DOE/NV/25946--2823

Fiber interferometer effects (linear only) in broadband laser ranging data

Brandon La Lone

National Security Technologies, LLC, Special Technologies Laboratory

June 9, 2016

UNCLASSIFIED

This work was done by National Security Technologies, LLC, under Contract No. DE-AC52-06NA25946
with the U.S. Department of Energy and supported by the Site-Directed Research and Development Program.

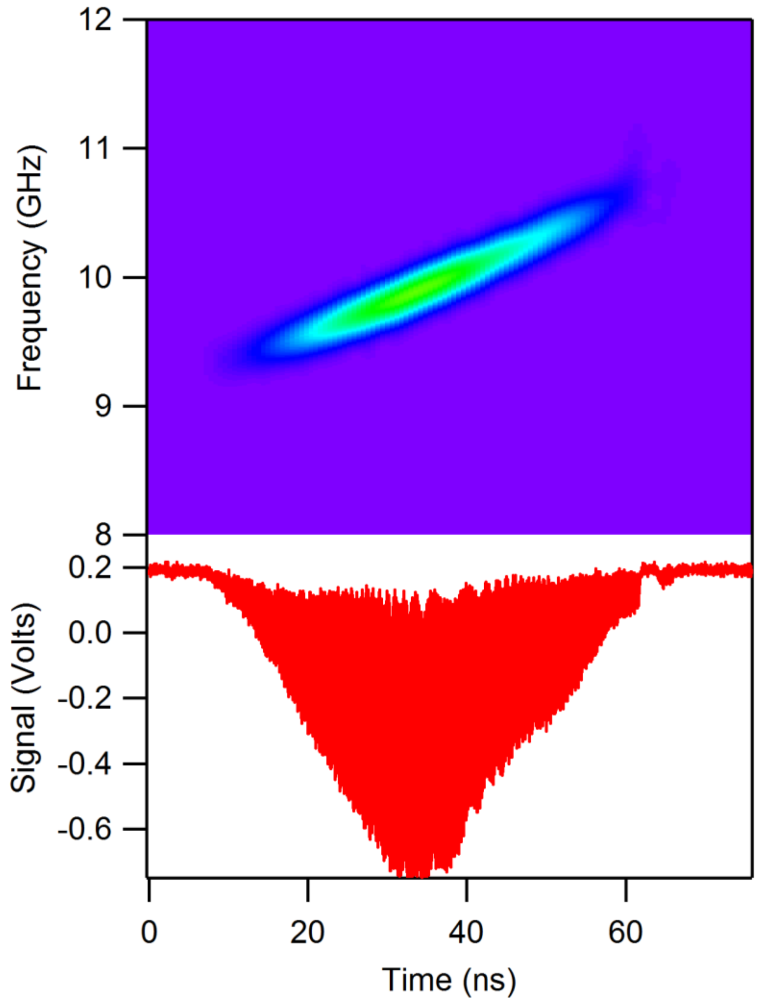
The measured frequency changes across a single BLR pulse for two reasons:

Reason 1 (largest effect): The dispersion modules that map the optical frequency spectrum into the time domain have nonlinear dispersion.

Solution: Resample the time base nonlinearly for each pulse so that optical frequencies are linear with the new time base.

Reason 2 (focus of this talk): The group delay dispersion in the interferometer is unbalanced, effectively making the path length difference between the two legs of the interferometer dependent on the wavelength.

Solution: Cannot be undone by a single time base remap. Our solution has been to balance the group delay dispersion in the two lengths of the interferometer. How well does it need to be balanced and what are the limits?



Fiber interferometer balancing effects in ranging data, simulations

Are long fibers in the interferometer going to make dispersion matching difficult and distort the spectral interference pattern?

What are the errors in precision and resolution caused by the distortion?

To help answer these questions I simulate variations due to mismatched lengths, dispersions, and dispersion slopes.

