PDV measurements of structured wave profiles at modest velocities (< 1 km/s)

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Z Accelerator

Veloce

Gas Gun

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1646 Dynamic Material Properties

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Motivation

- Achieve both optimal velocity & time precision
- Where does this matter?
  - $l_0 = 1550 \text{ nm}$, $v = 100 \text{ m/s}$, $f = 0.13 \text{ GHz}$
  - $\delta v \leq 10 \text{ m/s}$, $\tau = 6 \text{ ns}$
- “Modest” velocity (<1km/s) transients
  - Structured waves (ramps and multiple shocks)
  - Elastic precursor, phase transition

Background

- PDV beat frequency: $f = \frac{2v}{\lambda_0}$; uncertainty product: $(\delta v)(\tau) \geq \frac{\lambda_0}{8\pi}$, $\tau = \frac{\lambda_0}{8\pi \delta v}$

STFT analysis

$\tau = 20 \text{ ns}$

$\tau = 5 \text{ ns}$

Ramp loading on Veloce

LiF (VISAR) 6 GPa

T. Ao et al., RSI 79, 013903 (2008)
PDV Analyses

- **Detector measures output intensity**

\[
D(t) = aI_R + bI_T(t) + 2\sqrt{I_R I_C(t)} \cos \left[ \Phi(t_i) + 4\pi \frac{x(t) - x(t_i)}{\lambda_0} \right]
\]

- **Short-time Fourier Transform (STFT)**
  - Finite time window, usually over several fringes
  - Velocity from Gaussian fitting of power spectrum

- **Three-phase analysis (THRIVE\(^1\))**
  - Three signals shifted by 120°
  - Displacement from quadrature reduction (similar to VISAR analysis)
  - Velocity from differentiation of displacement

- **Local sinusoid**
  - Similar to STFT, less robust to transients

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\(^1\)D.H. Dolan and S.C. Jones, RSI 78, 076102 (2007)
Experimental Configuration

- **Gas gun**
  - Ring-up to shock state
  - Comparable target geometry to pulsed power loads

- **Three-phase PDV measurement**
  - Focusing probe (f = 12 mm)
  - DC detectors cleaner than AC detectors but are less sensitive

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![Diagram showing experimental setup and measurements](image-url)
- **STFT power spectrum**
  - 20 ns Hamming window
  - Gaussian fitting of peaks

![Diagram with primary and secondary reflections](Image)

- **Apparent velocity (m/s)**
- **Time (ns)**
- **Output (V)**
- **STFT (20 ns)**

**Measured PDV signal**

- **Apparent velocity (m/s)**
- **Time (ns)**

- **Sandia National Laboratories**
- $t = 20$ ns
  - THRIVE & STFT agree with WONDY prediction
  - Smaller oscillations with STFT

- $t = 5$ ns
  - Deviation between THRIVE & STFT
  - STFT’s average velocity biased systematically lower than WONDY
  - Smaller oscillations with THRIVE
- Attempt to reduce secondary reflection
  - Focusing probe insufficient
  - Add Quartz window to diminish multiple window transit effect
    \[ D(t) \propto \sqrt{I_R I_{C_1}(t)} \cos \Phi_1 + \sqrt{I_R I_{C_2}(t)} \cos \Phi_2 \]
- Oscillations smaller than with only Sapphire window but remains
  - Need anti-reflective coating at free surface
- **Anti-reflective coating on Sapphire**
  - Reflectivity < 0.05% at 1550 nm

- **STFT power spectrum**
  - 20 ns Hamming window
  - Gaussian fitting of peaks

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**Diagram:**
- PDV
- Sapphire 12mm
- Quartz 0.5mm
- AR coating

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**Graphs:**
- Apparent velocity vs. Time (ns)
- Apparent Velocity (m/s) vs. Time (ns)
- \( t = 20 \text{ ns} \)
  - THRIVE & STFT agree with WONDY prediction
  - Smaller oscillations with THRIVE

- \( t = 5 \text{ ns} \)
  - Deviation between THRIVE & STFT
  - STFT’s average velocity biased systematically lower than WONDY
  - Smaller oscillations with THRIVE
Mitigation of secondary reflection

- Anti-reflective coating with THRIVE analysis
  - Velocity oscillations of \( \frac{dv}{v} \approx 1\% \) (1s) and \( t=5 \) ns
  - Comparable to velocity and time precision of VISAR
Summary

- **Transient wave profiles at modest velocities (< 1km/s)**
  - Require optimization of both velocity and time precision

- **Short time Fourier Transform analysis (STFT)**
  - Robust and “simple”
  - Reliable over many fringes (large $t$) but suspect for small number of fringes (small $t$)

- **Three-phase analysis (THRIVE)**
  - More complicated (3 detectors/probe), more characterizations
  - Better for rapid transients
  - Consistent with STFT over many fringes (large $t$)

- **Must mitigate secondary reflection at window free surface**
  - Anti-reflective coating < 0.05%
  - Wedged window
Acknowledgements

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- Andy Shay
- Randy Hickman
Examine displacement profile

- Sinusoid riding on linear ramp

\[ x(t) = x(t_i) + vt + A \cos \left( \frac{4\pi}{\lambda_0} vt \right) + B \sin \left( \frac{4\pi}{\lambda_0} vt \right) \]

- Iteratively solve for velocity
  - Use time window covering at least one wavelength of sinusoid (\( t = 6 \text{ ns} \))