

Complete Pulse Characterization Based on Temporal Interferometry Using An Unbalanced Temporal Pulse Shaping System

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Outline



- Introduction
- Principle of UB-TPS system
- Pulse characterization using UB-TPS system
- Discussions
- Conclusion



Introduction



- Applications of ultrashort optical pulses:
 - Optical communications and signal processing
 - Microwave waveform
 - Medical diagnostics
 - Direct observation of ultrafast dynamics
- Optical pulse characterization is essential for optical systems based on ultrafast optics.
- Complete characterization (of both magnitude and phase) is desirable.



Introduction



How to characterize a ultrashort optical pulse?

➤ Techniques based on iterative algorithms:

- Frequency-resolved optical gating (FROG)^[1]
- Time-resolved optical gating (TROG)^[2]

Problems: time consuming, not implemented in real-time.

➤ Noniterative self-referencing interferometric techniques:

- Spectral phase interferometry for direct electric-field reconstruction (SPIDER)^[3]

Problems: nonlinear material to generate frequency shear
low speed due to slow spectrum measurement

- Temporal interferometry based on frequency-to-time mapping

[1] D. J. Kane and R. Trebino, *IEEE J. Quantum Electron.*, 29(571), 1993.

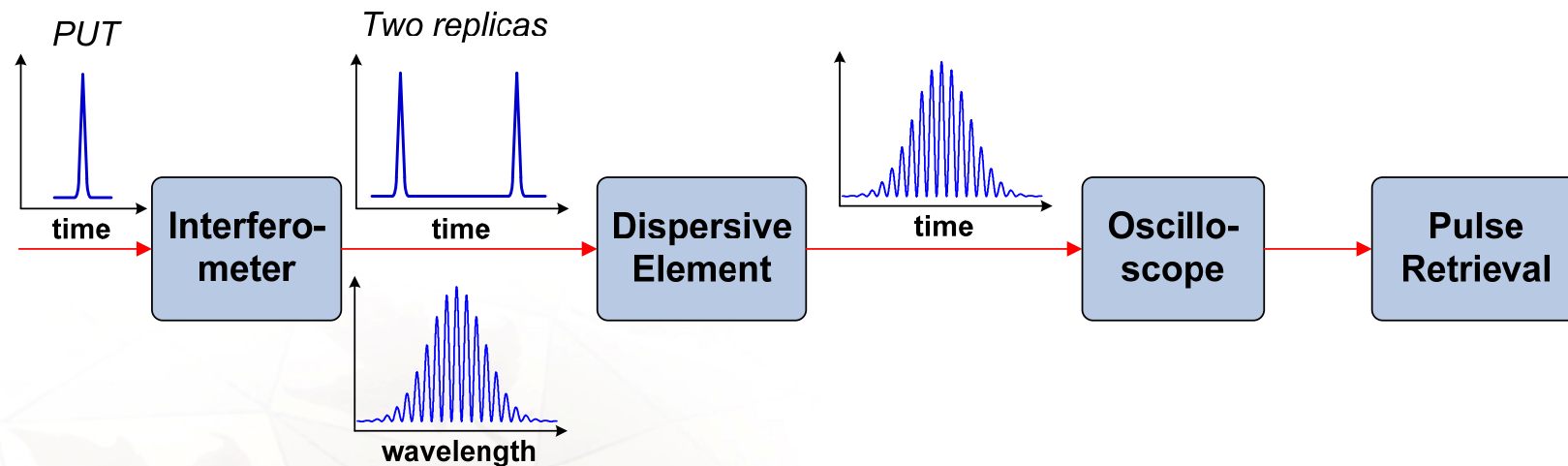
[2] R. G. Koumans and A. Yariv, *IEEE J. Quantum Electron.*, 36(137), 2000.

[3] C. Iaconis and I. A. Walmsley, *IEEE J. Quantum Electron.*, 35(501), 1999.

