PDV Technique Smorgasbord

I even stole the title from David's past talk

Philip Rae and David Holtkamp

LANL

Outline

- **Data Reduction**
  Hilbert Transform
  Wavelet Methods
  Wigner Distribution (Cohen's Class) Transform
  Synthetic Quadrature
- **Fiber Stretcher**
- **Optical Frequency Modulator**
- **Drop-weight Triature PDV**
- **Offset Laser Frequencies**

Analysis Techniques

Polychromic vs Monochromic Signals

- Most of what I do involves one surface moving. Thus the PDV signal should (should?) have a single instantaneous frequency
- Situations where the PDV probe sees multiple moving objects (e.g. shock ejecta) will introduce multiple velocity components all superposed on one another.
- In the literature these are termed polychromic or multi-component signals. As far as I am aware, only FFT or wavelet analysis are appropriate for these signals
- With monochromic signals, other analysis techniques are available

Hilbert Transforms

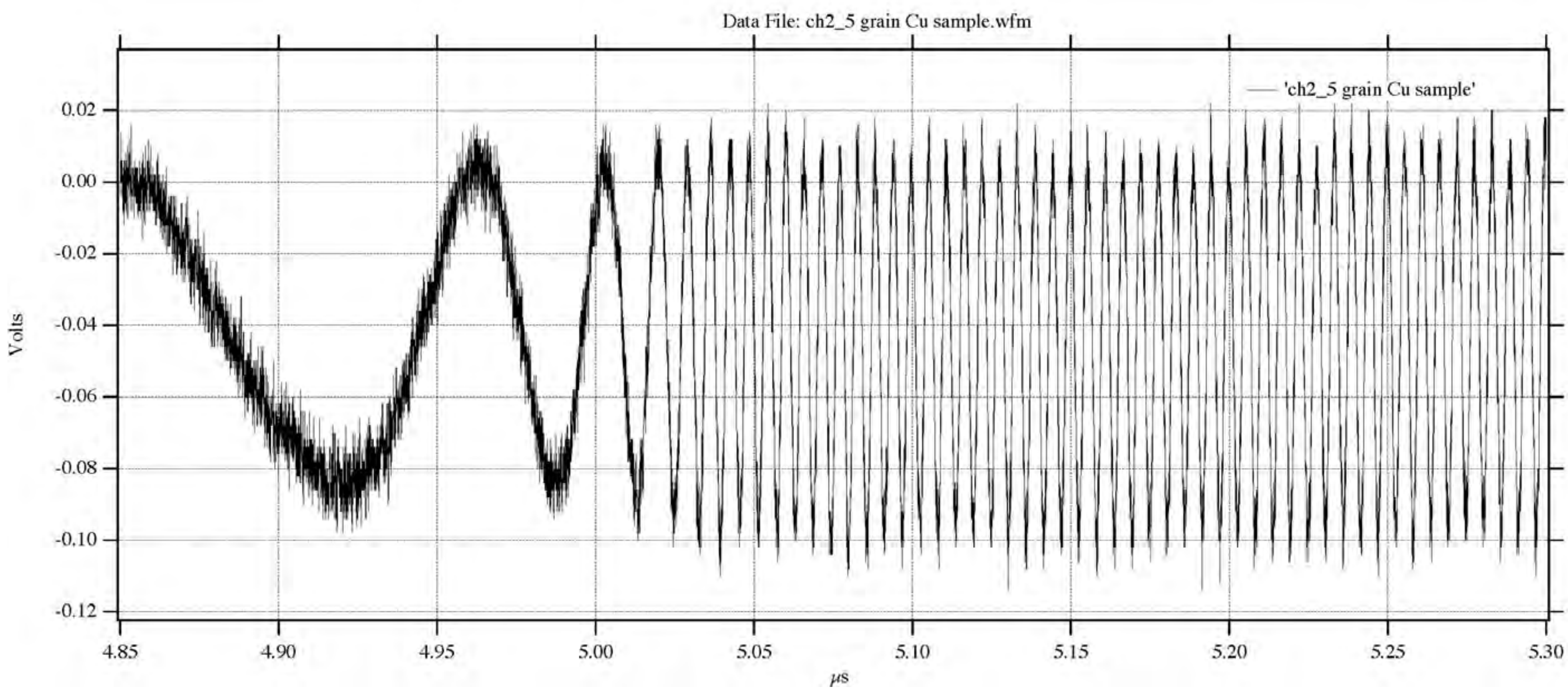
- It appears that one of the major remaining issues with PDV is the lower temporal resolution than VISAR
- I like the idea of using every point of data to obtain displacement and hence velocity, rather than averaging (FFTs, Wavelets etc.)
- One common Digital Signal Processing (DSP) technique is phase unwrapping
- That is, following the position along a periodic signal in terms of its phase with respect to time.
- To do that one requires to have, or to manufacture, two or more similar waves with a fixed phase difference
- One of the properties of the Hilbert transform is that the output from a sinusoidal signal input is the cosinusoidal version

Hilbert Transforms

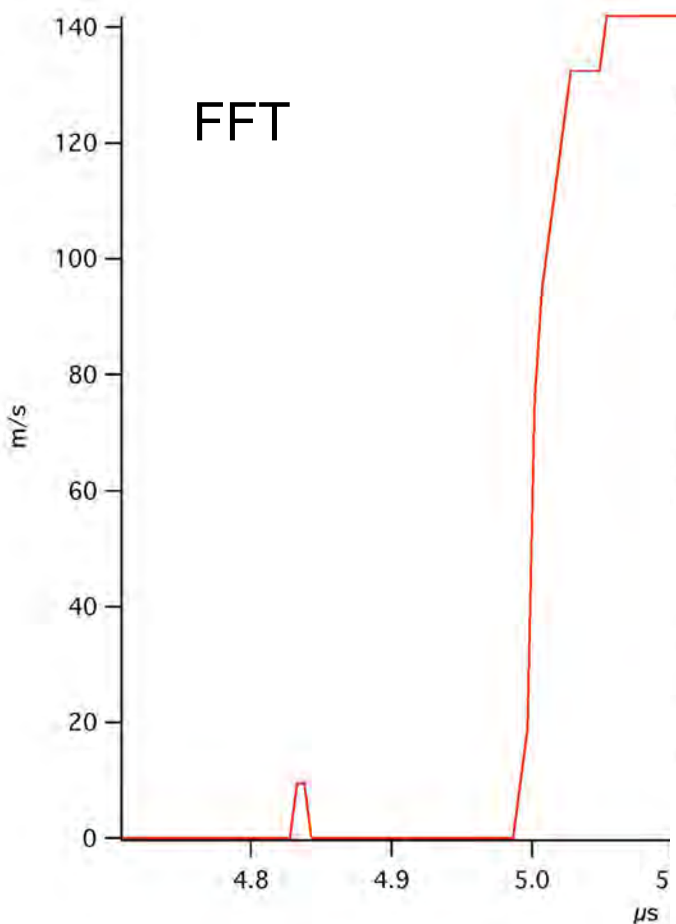
$$\tan\phi = \frac{\sin\phi}{\cos\phi} \quad \therefore \quad \phi = \tan^{-1}\left(\frac{I_{in}}{I_{Hilbert}}\right)$$

