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A Frequency-Shifted, Time-Multiplexed Many-Point PDV System

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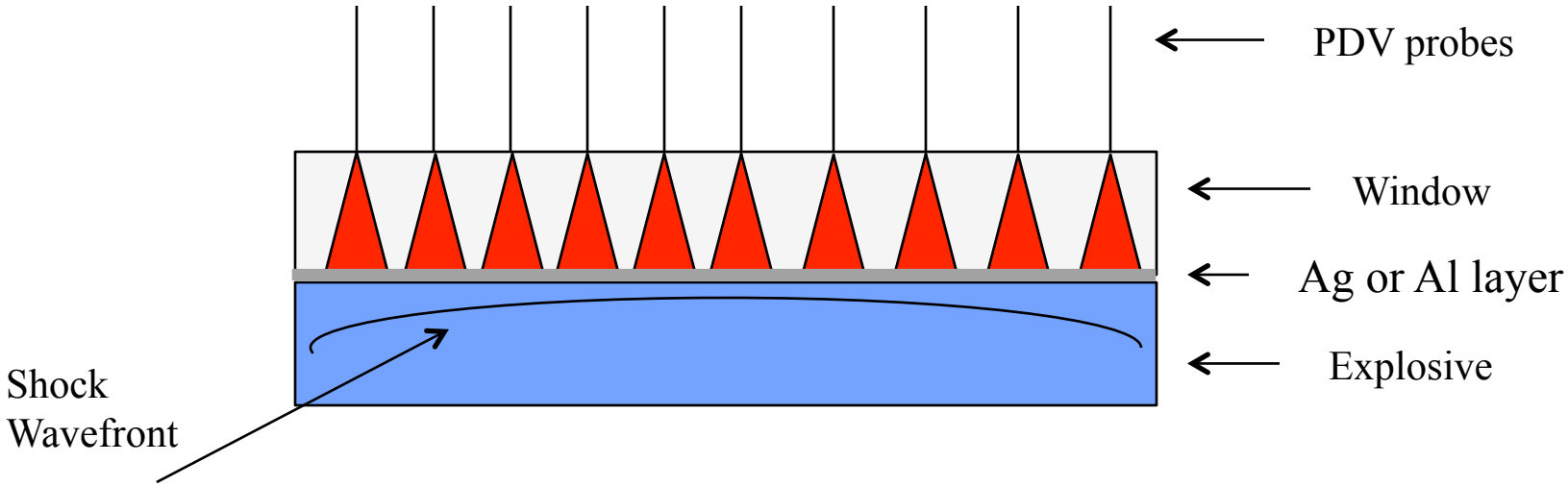
Motivation

- **Many-point PDV will enable arrays of probes to measure explosive wavefront curvature**