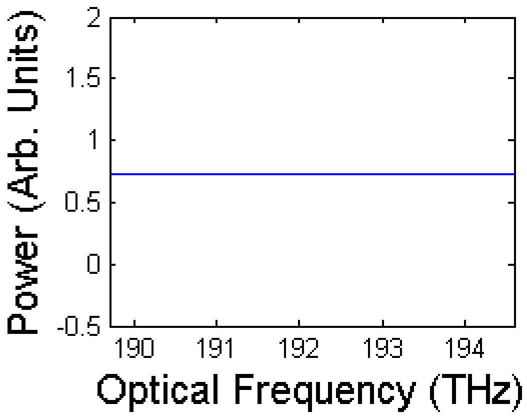
$$P(\lambda) = \frac{1}{2}E_1^2(\lambda) + \frac{1}{2}E_2^2(\lambda) + E_1(\lambda)E_2(\lambda)\cos\left(\frac{2\pi}{\lambda}\left[L_1 n_1(\lambda) - L_2 n_2(\lambda) + z + \phi\right]\right)$$

Input fiber lengths, dispersion and dispersion slope → Calculate spectral interference pattern → Take FFT of spectral interference and convert to distance

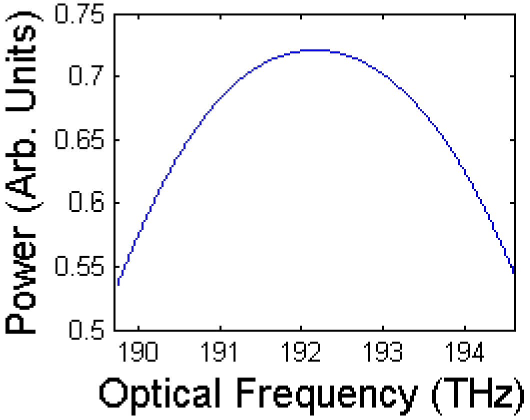
Important note: Refractive index in above equation is the actual index not the group index, you have to create an index that matches the dispersion in the group index that you want.

Unbalance fiber lengths keeping dispersion properties constant, D = 20 ps/nm/km at 1560 nm (192.1 THz), D’ = 0.058 ps/nm^2/km, group delay balanced at 1560 nm. Spectrum is 40 nm wide (4.9 THz), square shaped