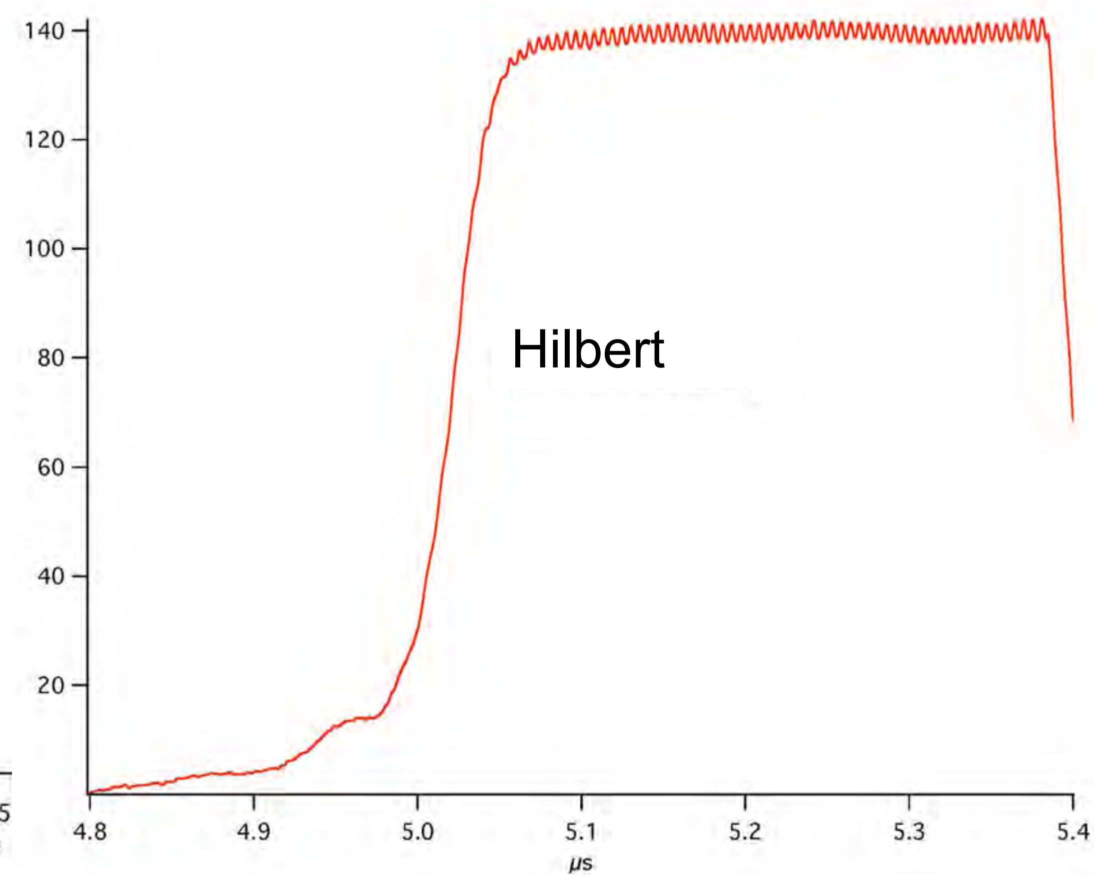
- **Thus the phase wrt. time is easily found. Displacement is a scalar function of phase.**
- **This is not a new idea. David (amongst, no doubt, others) used it early on.**
- **The snag is that the signals must be ‘clean’**
- **The advantage is that every single data point is used used to measure position, thus the temporal resolution is potentially very high**
- **Does it work?**

Copper Single Crystal Elastic Breakout



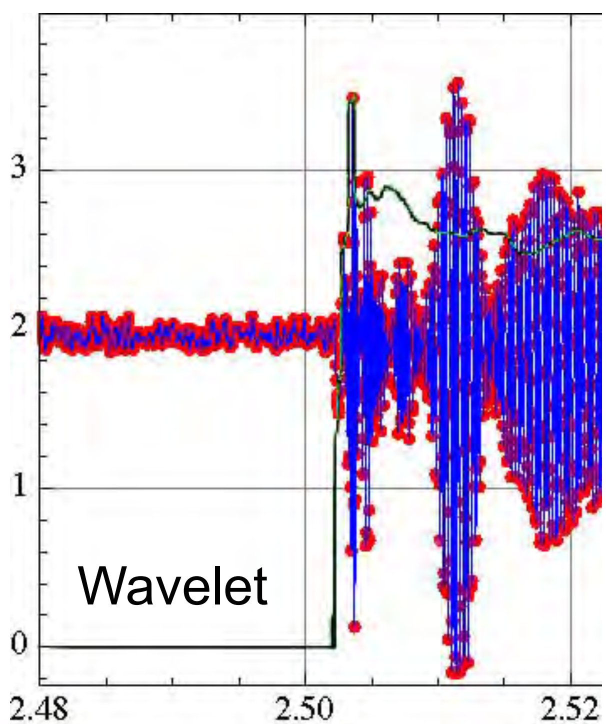
1024 point FFT method vs. Hilbert Transform

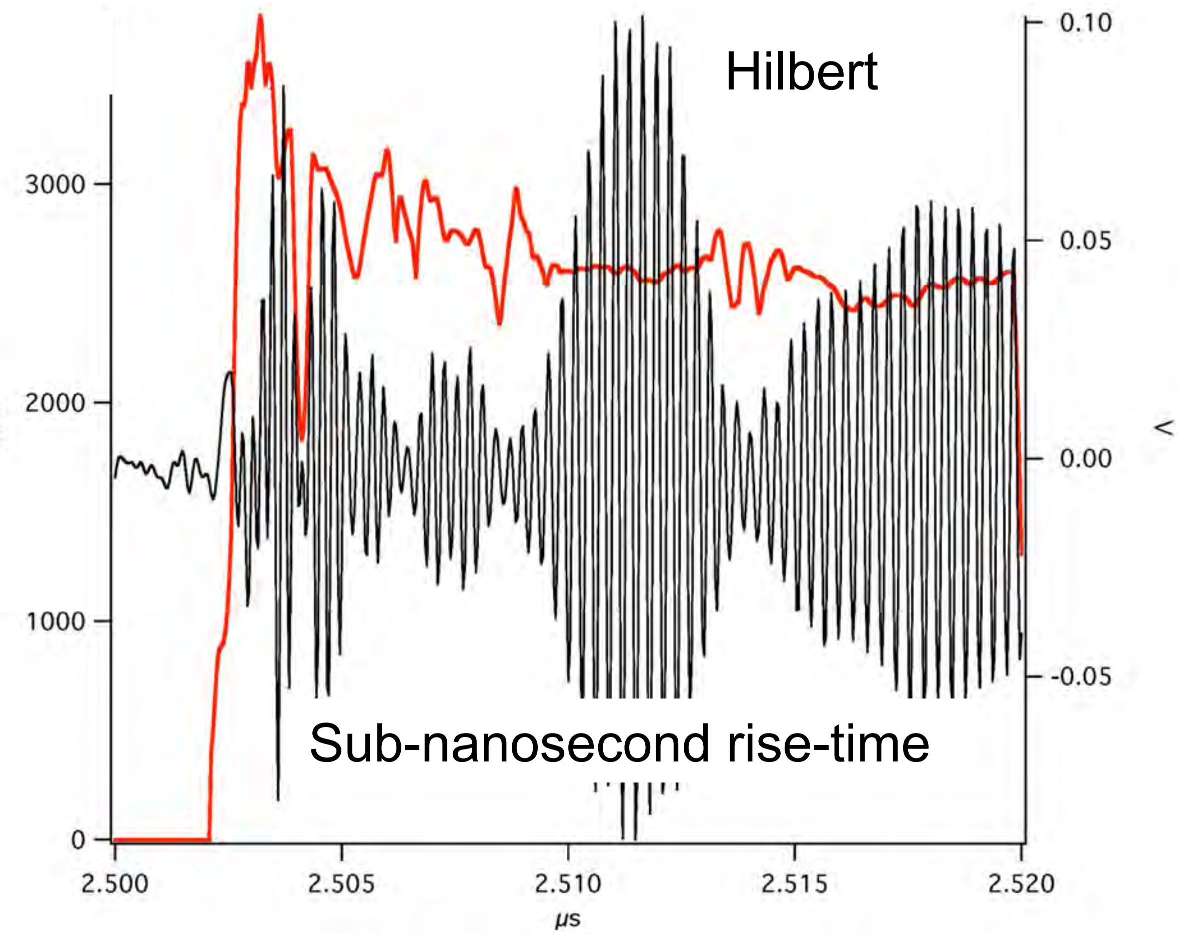




What is the Temporal Resolution?