Introduction



Temporal interferometry based on frequency-to-time mapping^[4]



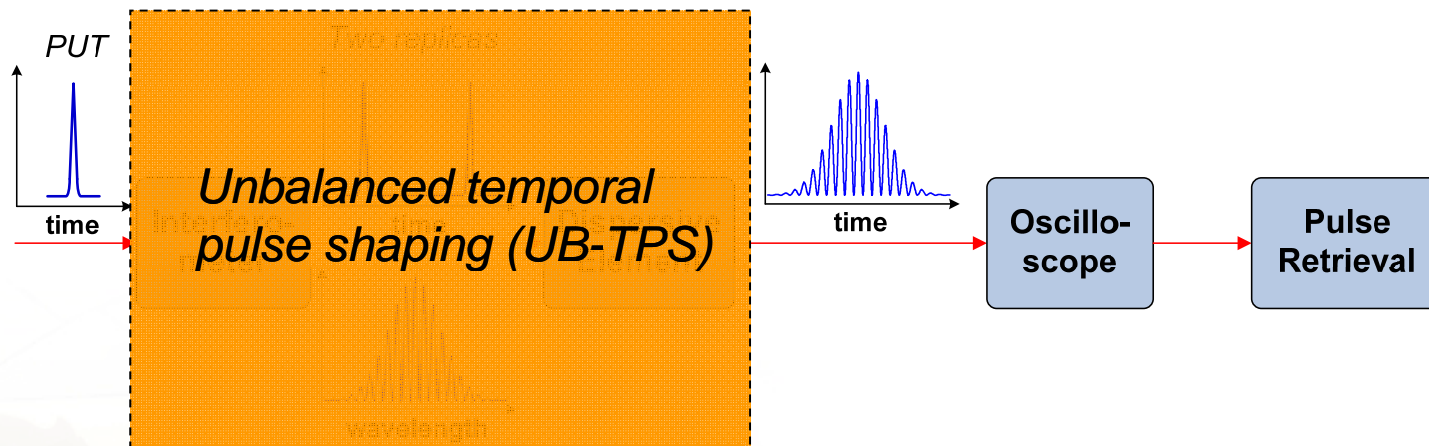
Features: linear operation, ultrafast with single-shot measurement.

Problems: poor stability due to interferometer and low accuracy.

Proposed Work



- Pulse characterization based on temporal interferometry **without using an optical interferometer.**

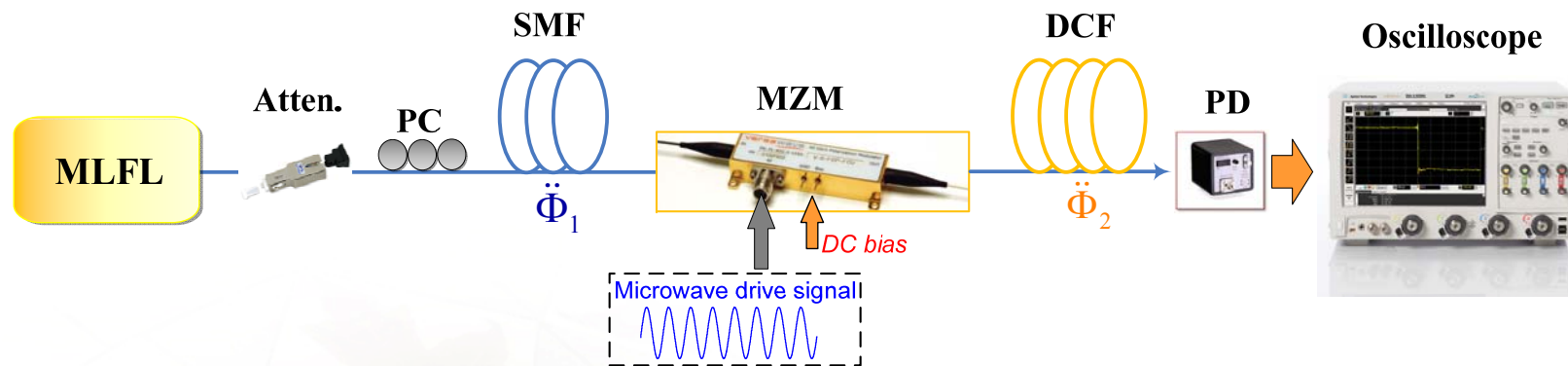


- Simultaneous **generation** and **stretching** of the two replicas by UB-TPS system.
- Greatly **improved stability** by avoiding physical optical interferometers.
- **Adaptive** measurement.