Challenge: How to get many points of PDV data using only one O-Scope

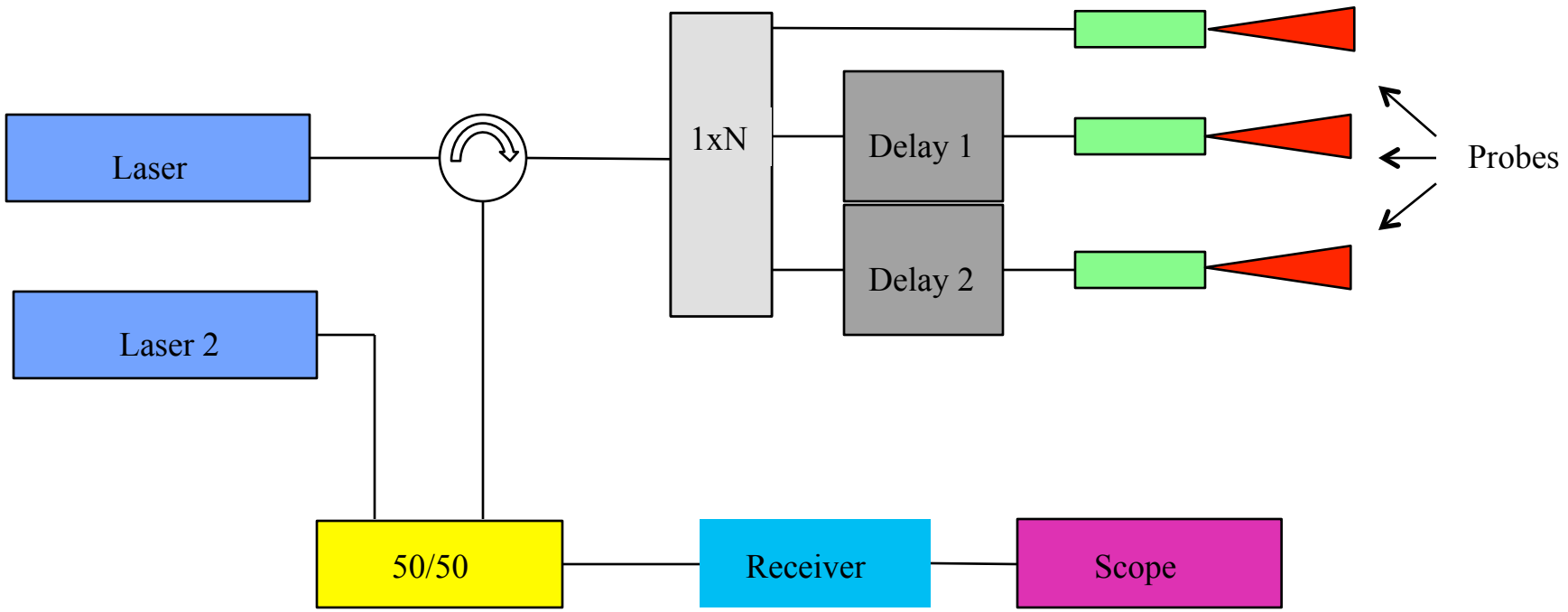
Frequency multiplexing (Daykin, et al. at NS Tech)

- Only good if you have lots of unused bandwidth (fast scopes reading relatively slow events)
- Need extra tunable lasers or modulators

Time multiplexing (Hodgins, LLNL; Welle, AFRL)

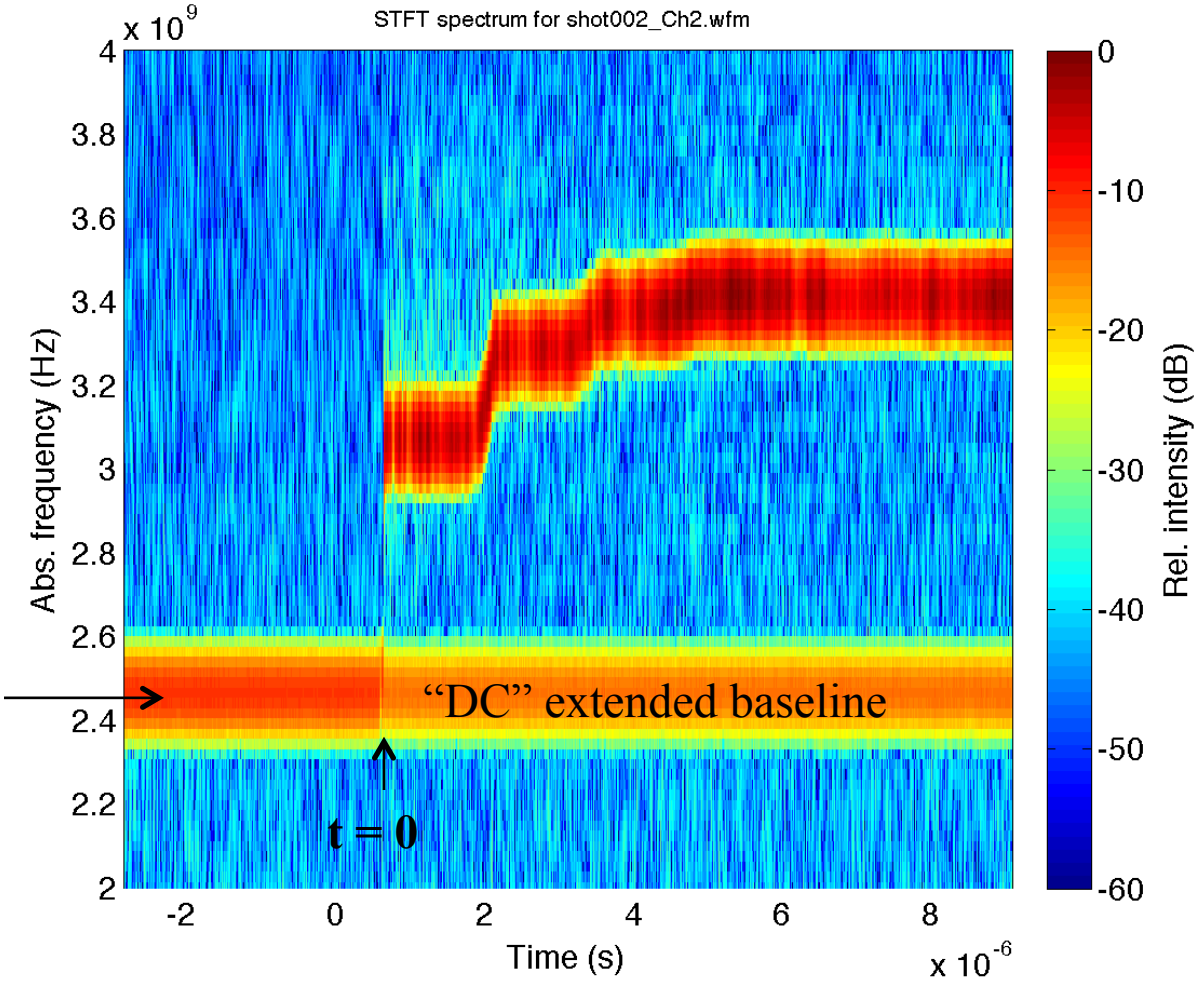
- Only good if your scope has plenty of record length
- Data from each probe delayed with respect to each other using kilometers of fiber