HE breakout into LiF





Data Repository of Example Waveforms

- Should we establish a web-based data repository of example PDV data?
- It would make testing of new analysis techniques of real world data much easier
- The files could be stripped of proprietary or classified details. Only the bare minimum details are required for the user.
- It would be great to get some ceramic on ceramic shot data (fast rise times <1ns)
- It would be great to get some metal flyer data of different quality but from similar experiments
- Could we get some ejecta waveforms?
- etc.

Wavelet Transform Based Methods

Wavelet Transforms

- I have not been happy with the results of using the Wavelet Transform routines in IGOR
- I know Ric Gustavsen uses them for PDV (Mathematica)
- Who else? Is the game worth the candle?
- Has anyone done calibration against the Fourier based techniques. As I understand it, there is not always a 1:1 correlation between the wavelet ‘bins’ and frequency (i.e. velocity)
- Has this problem been seen in practice?

Wigner-Ville Distribution Transforms

Wigner Transforms

- I have had some success with using Wigner Transforms. The temporal resolution does seem to be slightly better than FFT
- The Wigner-Ville is a subset of the Cohen's Class
- Basically, this approach can only reliably be used on monocomponent signals. The cross-terms of polychromic signals will be a big problem
- Various people have altered the kernel to improve the cross-term response, but it seems they are whipping a dead horse
- Does anyone have experience (LLNL published a talk several years ago using IGOR and the Wigner-Ville)?

Time-Frequency Analysis Books

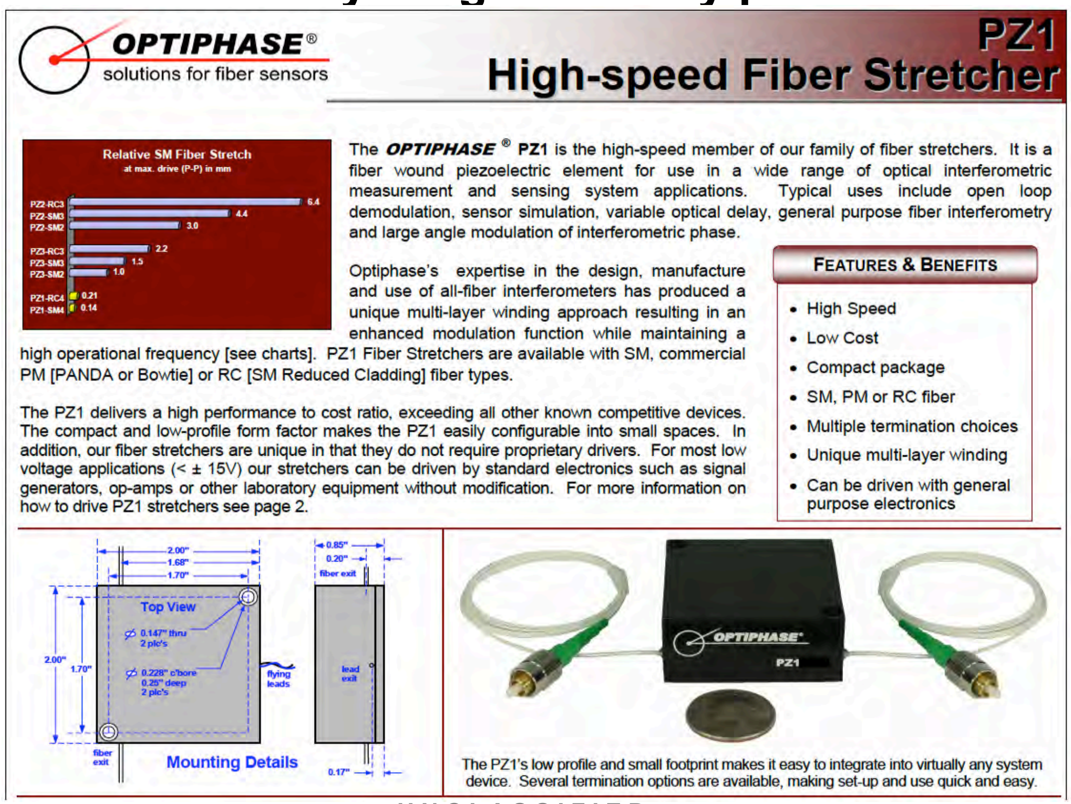
Books

- Time-Frequency Analysis. Concepts and Methods. Hlawatsch & Auger Eds., Wiley*
- Time Frequency Signal Analysis and Processing. A Comprehensive Reference. Boashash, Elsevier
- * My Preference
- Both books contain variants on the themes already discussed, FFT, Wigner, Wavelet, quadrature etc.
- There is nothing radical in either that I am not aware of being tried for PDV

Fringe Generation for Alignment Purposes using a Fiber Stretcher

Fiber Stretcher

- **David suggested the following fiber stretcher.**
- **I drive it with a 120kHz 5Vp-p sine wave from a regular signal generator to get an idea of the likely fringe intensity prior to a shot.**



OPTIPHASE® solutions for fiber sensors

PZ1
High-speed Fiber Stretcher

The ***OPTIPHASE*** ® **PZ1** is the high-speed member of our family of fiber stretchers. It is a fiber wound piezoelectric element for use in a wide range of optical interferometric measurement and sensing system applications. Typical uses include open loop demodulation, sensor simulation, variable optical delay, general purpose fiber interferometry and large angle modulation of interferometric phase.

Optiphase's expertise in the design, manufacture and use of all-fiber interferometers has produced a unique multi-layer winding approach resulting in an enhanced modulation function while maintaining a high operational frequency [see charts]. PZ1 Fiber Stretchers are available with SM, commercial PM [PANDA or Bowtie] or RC [SM Reduced Cladding] fiber types.

The PZ1 delivers a high performance to cost ratio, exceeding all other known competitive devices. The compact and low-profile form factor makes the PZ1 easily configurable into small spaces. In addition, our fiber stretchers are unique in that they do not require proprietary drivers. For most low voltage applications (< ± 15V) our stretchers can be driven by standard electronics such as signal generators, op-amps or other laboratory equipment without modification. For more information on how to drive PZ1 stretchers see page 2.

