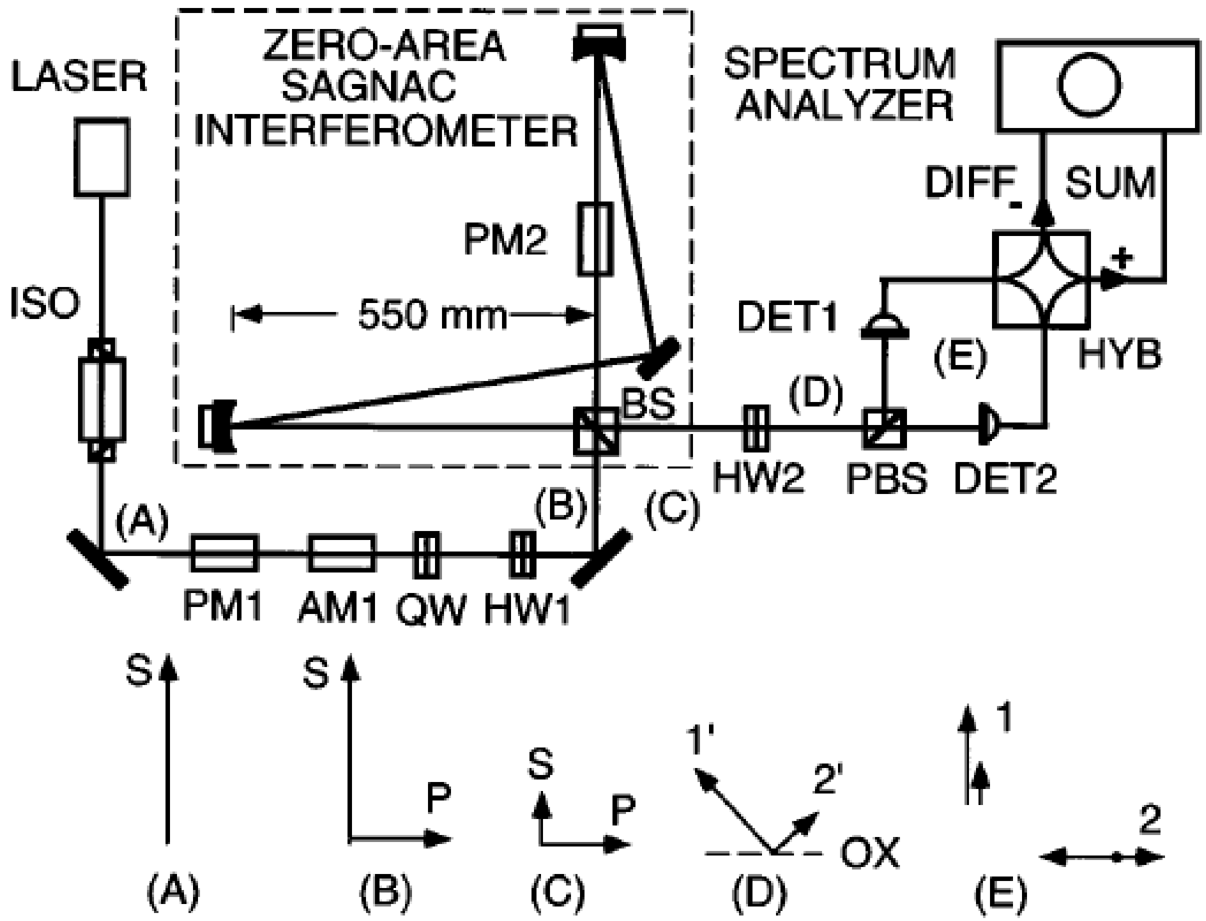
Edward L. Ginzton Laboratory, Stanford University, Stanford, California 94305-4085

Received March 21, 1997

We describe a balanced heterodyne detection method for a Sagnac interferometer that uses a polarization-dependent beam splitter. The signal and the local oscillator are orthogonally polarized components of a single laser beam, permitting the detection of the signal by subtraction of two photocurrents produced in appropriate polarization projections. Using this scheme, we experimentally demonstrate a phase measurement with a sensitivity of 9×10^{-10} rad/$\sqrt{\text{Hz}}$. The measurement is robust in the presence of laser frequency noise, as a result of preserving the common-path nature of the Sagnac interferometer, and of laser-amplitude noise, as a result of balanced detection.

PACS numbers: 04.80.Nn, 07.60.Ly, 42.25.Hz, 42.62.-b.