Simple Time Multiplex PDV System



Each km of fiber delays the signal by ~ 5 μs

What does the spectrogram look like?



Pre-shock frequency shift

Data courtesy of Dan Dolan (SNL) dhdolan@sandia.gov

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Addressing the Challenges

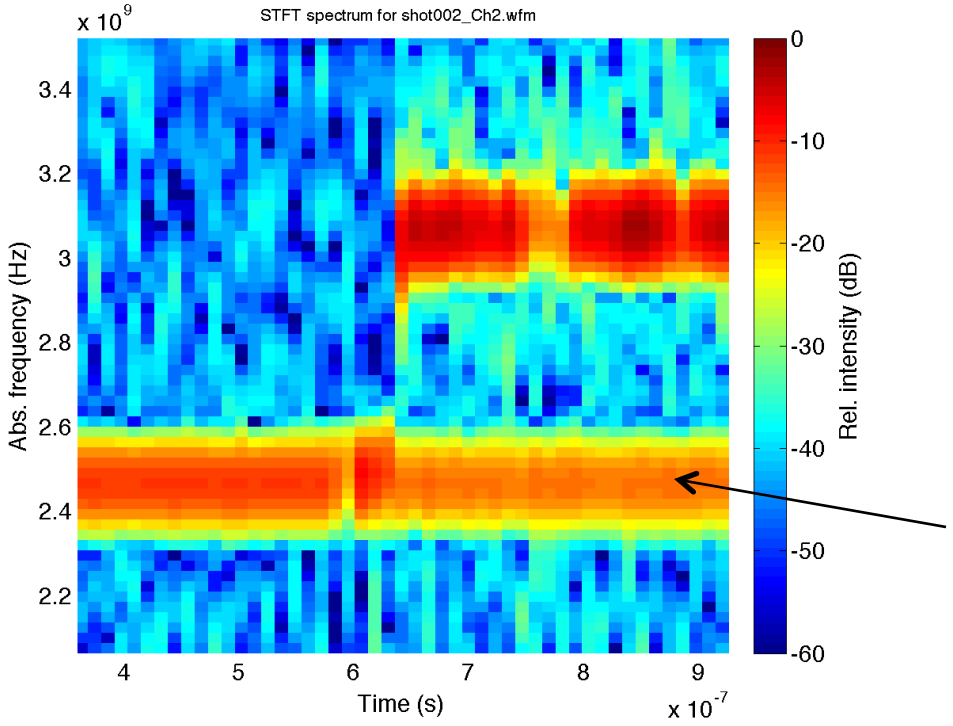
Measuring the time-of-arrival of shock wavefront on silvered window requires precise time correlation of the data from different probes.