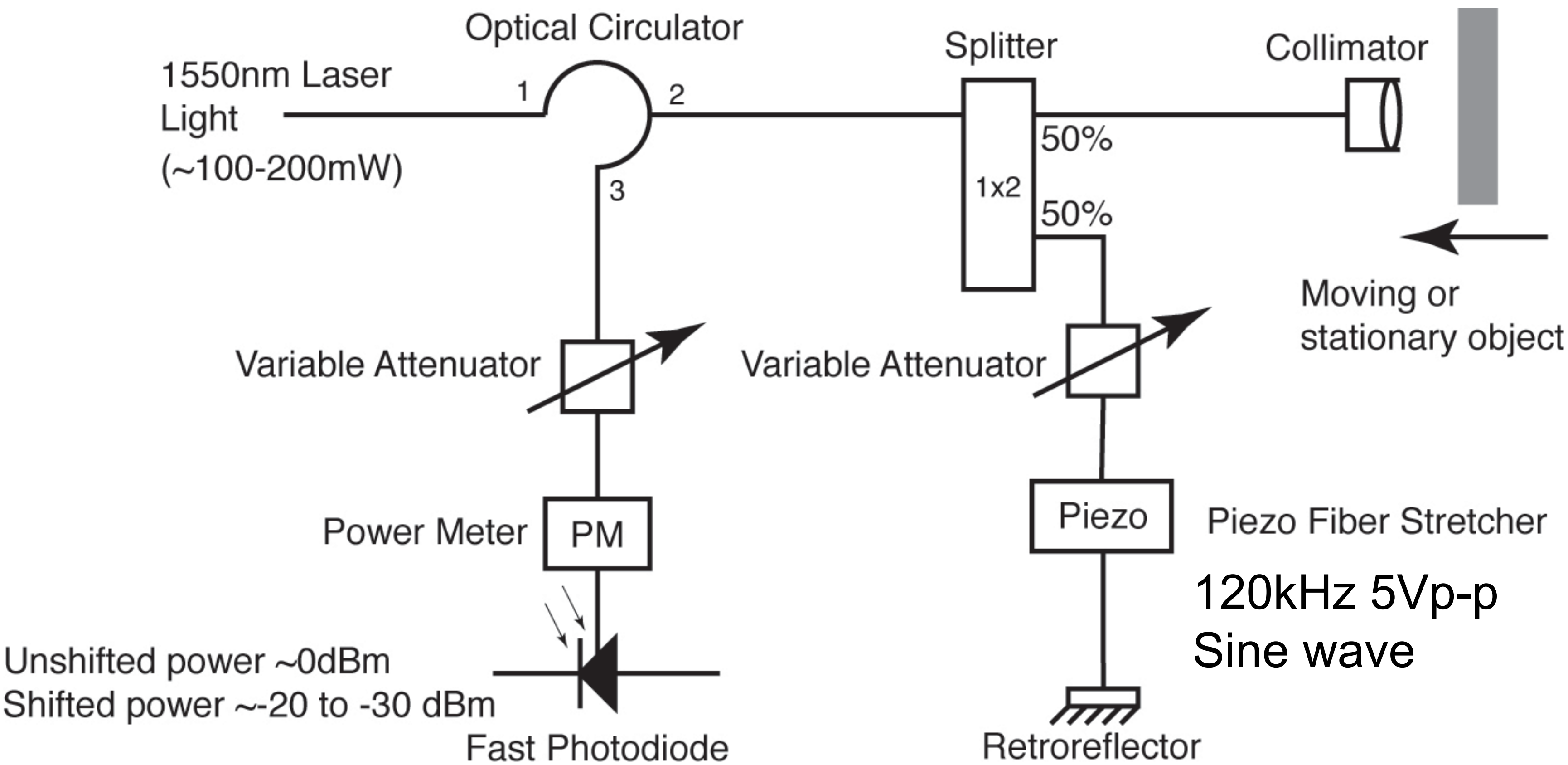
FEATURES & BENEFITS

- High Speed
- Low Cost
- Compact package
- SM, PM or RC fiber
- Multiple termination choices
- Unique multi-layer winding
- Can be driven with general purpose electronics

Mounting Details

The PZ1's low profile and small footprint makes it easy to integrate into virtually any system device. Several termination options are available, making set-up and use quick and easy.