Principle of UB-TPS system



➤ System diagram

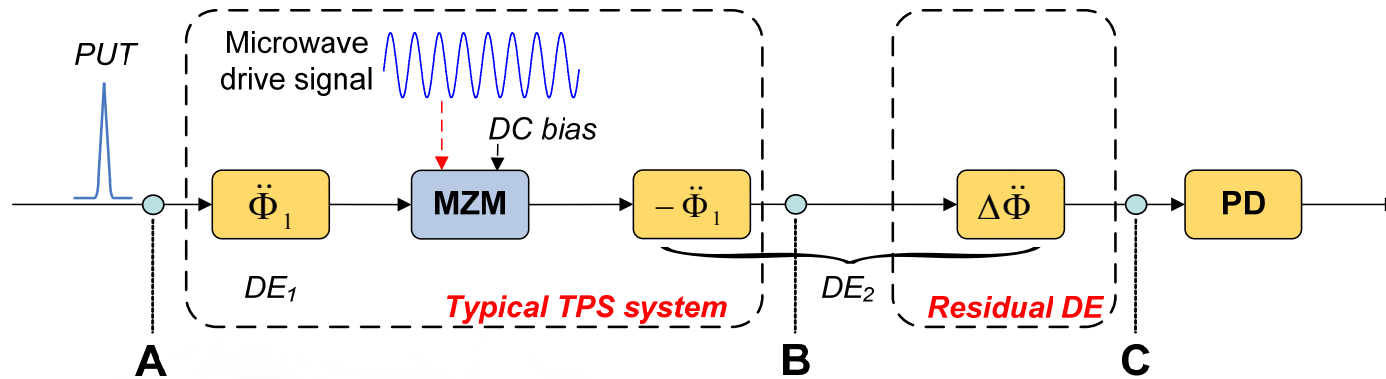


- SMF and DCF have opposite dispersion, but non-identical in magnitude.
 $\Phi_1 \Phi_2 < 0$ and $|\Phi_1| \neq |\Phi_2|$
- MZM DC-biased at the minimum transmission point for DSB-SC modulation.

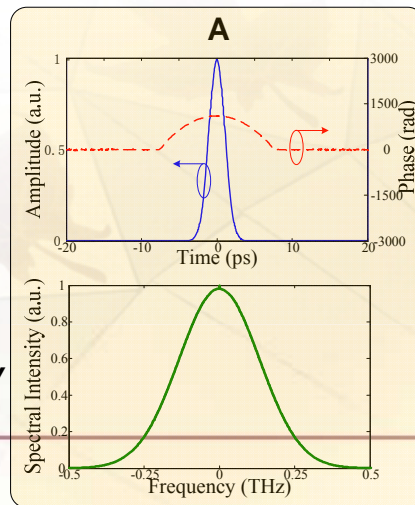
Principle of UB-TPS system



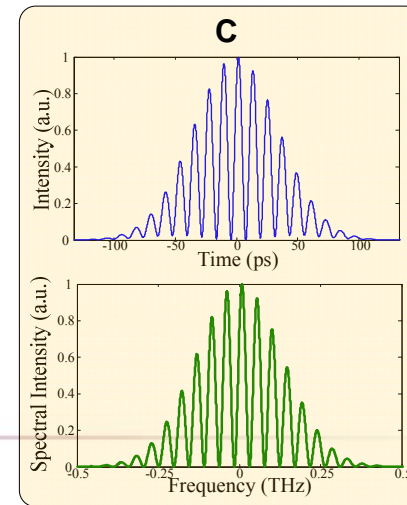
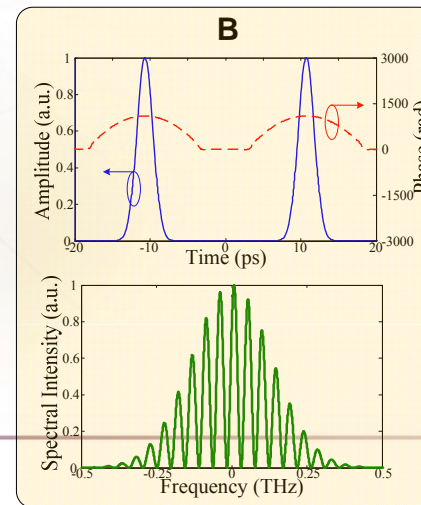
➤ Equivalent model