“DC” extended baseline from other probes creates a difficulty in distinguishing first moments of movement.

An independent timing fiducial would be nice!

Getting rid of the "DC" extended baseline

Caused by laser operating in CW mode.



Pre-shock "DC" extended baseline from other probes

"DC" extended baseline will be stronger the more points you multiplex.

Data courtesy of Dan Dolan (SNL) dhdolan@sandia.gov

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Pulsed Laser PDV

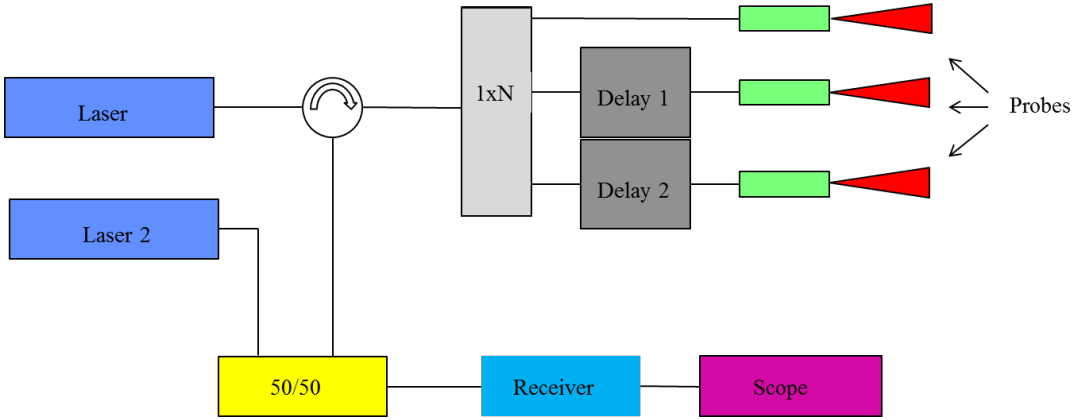
Having a pulsed laser solves two problems, but creates another.

- Eliminates “DC” extended baseline contamination from other probes
- Creates a good timing fiducial if laser pulse is created using a fast pulser and electro-optic modulator.

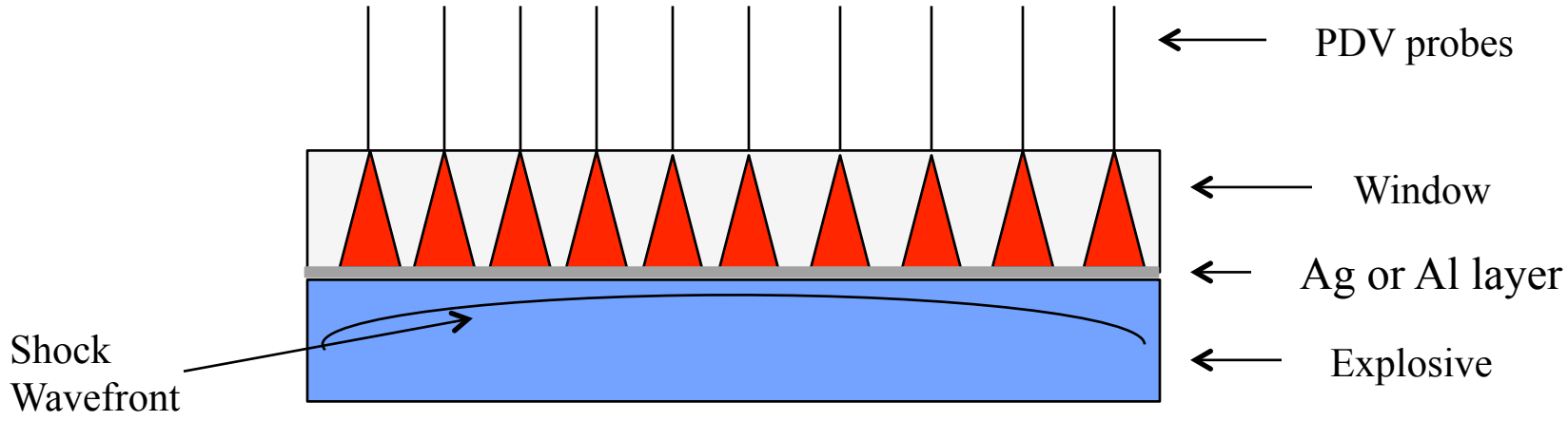
But . . .