Fiber Stretcher



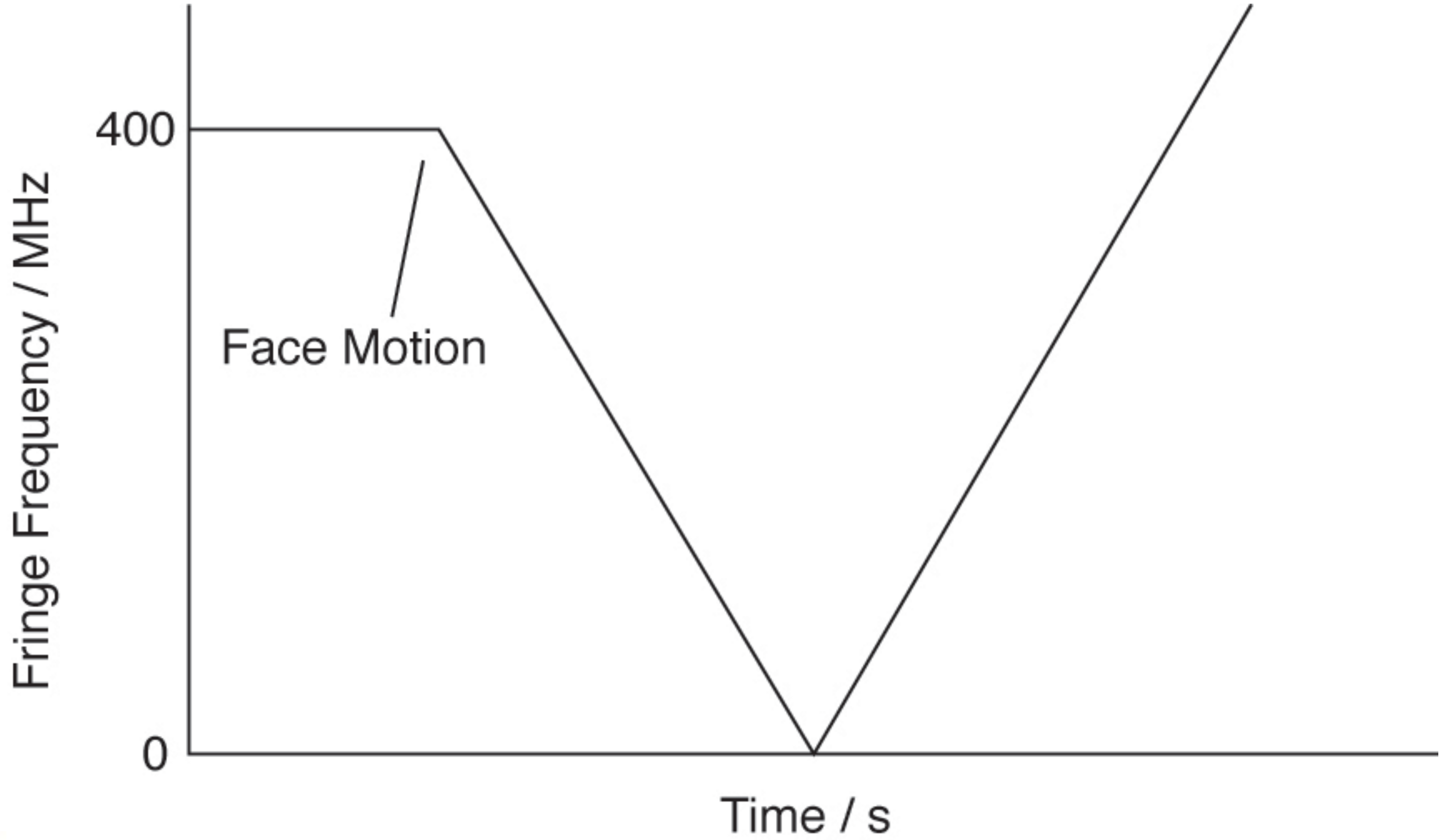
120kHz 5Vp-p
Sine wave

Creating Continual Fringes using a Optical Frequency Modulator

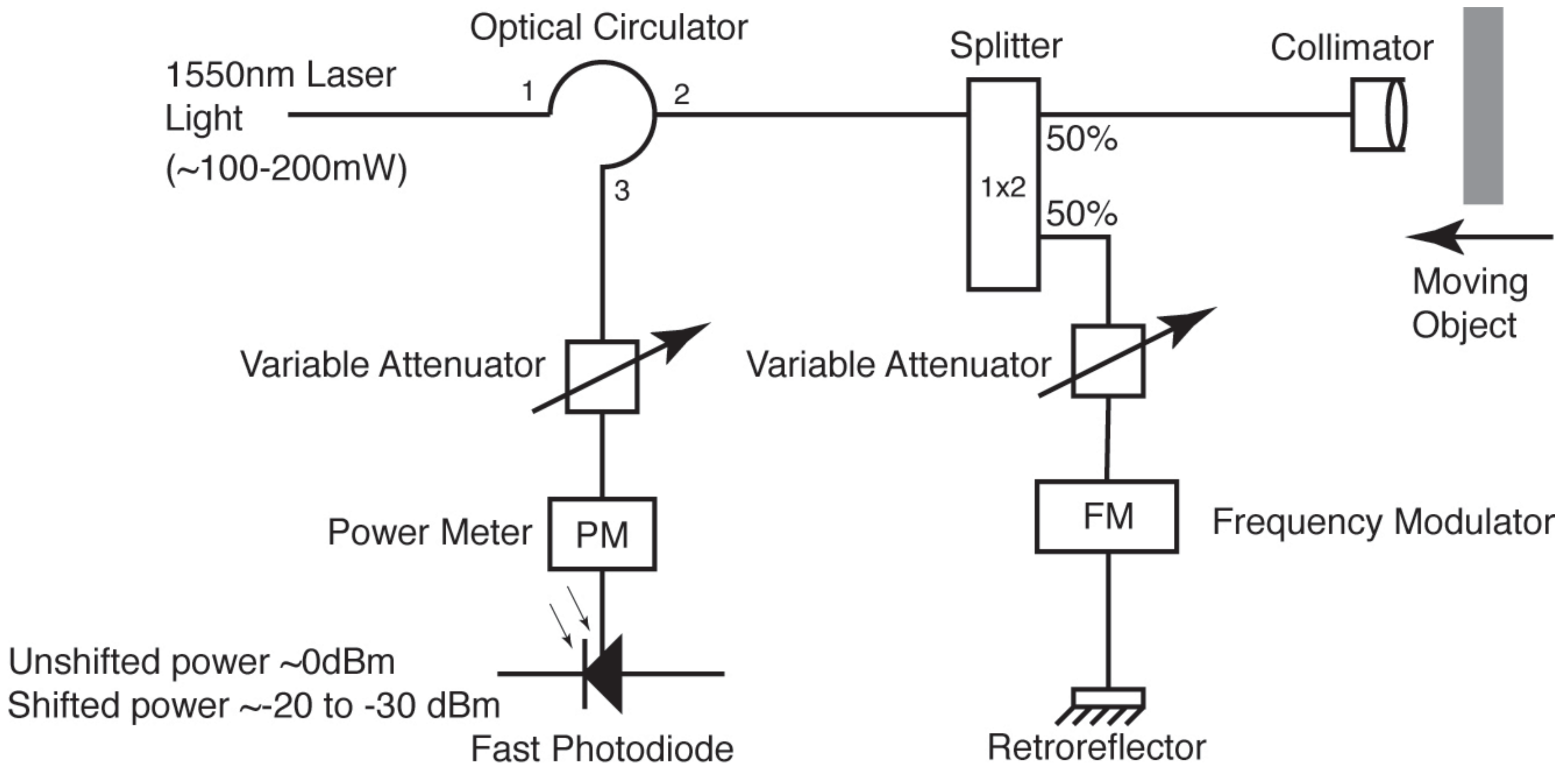
Optical Frequency Modulator

- We bought a 200MHz Acousto Optical Frequency Modulator
- With effective frequency doubling (double pass through device) we get standing fringes of 400MHz when the target is stationary
- Snafu with trusting intuition. We ordered a +200MHz shift. Objects approaching probes now lower the fringe frequency!
- This would have caused issues then with automatic analysis as the frequency passes through zero.
- I sent it back for swapping to -200MHz for an extra $400
- Greater bandwidth required, but analysis simplified
- Intraaction seem to produce fine equipment, but they take their time about everything.

Positive Frequency Shift Effect



The Arrangement



Intraaction Specification

IntraAction Corp.
QUALITY PRODUCTS FOR LASER TECHNOLOGY

PRICE QUOTATION NO. 09465

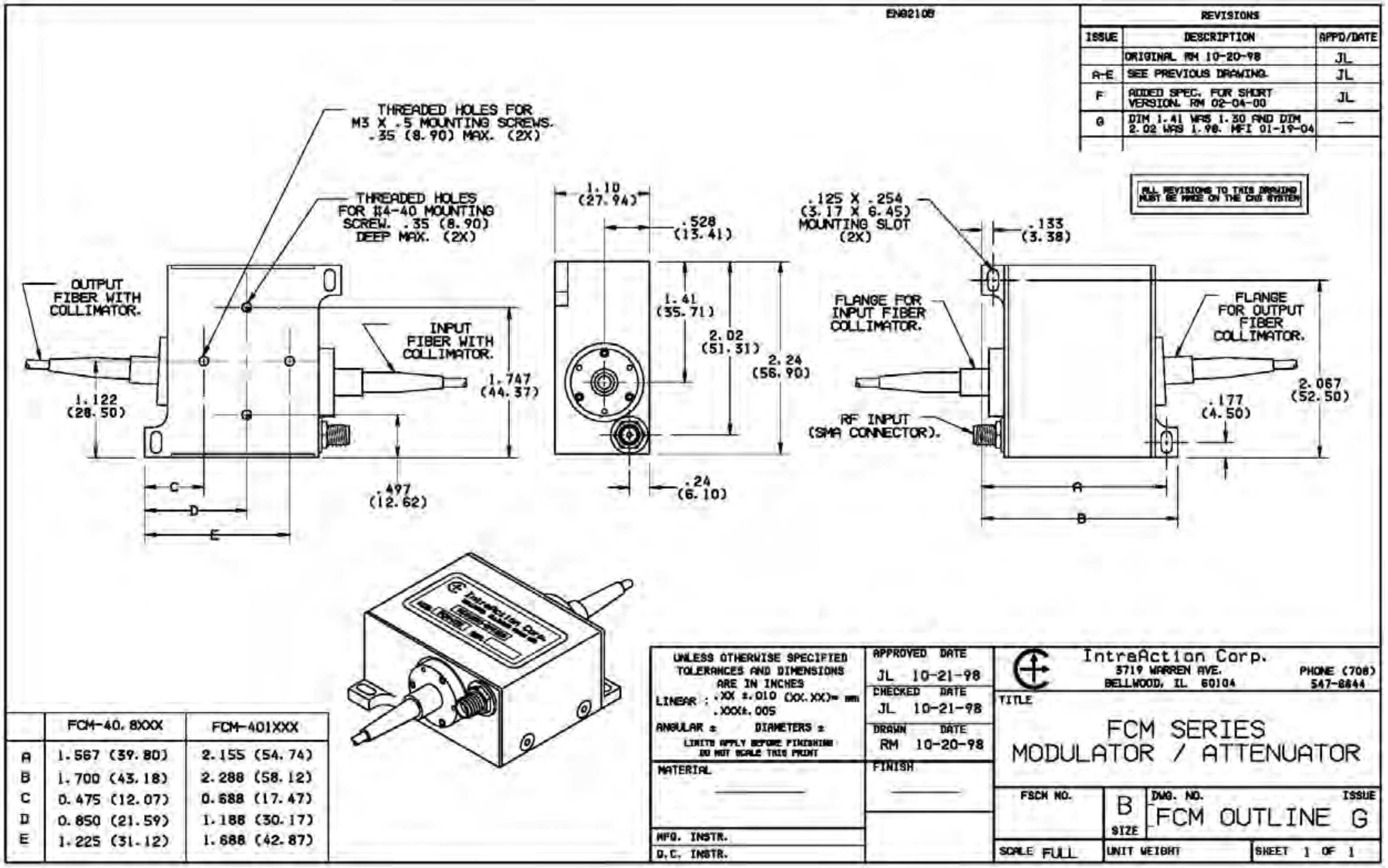
3719 Warren Avenue · Bellwood, IL 60104 · 708 547-6644 · Fax 708 547-0687 · iac@intraaction.com