Time domain

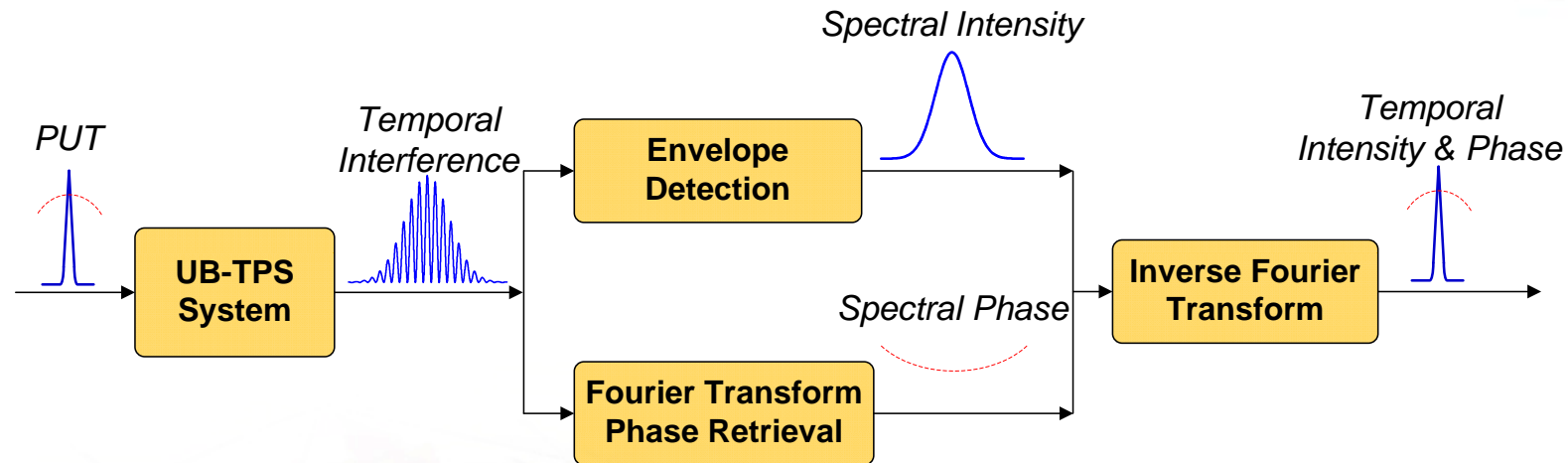


Frequency domain



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Pulse characterization procedure



1. Temporal interference pattern obtained at the output of UB-TPS system.
2. Spectral intensity obtained by envelope detection.
3. Spectral phase retrieved by Fourier-transform algorithm^[6].
4. Temporal profile obtained by an inverse Fourier transform.

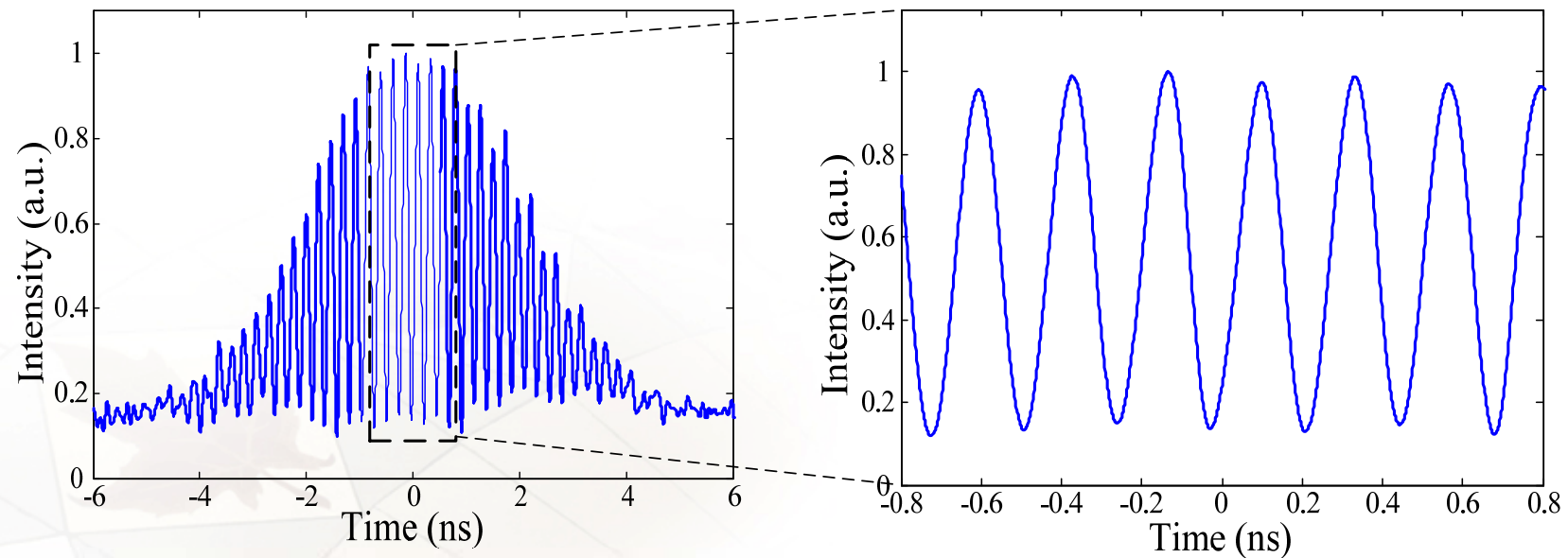
[6] M. Takeda, H. Ina, and S. Kobayashi, *J. Opt. Soc. Am.*, 72(156), 1982.