Illumination Frustration

Recall that the delay lines had to be between the circulator and probes:



Not only is the return light from each probe delayed w.r.t. each other, but the sent pulse is, too!



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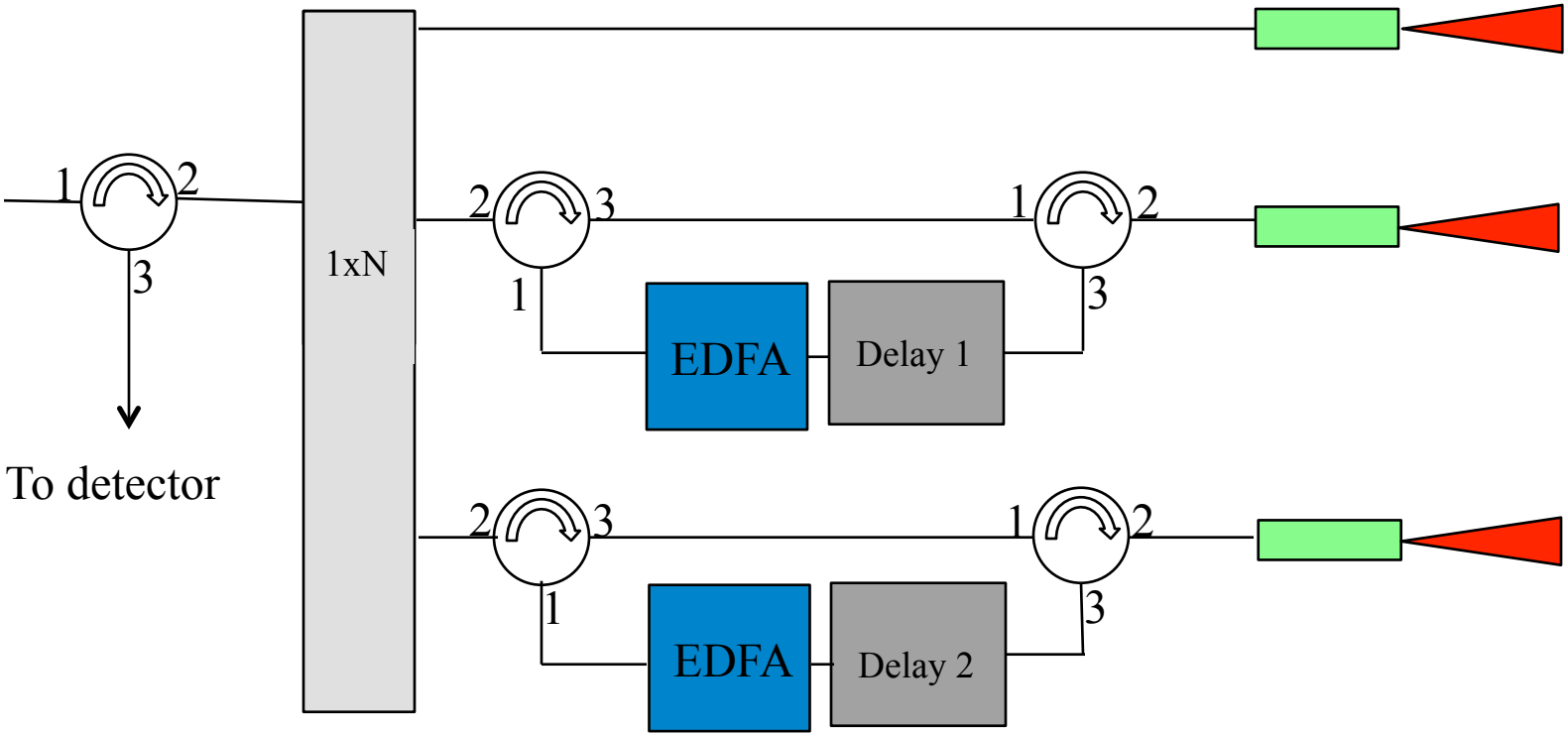
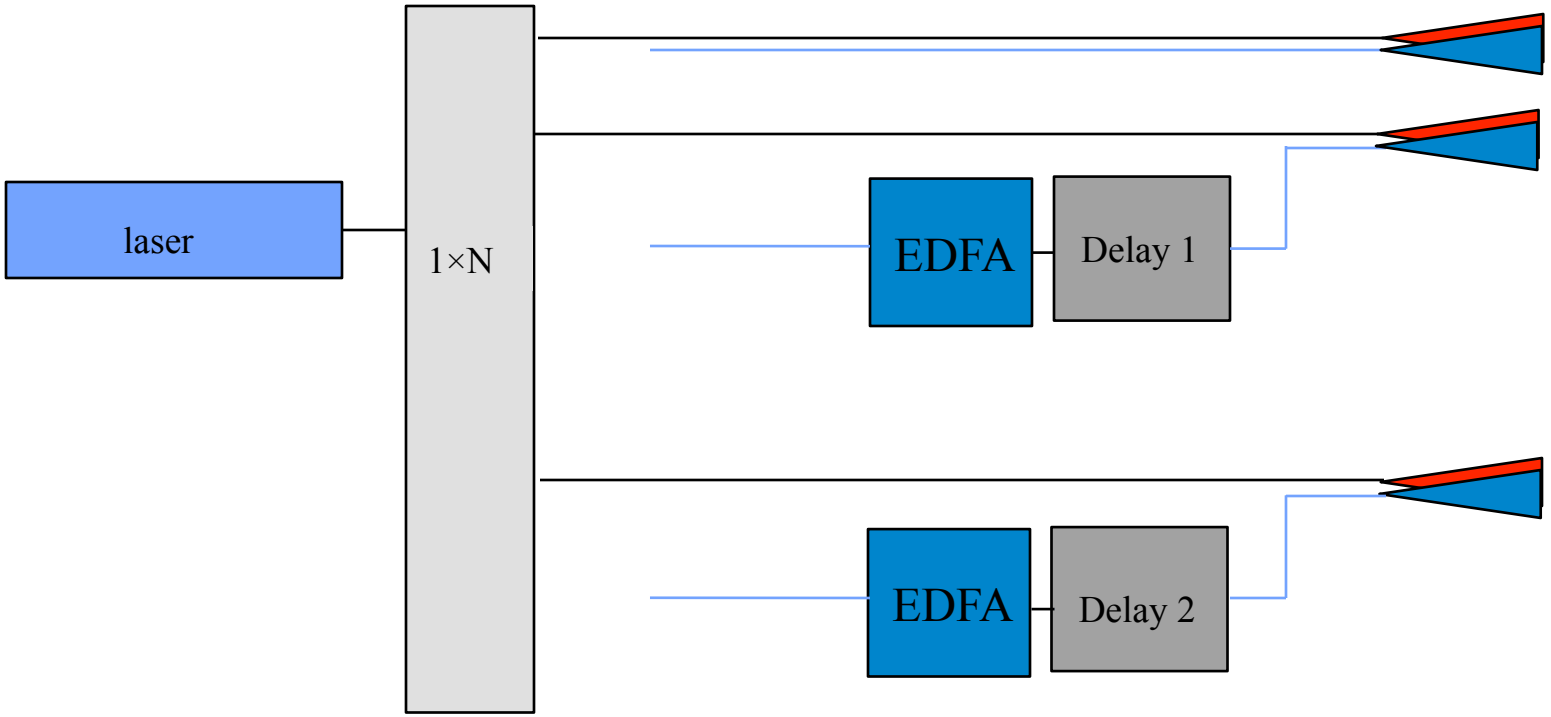
Two Work-Arounds