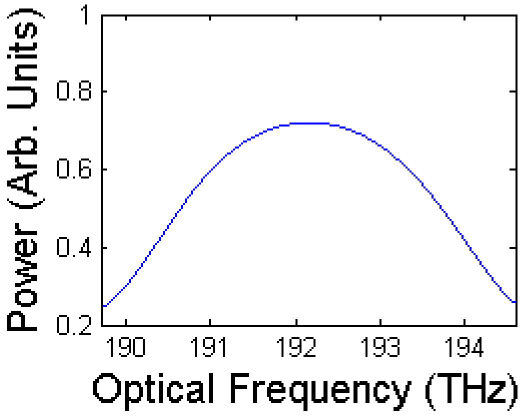
balanced



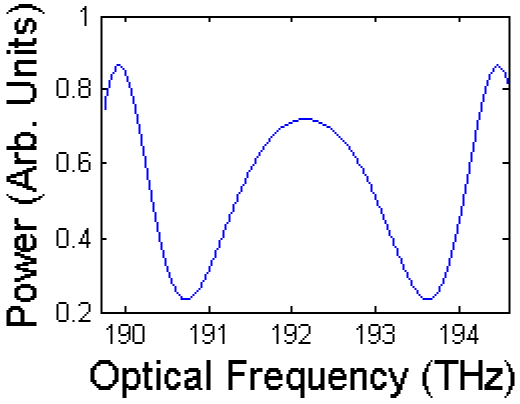
10 cm unbalanced



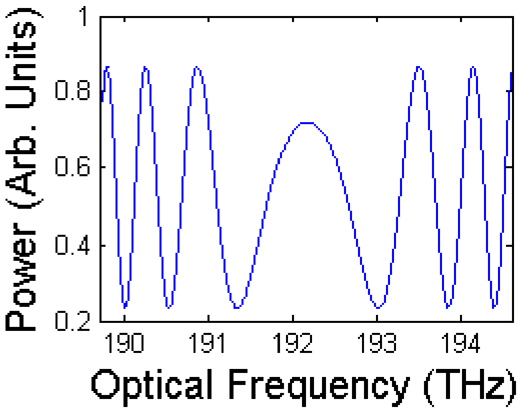
30 cm unbalanced



100 cm unbalanced

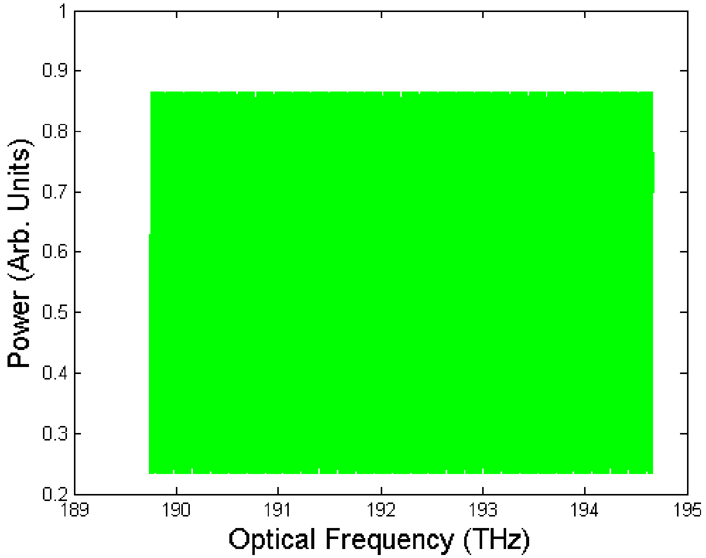


300 cm unbalanced

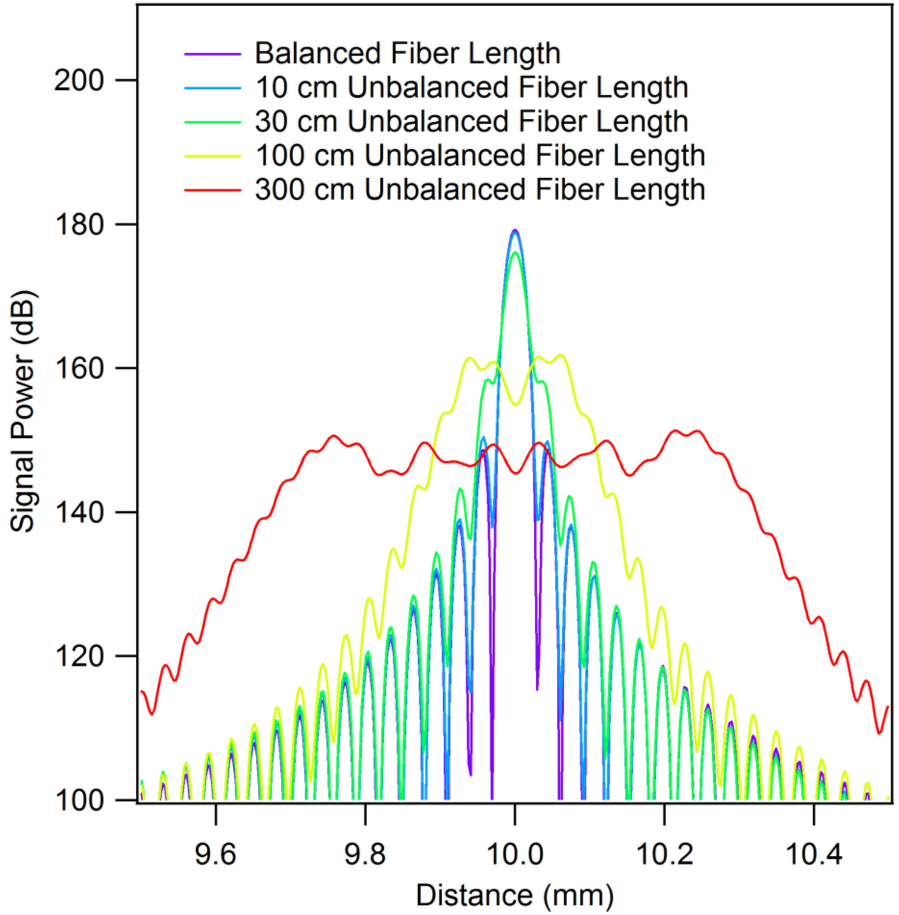


Unbalance fiber lengths keeping dispersion properties constant, D = 20 ps/nm/km at 1560 nm (192.1 THz), D' = 0.058 ps/nm^2/km. Group delay balanced at 1560 nm then shifted an extra 10 mm free space and FFT calculated (mimics a 10 mm range measurement)