Experiment



- Characterization of a transform-limited optical pulse

Temporal interference pattern

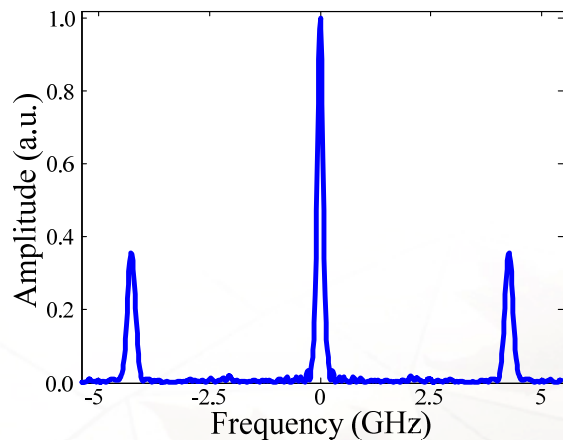


Experiment

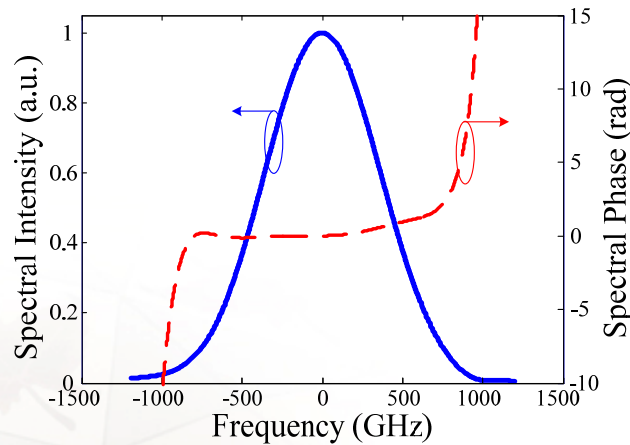


➤ Characterization of a transform-limited optical pulse

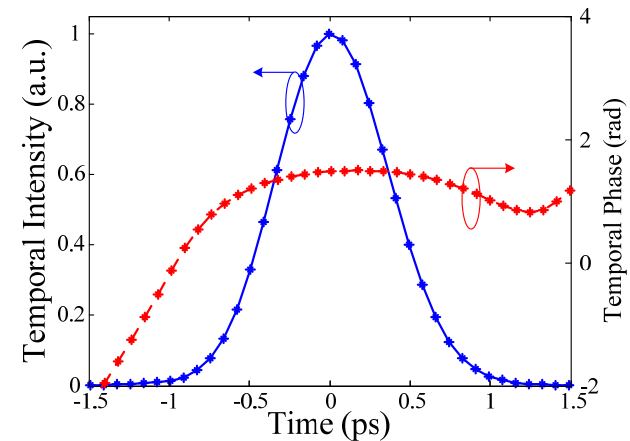
Fourier-transform pulse retrieval algorithm