TO:	**LOS ALAMOS NATIONAL LABORATORY**	MESSAGE NO. E09534
ATTN:	**PHILIP RAE**	DATE: November 19, 2009
FAX #:		FROM: JOHN LEKAVICH
PHONE:	505 667-4436	PAGE 1 OF 6
RE:	YOUR REQUEST FOR QUOTATION	

QUANTITY	MODEL	PRICE EA.
1 EA	FCM-2001.5E5A FIBER PIGTAILED MODULATOR MATERIAL, CHALCOGENIDE GLASS/AMTIR I A/R COATING/DESIGN WAVELENGTH, 1.55 µm OPTICAL INSERTION LOSS[1], 3 dB MAX OPTICAL BACK REFLECTION, -55 dB RF FREQUENCY, 200 MHz OPTICAL FREQUENCY SHIFT, +200 MHz EXTINCTION RATIO (RF ON/RF OFF), >55 dB OPTICAL RISE TIME, 260 NSEC RF DRIVE POWER, 2 WATTS INPUT IMPEDANCE/VSWR, 50 OHMS/1.25 RF CONNECTOR, SMA FIBER CONNECTORS, FC-APC FIBER TYPE / LENGTH, SMF / 1 METER SIZE (LESS CONNECTORS), 1.11(2.9)H x 2.24(5.7)D x 2.3(5.9)W INCHES(CM)	$3350.00