Polarization Arrangement to Enable Balanced Heterodyne Detection



High Precision Phase Measurements with Balanced Heterodyne Detection

- 9E-10 rad/Hz$^{-1/2}$ or ~1 fm/Hz$^{-1/2}$
- Robustness against laser frequency and amplitude noises

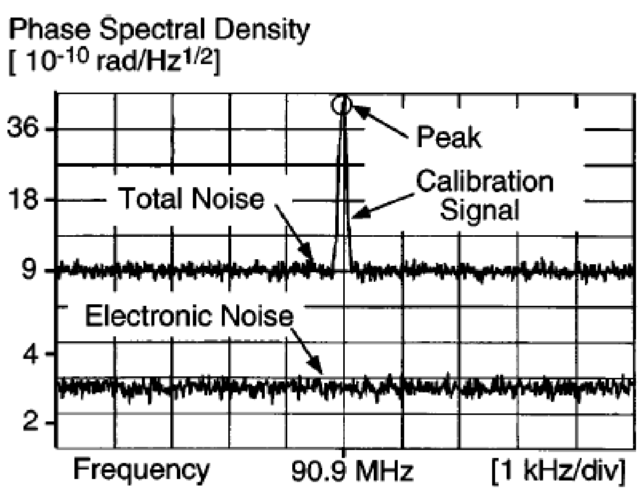
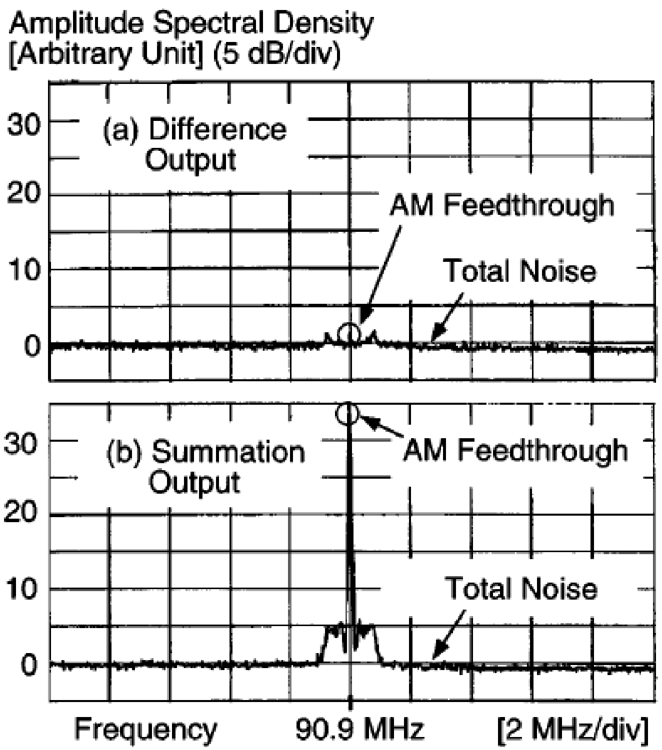


Fig. 2. Shot-noise-limited phase-sensitivity measurement at 90.9 MHz for the Sagnac interferometer. The calibration signal, the total-noise level (shot noise plus electronic noise), and the electronic-noise level are shown. The phase sensitivity is 9×10^{-10} rad/$\sqrt{\mathrm{Hz}}$.



Post RF Modulation for Signal Extraction

Frequency Shift at Ease

- Place modulator after the interferometer to lower the laser power impinged on crystal
- Eliminate the modulation effects at the input chain
- Can be used for frequency up shifting for dynamic range expansion

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Balanced heterodyne signal extraction in a postmodulated Sagnac interferometer at low frequency

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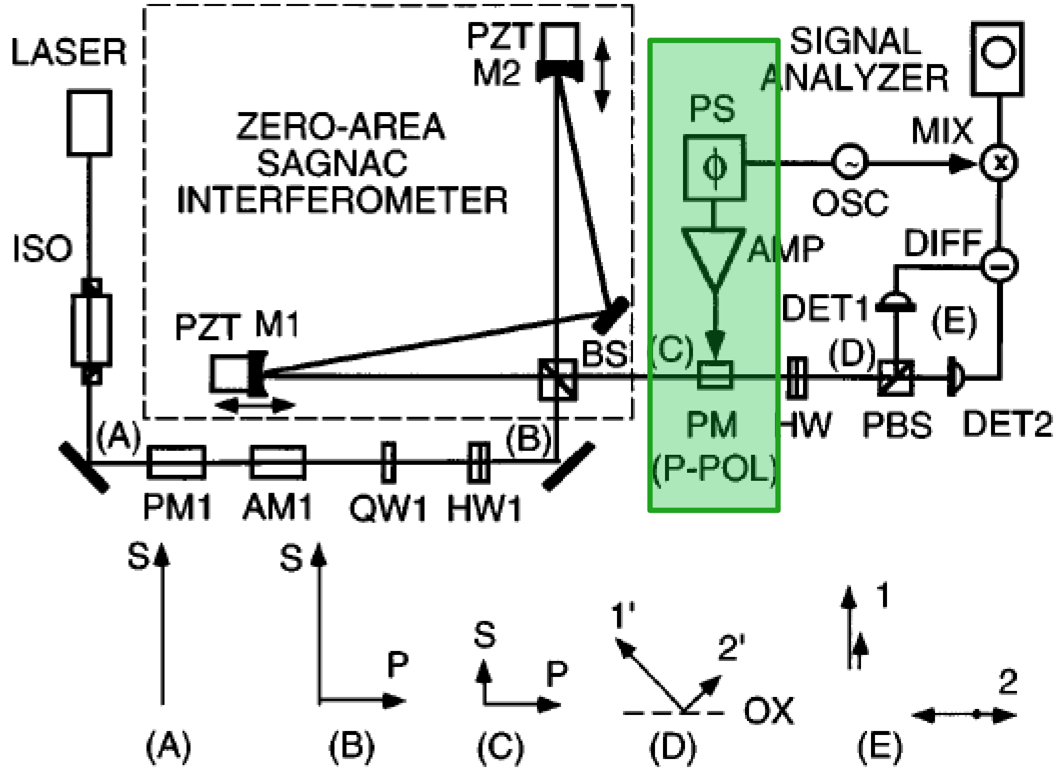
Received May 15, 1997