Fourier-transform of
Interference Patter



Reconstructed
Spectral Profile



Reconstructed
Temporal Profile

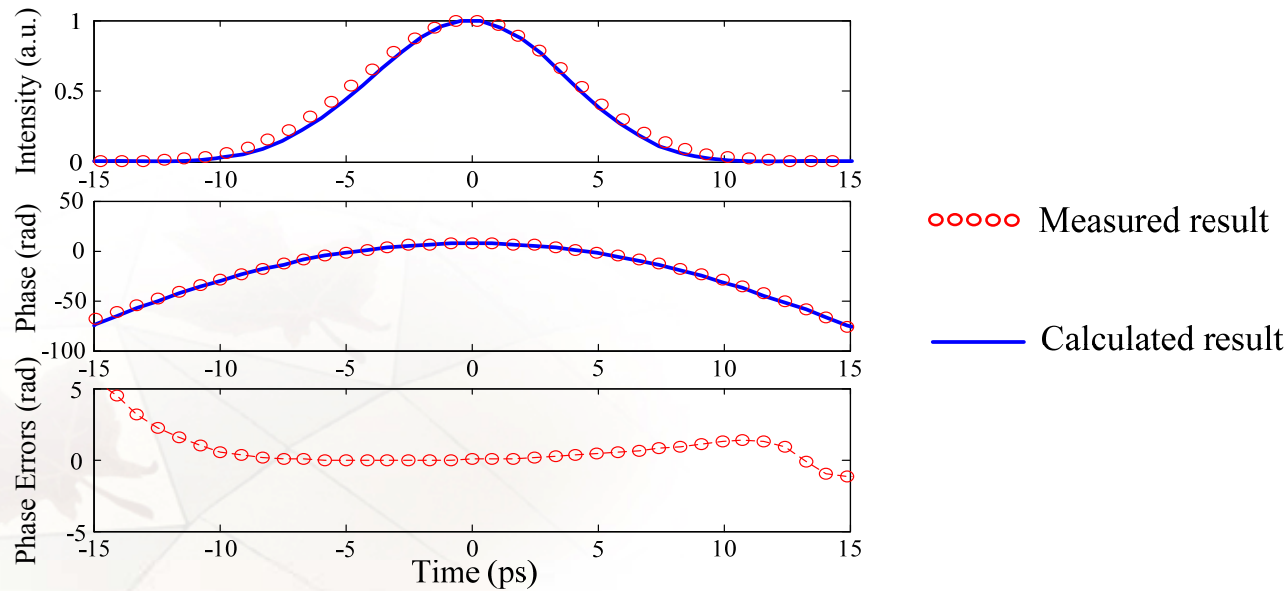
- Gaussian-shape temporal intensity profile with a FWHM of 810 fs.
- ~ 0.7 rad phase variation, $TBWP=0.77 \rightarrow$ a nearly transform limited pulse.

Experiment



- Characterization of a slightly dispersed optical pulse by 60-m SMF

Reconstructed temporal profile.