Add two more circulators so send and receive travel different paths (idea from Dan Dolan)



EDFAs needed because beams are combined with 1×N splitter, resulting in ~1/N return

Separate send/receive fibers (a la VISAR)

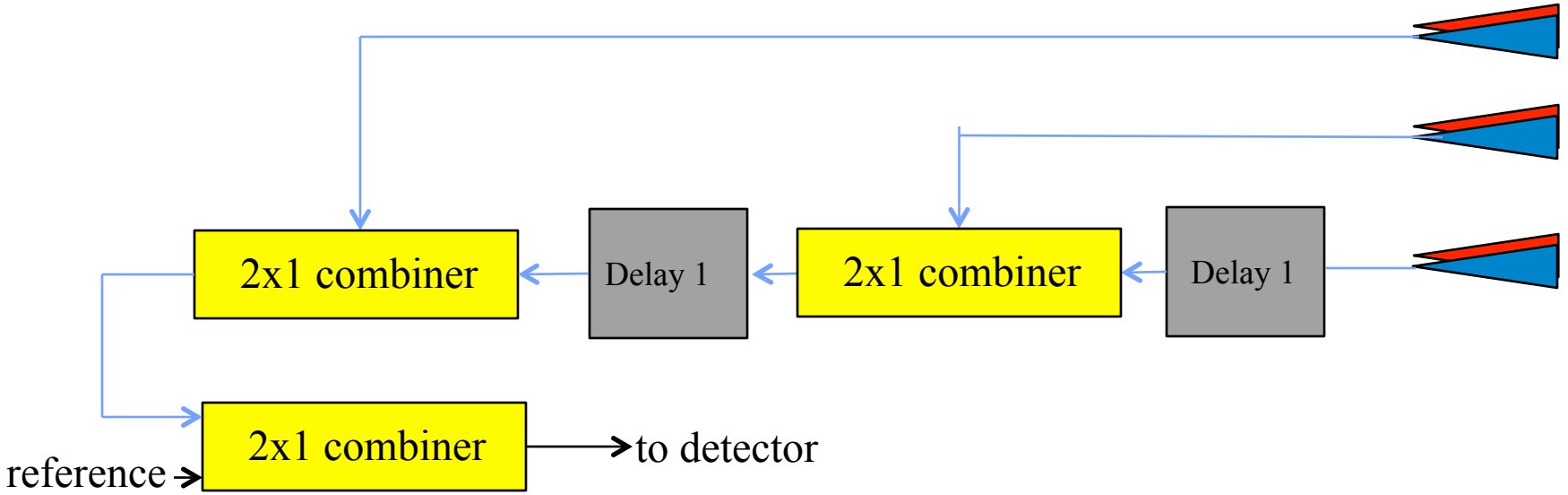


EDFAs still needed and another 1×N splitter is required, but circulators are eliminated.

- Less cost because of elimination of circulators
- Return signals probably not as good, but we're amplifying anyway.
- Each probe has its own delay: lots of fiber

A slick solution, but . . .

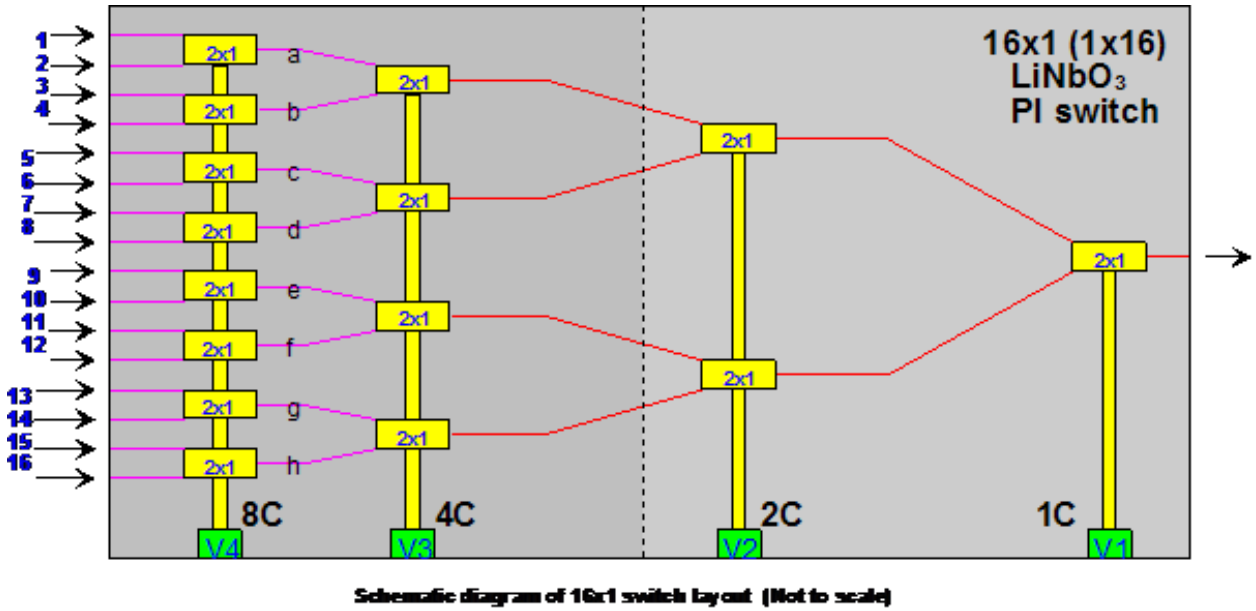
Instead of each return leg having its own delay line, we could daisy-chain them.