Spectral Interference



FFT of data with different fiber length mismatches

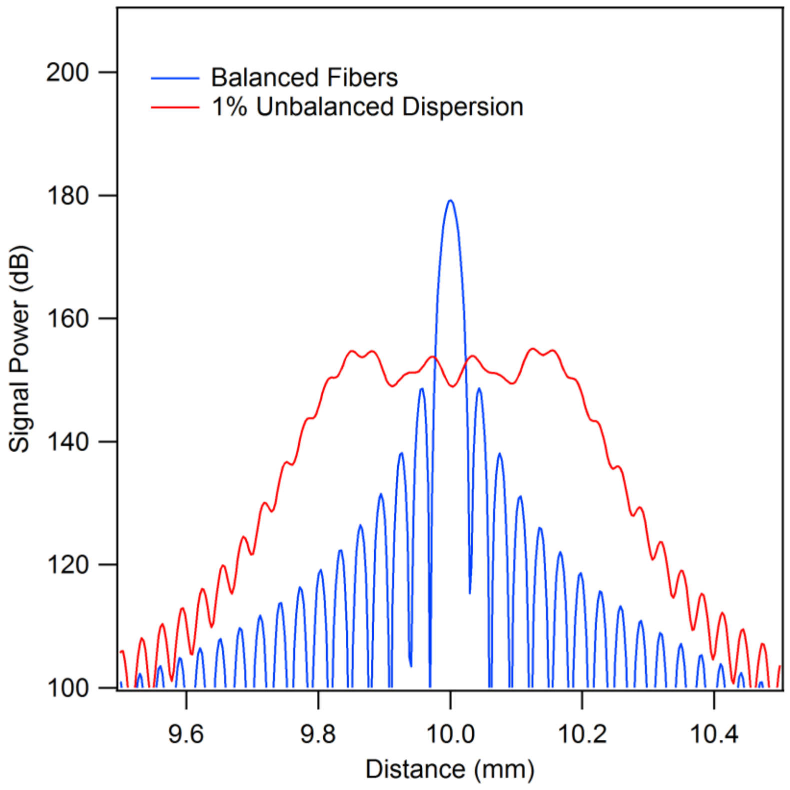


For this 40 nm wide spectrum, the width at the 10 dB point is 35 microns, it's hardly broadened with 30 cm of length mismatch, but is substantial past 1 meter

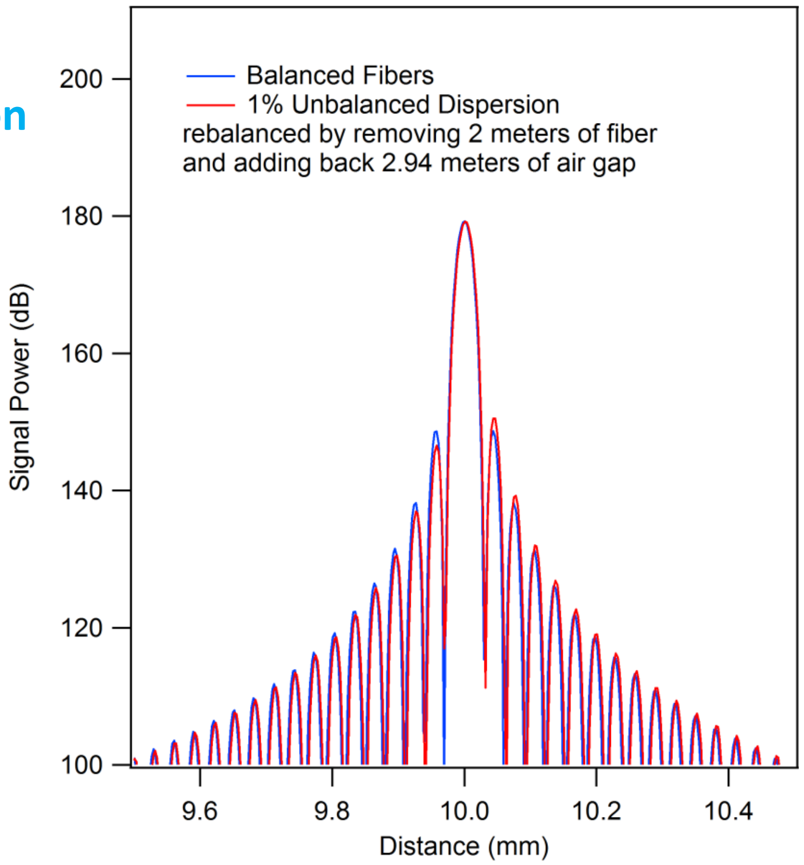
Balanced fiber lengths and unbalanced dispersion, extreme case of 200 meter long fibers in the interferometer (10 mm free space difference included)

Changing the dispersion of one fiber by 1% (from 20 ps/nm/km to 20.2 ps/nm/km) has as much affect as mismatched fiber lengths of 2 meters. 0.1% changes are acceptable.