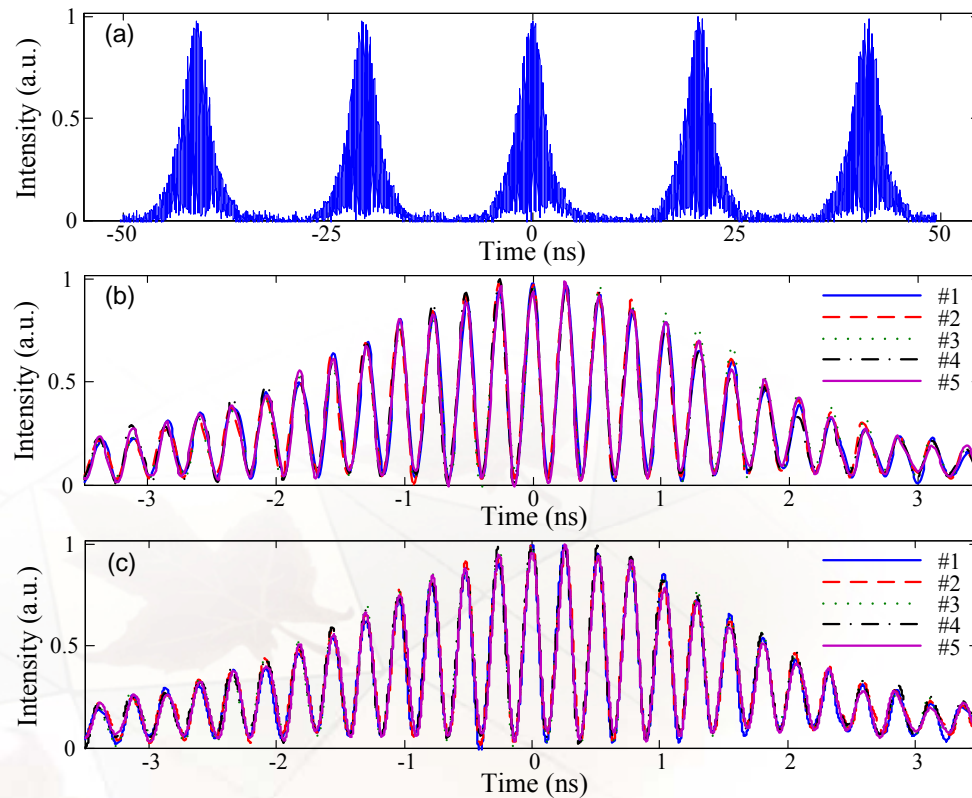


- Average phase error as small as 0.6 rad

Discussions



➤ System stability



Five successive patterns measurements

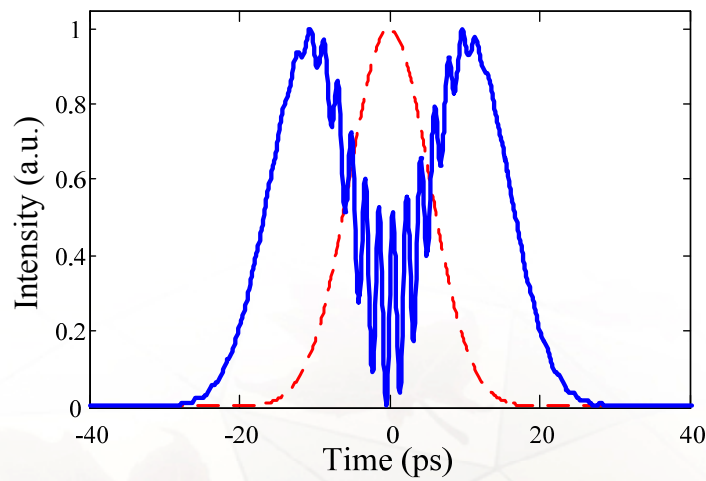
Five measurements every 2 min. in 10-min period

Discussions



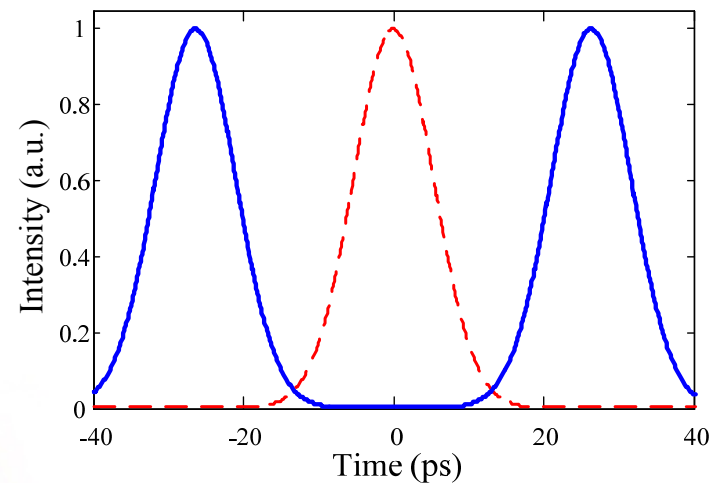
➤ Adaptability

Modulation frequency $f_m = 4$ GHz



--- Input pulse

Modulation frequency $f_m = 10$ GHz



— Pulse replicas

- Pulse spacing easily tuned by controlling modulation frequency to avoid overlap between the two generated pulse replicas.