- No circulators or EDFAs mean lower cost and more simplicity.
- Unfortunately, low-loss combiners don't exist. All have >3 dB loss.
- If you want 20 time-multiplexed points, you'll have 20x3 dB = 60 dB loss!

Alternatives to low-loss combiners

High-speed switches could sequentially switch many inputs to one output



Schematic diagram of 16x1 switch layout (Not to scale)

- Proposed 16×1 switch (EO Space) could combine 16 probes with ~6-8 dB loss
- Requires 4 voltage sources capable of 50-100 V outputs
- Low enough loss so no EDFAs needed
- Each probe will need its own delay

Diagram courtesy of Ed Miao at EO Space ed.miao@eospace.com

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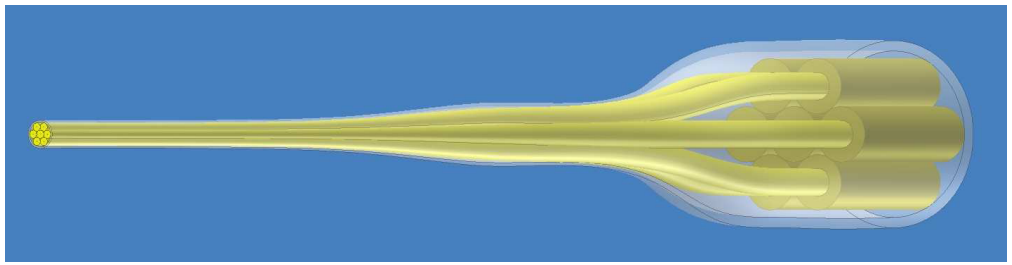
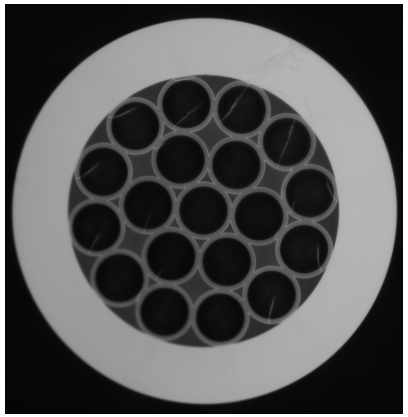
Tapered fiber combiners



Tapered fibers could potentially be used to combine many single mode fibers into one multimode fiber with low loss.



19×1 combiner

- Not currently possible to combine single mode fibers into another single mode fiber
- Miteq receivers have single mode fiber inputs
- However, the Picometrix AD-40xr-FC receiver (8.5 GHz, -19 dB sensitivity) has a 62.5 μm fiber and the Picometrix D-15-FC detector (21 GHz) has a 50 μm fiber

Photos from "**Review of Fabrication Techniques for Fused Fiber Components for Fiber Lasers".** Baishi Wang, Eric Mies, Vytran LLC. SPIE Photonic West '09, Fiber Lasers VI: Technology, Systems, and Applications (Proc. 7195)

Conclusions

- Many-point PDV systems based on time-multiplexing will allow the measurement of shock-front curvature and propagation.
- Pulsed laser sources can be created with fast pulsers and EOMs to create timing fiducials in data with resolutions of hundreds of ps.
- Pulsed lasers also eliminate “DC” contamination from other points.
- Creative methods of delaying signals must be implemented to ensure the target is illuminated at the proper times.
- If 1×N splitters are used in reverse for combining, you incur approximately 1/N throughput and EDFAs will probably be necessary.
- If low-loss 2×1 combiners existed, it would solve most of the problems with time-multiplexing. (SBIR anyone?)
- High speed switches or tapered fiber combiners may give us the low-loss combining we need, but at greater expense and complexity.

Thanks to Dan Dolan, Ralph Hodgins, and Eric Welle for many fruitful discussions!