[1] DOES NOT INCLUDE LOSSES AT FC-APC CONNECTORS

Intraaction Modulator

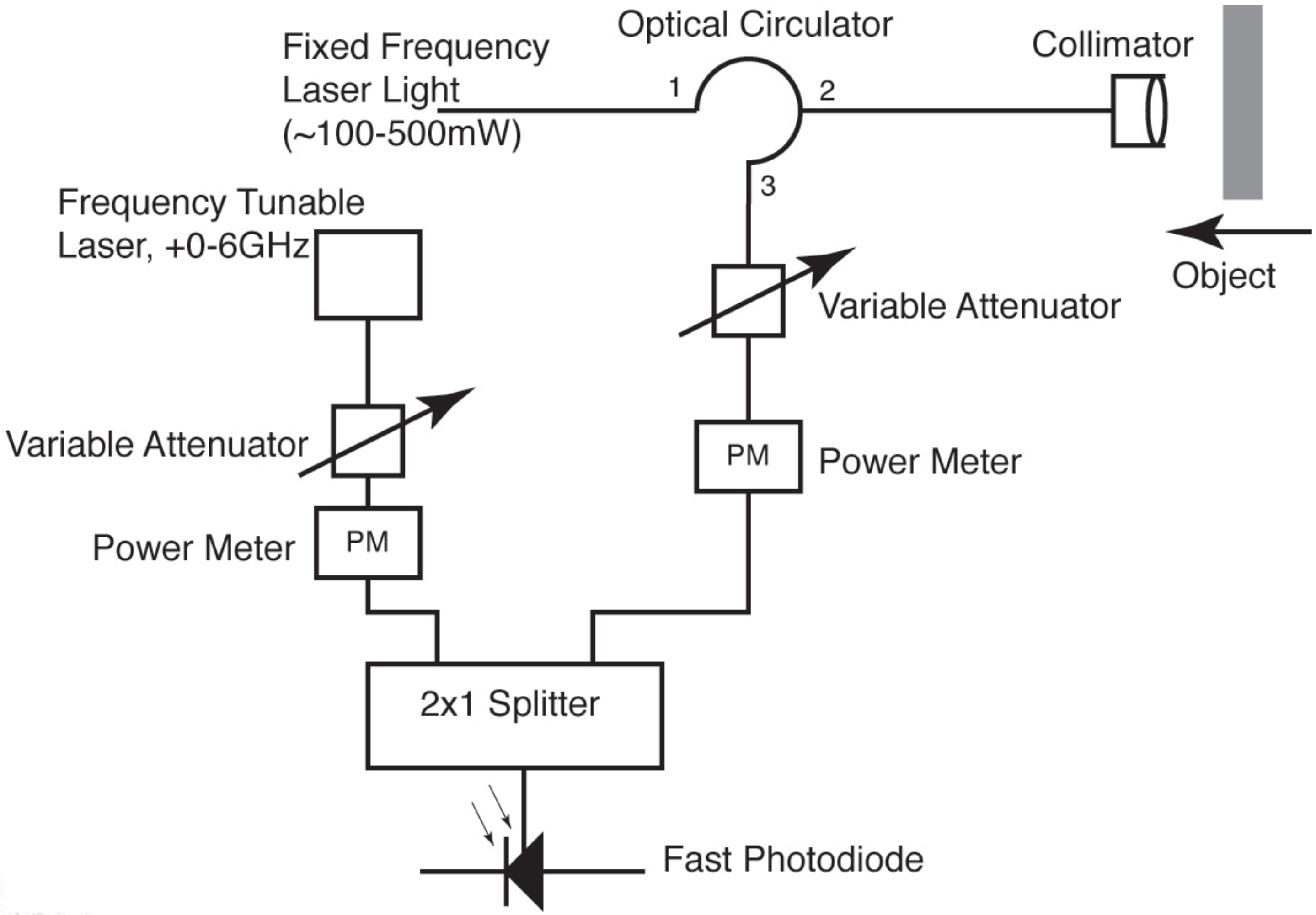


PDV Using Two Matched, But Frequency Offset Lasers

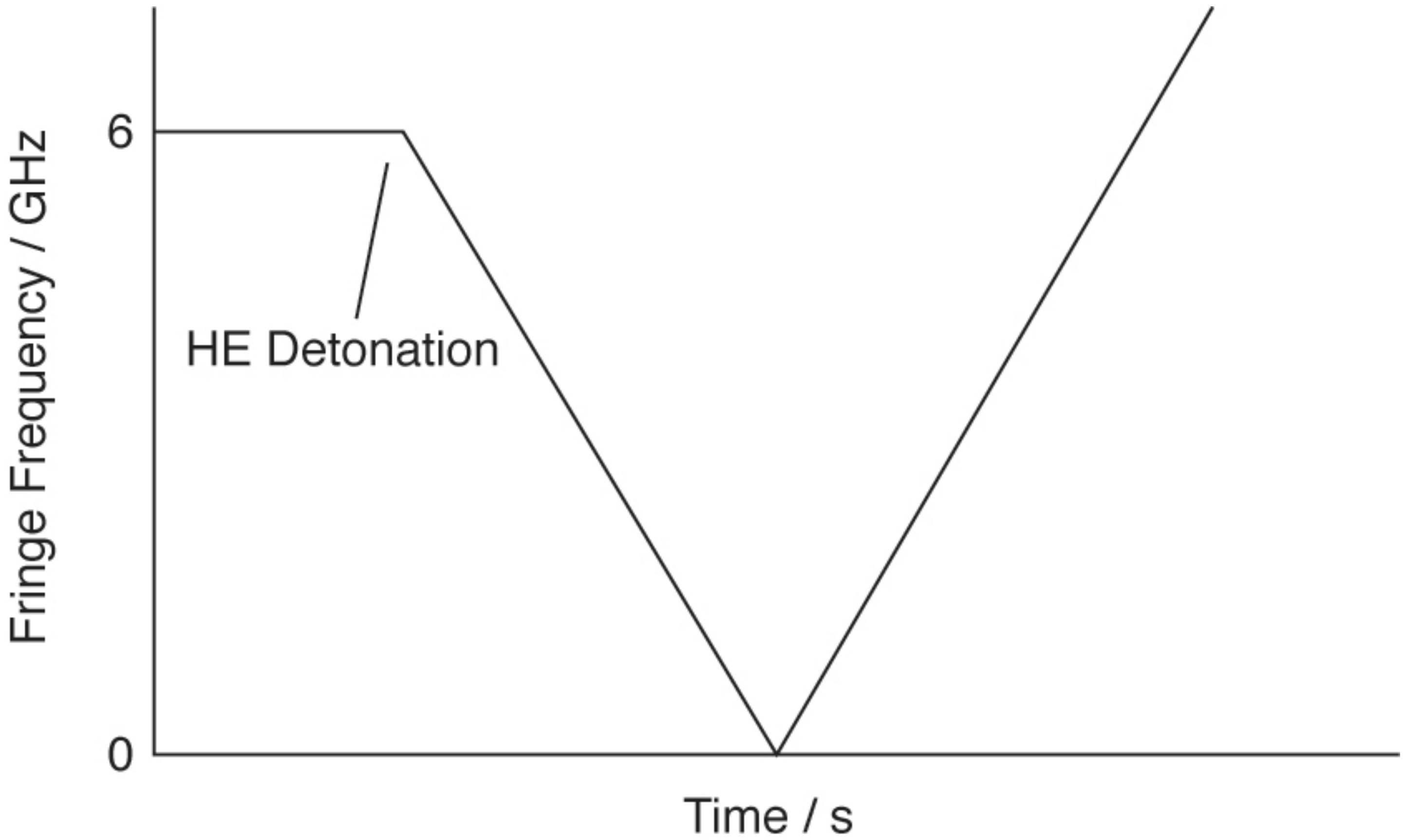
Matched Lasers

- I recently ordered a pair of matched lasers from Redfern optics (http://www.rio-inc.com/).
- Laser 1 is a 10mW frequency tunable laser (+0-6GHz) (~$4600)
- Laser 2 is a fixed frequency 0.1-1W minimum (2W probable) erbium amplified laser ($17,100)
- The base frequency of each laser is matched. Linewidth <15kHz.
- After a warm up period, and if the seed laser on the power laser is left on, the frequency change between the lasers beat frequency upon going to full power is <320MHz in the first few seconds and reaches less than 10MHz after 60 sec.
- I will be building and testing a PDV based on these lasers for use with very fast fringe frequencies (embedded optical fiber in HE)

Matched Lasers

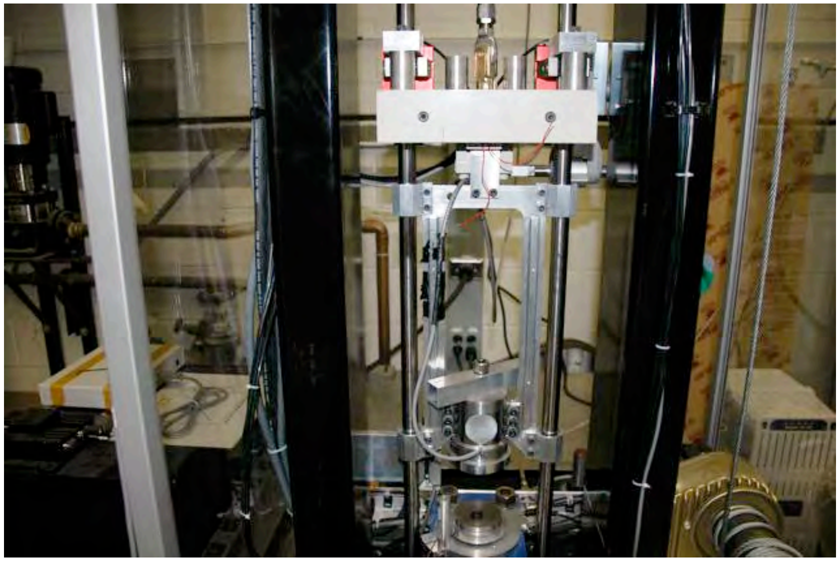


Frequency Offset



A Triature System for a Drop-Weight System

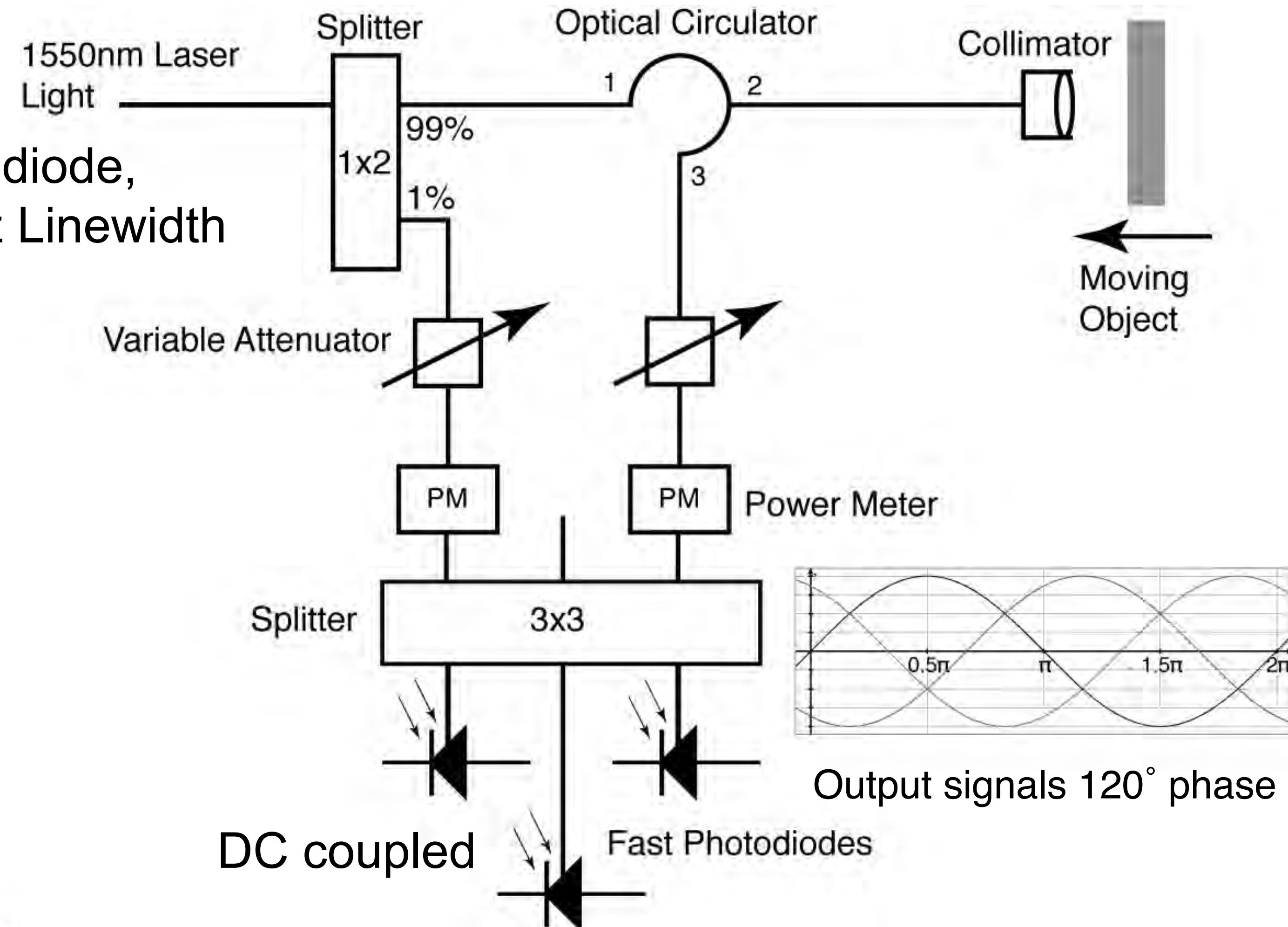
The Drop Weight



Triature PDV

Retroreflective tape used!