The 1% dispersion mismatch could actually be compensated for be removing 2 meters of fiber from the higher dispersion leg, requires adding back 2.94 meters of air gap to the path which is probably not practical

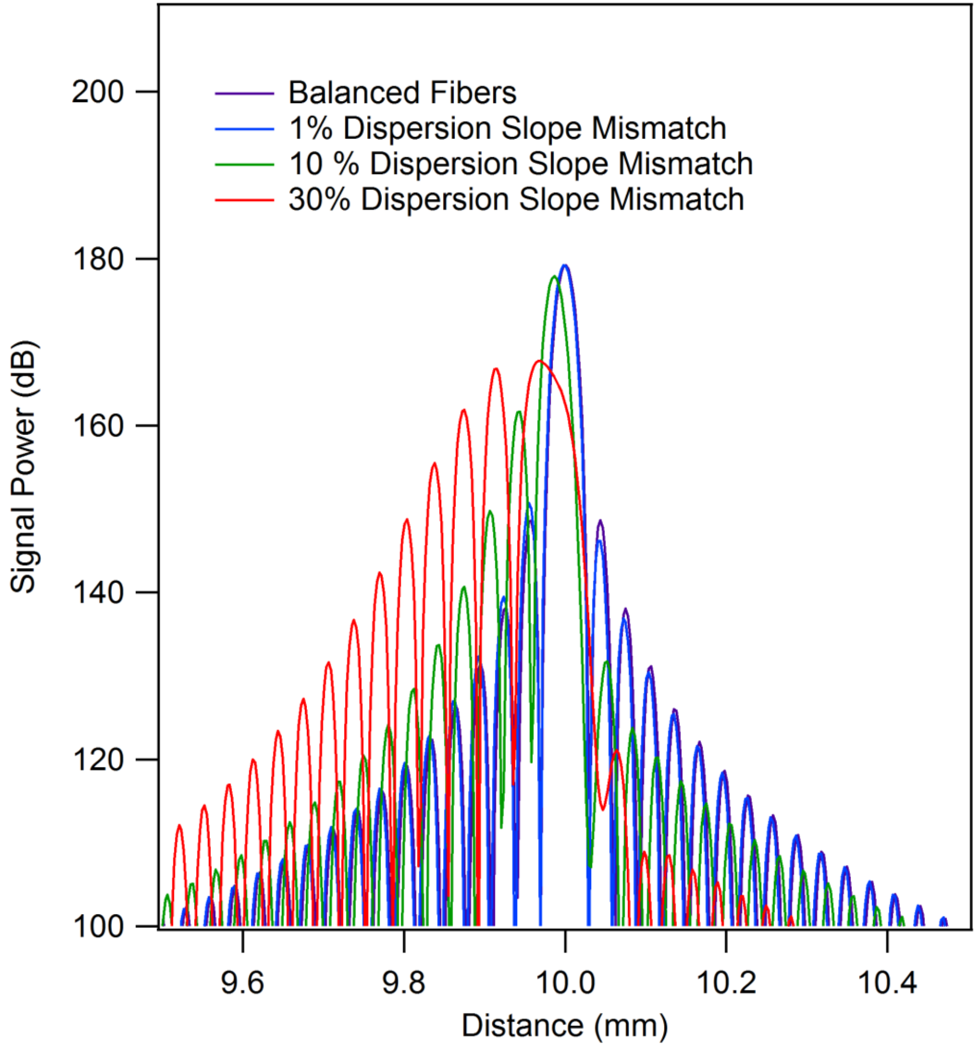


It's the group delay dispersion (D*L) in ps/nm that matters!



Balanced fiber lengths and unbalanced dispersion slope, extreme case of 200 meter long fibers in the interferometer

Dispersion slope increased in one leg from 0.058 ps/nm^2/km by 1%, 10%, and 30%. First time seeing a peak position shift, a 10% change shifts the peak by 12 microns, and is probably the most we could tolerate.



Remarks on interferometer simulations

Simulations are a quick way to assess how length and dispersion mismatches will affect the ranging data.

Fiber length mismatch and fiber dispersion mismatches broaden the peak of the FFT but do not shift the peak position.

Group delay dispersion mismatch up to 6 fs/nm is tolerable (equivalent to about 30 cm of fiber, or 0.15% dispersion unbalance on 200 meter long fibers)

Dispersion slope mismatch is the only affect tested that shifts the FFT peak position but we can tolerate rather large changes in dispersion slope (up to about 10% for 200 meter fibers).

Important to measure fiber dispersion at facilities that want BLR, this effort is just beginning!