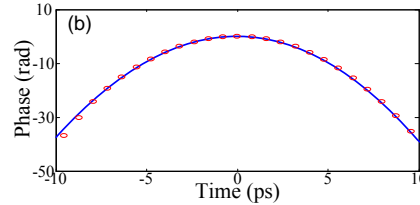
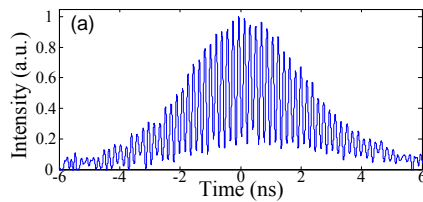


Discussions

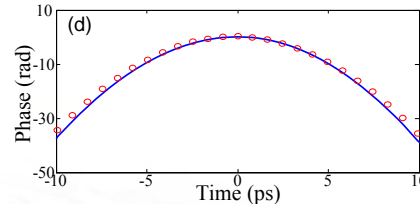
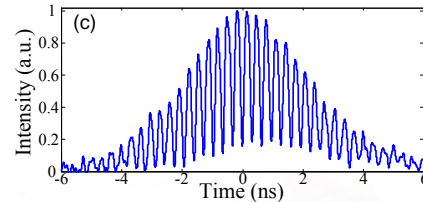


➤ Reduced bandwidth requirement

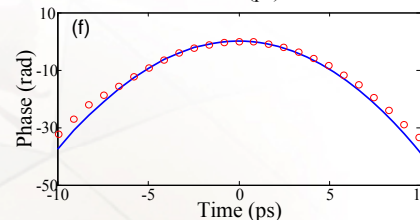
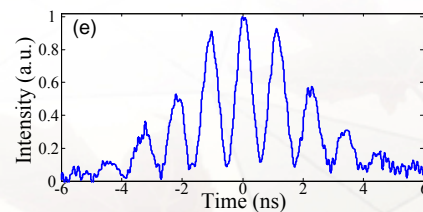
$f_m = 5 \text{ GHz}$
 $N = 40$



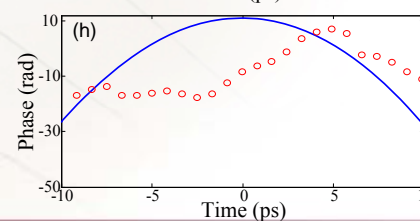
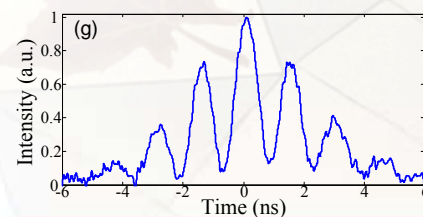
$f_m = 3 \text{ GHz}$
 $N = 25$



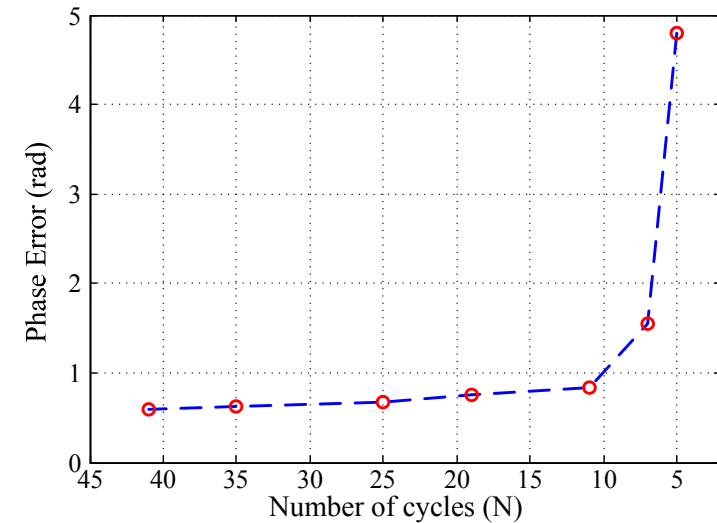
$f_m = 0.85 \text{ GHz}$
 $N = 7$



$f_m = 0.65 \text{ GHz}$
 $N = 5$



RMS phase error



$N > 10$



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Conclusion



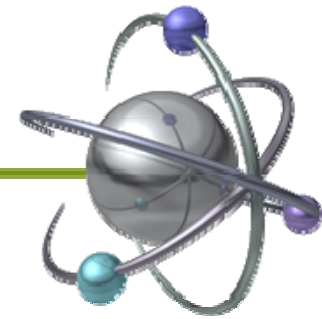
- The proposed approach based on temporal interferometry in an UB-TPS system without using an optical interferometer.
- Better system stability & adaptability.
- Complete characterization of a transform-limited optical pulse before and after passing through a 60-m SMF was experimentally demonstrated.
- Low-bandwidth microwave signal for ultrashort pulse characterization.



Acknowledgements



Thank you



Questions
Comments



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