We describe a balanced-heterodyne postmodulated Sagnac interferometer signal extraction method that is suitable for gravitational wave detection. The method is simple to implement by placement of a polarization-selective modulator after the beam splitter in the dark port of the interferometer. The postmodulated Sagnac interferometer retains its common path advantage and exhibits insensitivity to laser frequency noise below, at, and above the heterodyne frequency. Balanced detection reduces sensitivity to laser amplitude noise. In this scheme mirror displacement signals were rf demodulated and observed from 0.2 to 10 kHz.

PACS numbers: 04.80.Nn, 07.60.Ly, 42.25.Hz, 42.62.-b

Post Modulation Optical Arrangements

- Local Oscillator and Signal orthogonally polarized
- Electro-Optical Modulator is polarization sensitive
- LO and Signal are differentially modulated
- Precision phase detection by heterodyning



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Sagnac Interferometer with Balanced Polarization Maintaining Fibers

- Follow up research in fiberized interferometer (2011)

Balanced polarization maintaining fiber Sagnac interferometer vibration sensor

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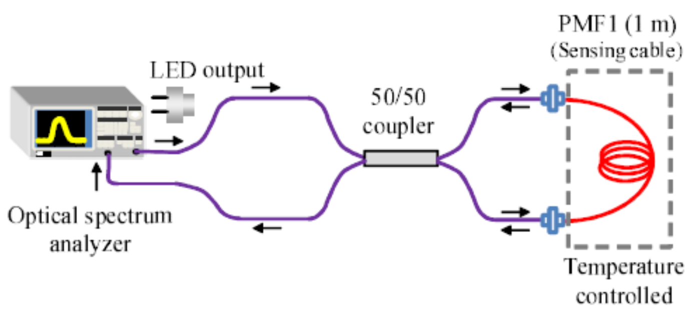
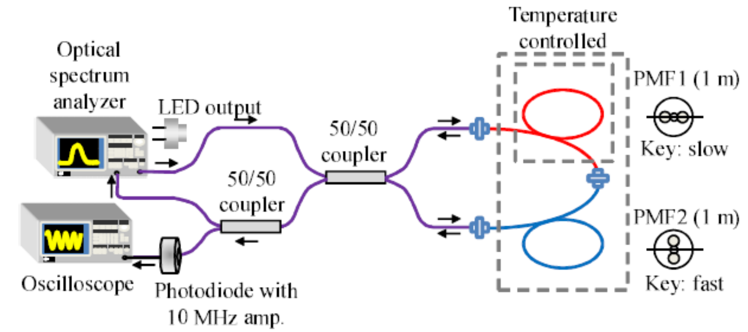


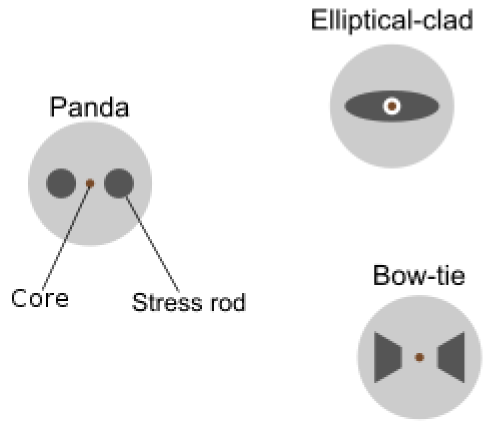
Abstract: To achieve a nearly zero-delay operating point in a polarization-maintaining (PM) fiber Sagnac interferometer, two identical PM fibers were incorporated so that their two main axes were orthogonally coupled to each other. A simple fiber vibration sensor system was constructed with a light emitting diode and a balanced PM fiber Sagnac interferometer, in which one of the PM fibers was used as a sensing cable and the other as a reference cable. The vibration sensor was confirmed to be temperature-compensated and generated a phase shift per unit length and unit strain of the sensor of 4.7 milliradian / (m·$\mu\varepsilon$) when mechanical vibrations with 1 kHz sinusoidal and triangular waves were stably observed under an input power of 10 μW.