40mW diode,
<1MHz Linewidth



Output signals 120° phase shifted

DC coupled

Analysis Routines Written in IGOR

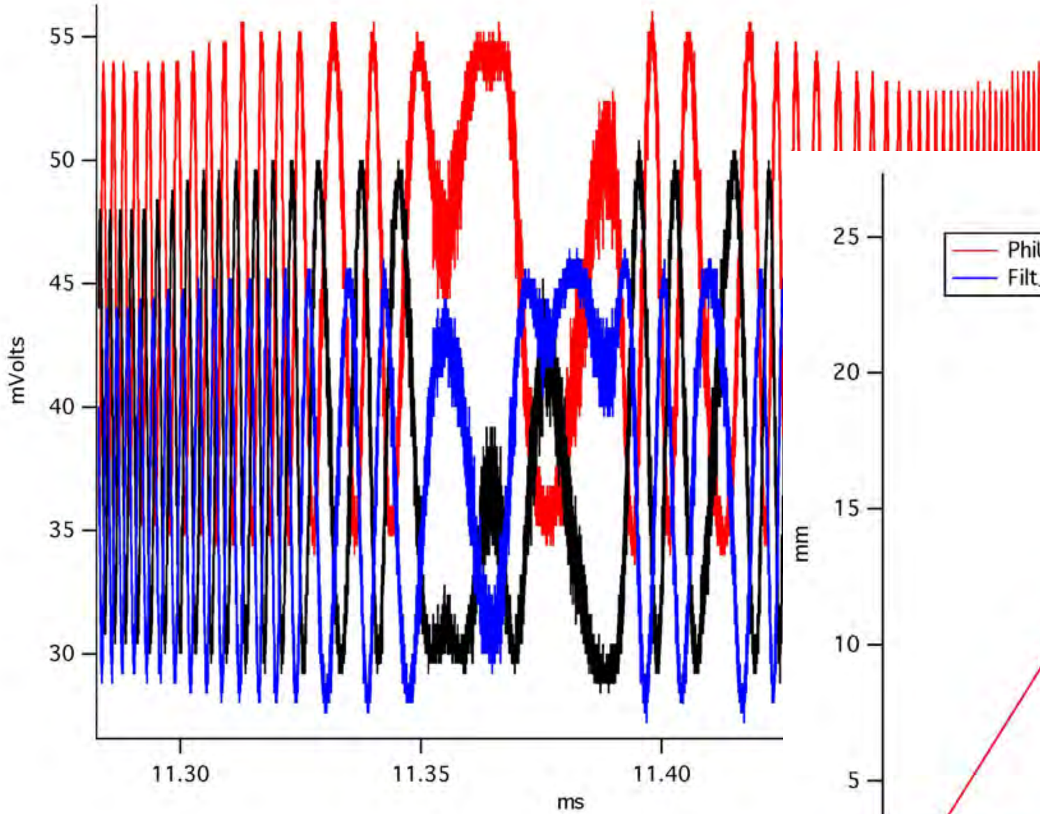
- In this case, we actually wanted a displacement interferometer
- Borrowing ideas from Sandia's THRIVE program.
- We perform quadrature phase unwrapping using the three signals
- I implemented the full correction for the true phase difference not being +/-120˚. In reality, this made a negligible correction (<1:1E6).
- Far, far more important is normalizing the 3 signal amplitudes to be equal and have zero DC component
- At present I just use a global averaging procedure. Better would be an adaptive correction that is undertaken throughout the waveform.
- 5 million point files easily processed in the early stages of validation. Fewer points are actually recorded from real experiments
- Igor is very good about large data sets

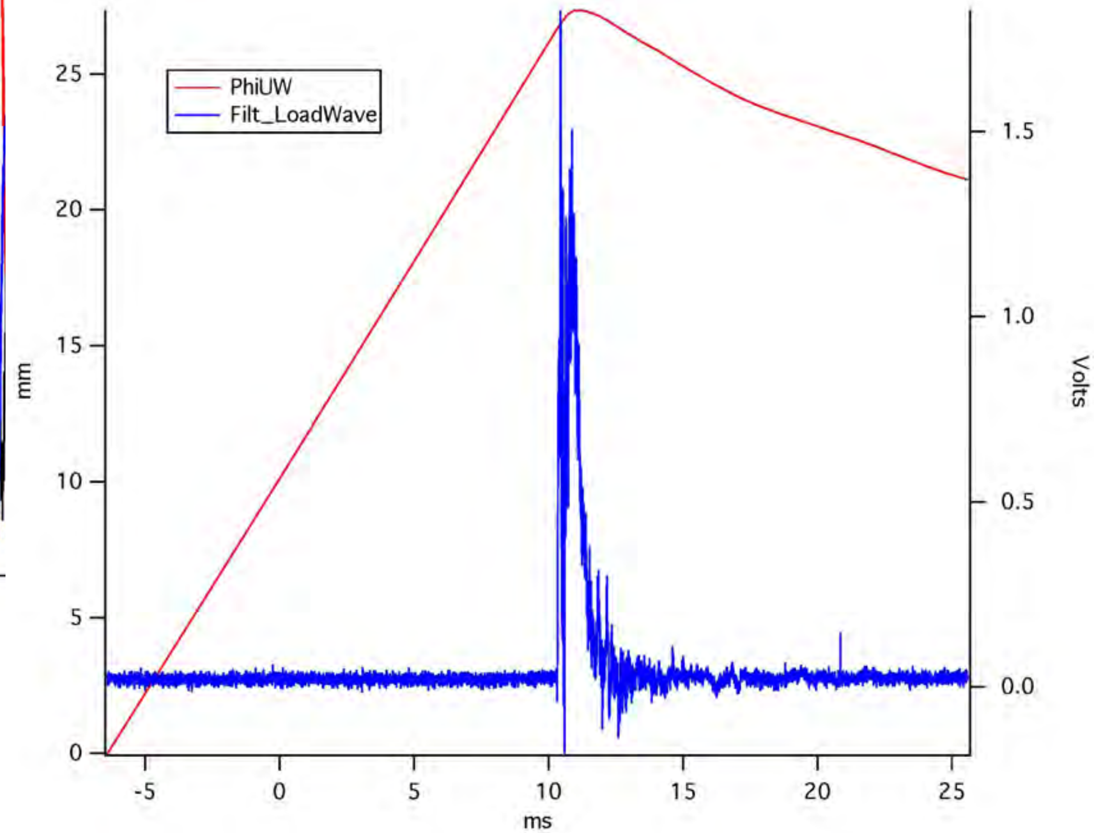
Quadrature Analysis

- **Calculate phase from the intensity records**
- **Unwrap the discontinuities to get a continuous phase versus time record. Use the system scalar to generate displacement vs. time**
- **Differentiate to get velocity if required. Smoothing the data is the trick prior to this operation.**
- **In my experience, box car averaging, binomial averaging and Savitzky-Golay smoothing and differentiation all work well on different data sets, but none is always the best.**

$$\phi = \tan^{-1}\left(\frac{\sqrt{3}(I_3 - I_2)}{2I_1 - I_3 - I_2}\right)$$

Traces & Results





Questions