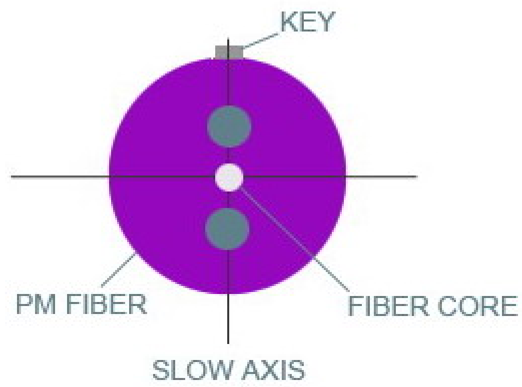
OCIS codes: (060.2370) Fiber optics sensors; (060.2420) Fibers, polarization-maintaining; (060.2430) Fibers, single-mode; (120.4820) Optical systems; (230.3670) Light-emitting diodes.



Polarization Maintaining Optical Fibers

- Panda fiber
- Elliptical clad
- Bow Tie





PM Fiber, Panda: 460 – 1100 nm

These polarization-maintaining fibers are designed for transmission of visible or NIR wavelengths. Their panda stress rod structure typically allows for tighter manufacturing tolerances than other PM fiber types. As a result, splicing and coupling can be done more reproducibly. Each of these fibers is available as a patch cable on pages 1010 - 1012. If you wish to create your own patch cable using these fibers, we offer the 301255D1 adjustable key FC/PC connector on page 1142.

Short Wavelength PDV

- Shorter wavelength
  - Example 532 nm (~1/3 of 1550 nm)
  - Enhances PDV shot noise limited sensitivity
  - Increases fringe counting, thus bandwidth
  - Can be combined with optical up conversion to extend the bandwidth
  - Complementary with 1550 nm PDV
  - Can parallel with 1550 nm PDV

Signal to Noise Ratio Enhancement Thanks to Shorter Wavelength

- Considering shot noise limited case
  - Signals $\propto$ $1/\lambda$
  - Noise $\propto$ $1/\lambda^{1/2}$
  - SNR $\propto$ $1/\lambda^{1/2}$

From Ted Strand (2009 SDRD Proposal Collaborator):
The current state of the art utilizes laser and telecommunication equipment at 1550 nm. In spite of the popularity of the 1550 nm PDV, any experiment that involves very short time scales or very small total displacements are still better served by VISAR or Fabry-Perot. In particular, measurements taken with 1550 nm PDV on initiation system flyer pressure experiments and on laser driven targets resulted in comparatively poor data quality. Using a short wavelength PDV should produce higher quality data.

Components Becoming Ready

- CW Green 532 nm Fiber Laser up to 100 W
- Single mode optical fibers at 532 nm

532 nm Electro-Optical Modulator

- Electro optical modulators (Amplitude & Phase)

The integrated optical light modulators utilize the fast electro-optical response of photonic crystals for fast amplitude and phase modulation of laser light in the visible and the infrared spectrum. High modulation frequencies and low modulation voltages characterize the compact modulators.

Optical coupling is realized by different optional waveguide types. On request the modulators can be combined with specially adapted controllers or analog amplifiers.

- Wavelengths between 500 nm and 1600 nm
- High modulation frequencies
- Short switching times
- Modulation of amplitude and phase
- Reduction of laser pulse rates

The UNLV Proposal

- 1550 nm PDV
- Polarization Controlled PDV
- Short wavelength PDV
- Combined PDV operations
- Quantum noise limited PDV

A New Research Group at the University of Nevada, Las Vegas (UNLV)

- UNLV Electrical and Computer Engineering
- New Security Science & Engineering Group
  - Faculty: Professor Ke-Xun (Kevin) Sun
  - Graduate students
  - Undergraduate students
- Research areas
  - GaN semiconductors and devices
  - Optics and Lasers
  - High speed electronics
  - Micro and Nano technologies
  - HEDP Diagnostics
- Supports and Collaborations
  - National Security Technologies (NSTec)
  - Sandia National Labs
  - Lawrence Livermore National Lab
  - Los Alamos National Labs