Optical Ranging Overview and Analysis of Calibration Data

PDV Workshop 2016

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“Not with a Bang But a *Chirp*”

Barney Oliver (Bell Labs)
Memorandum on high-power radar pulses

“This is the way the world ends. Not with a bang but a whimper.” –T.S. Eliot

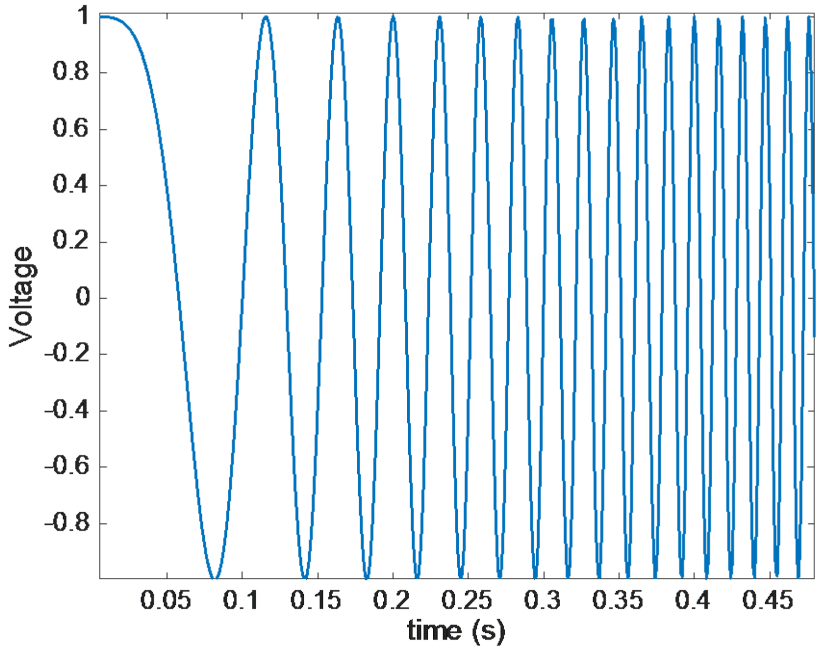
What is a chirp?

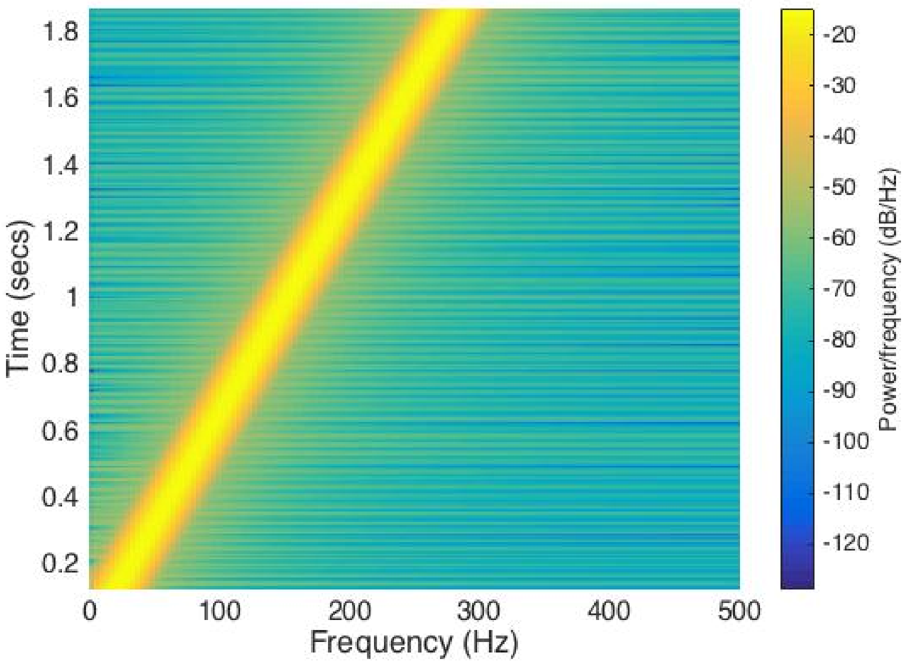
- A **chirp** is a signal in which the *frequency* increases or decreases with time
- In this talk, we mostly care about ***linear chirps***:

$$x(t) = \sin\left[\phi_0 + 2\pi\left(f_0 t + \frac{k}{2}t^2\right)\right]$$

Quadratic Phase

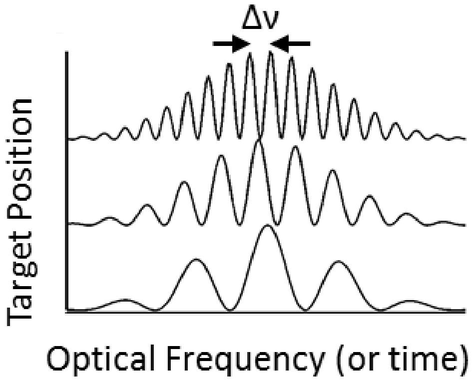
Time Domain → **Frequency Domain**



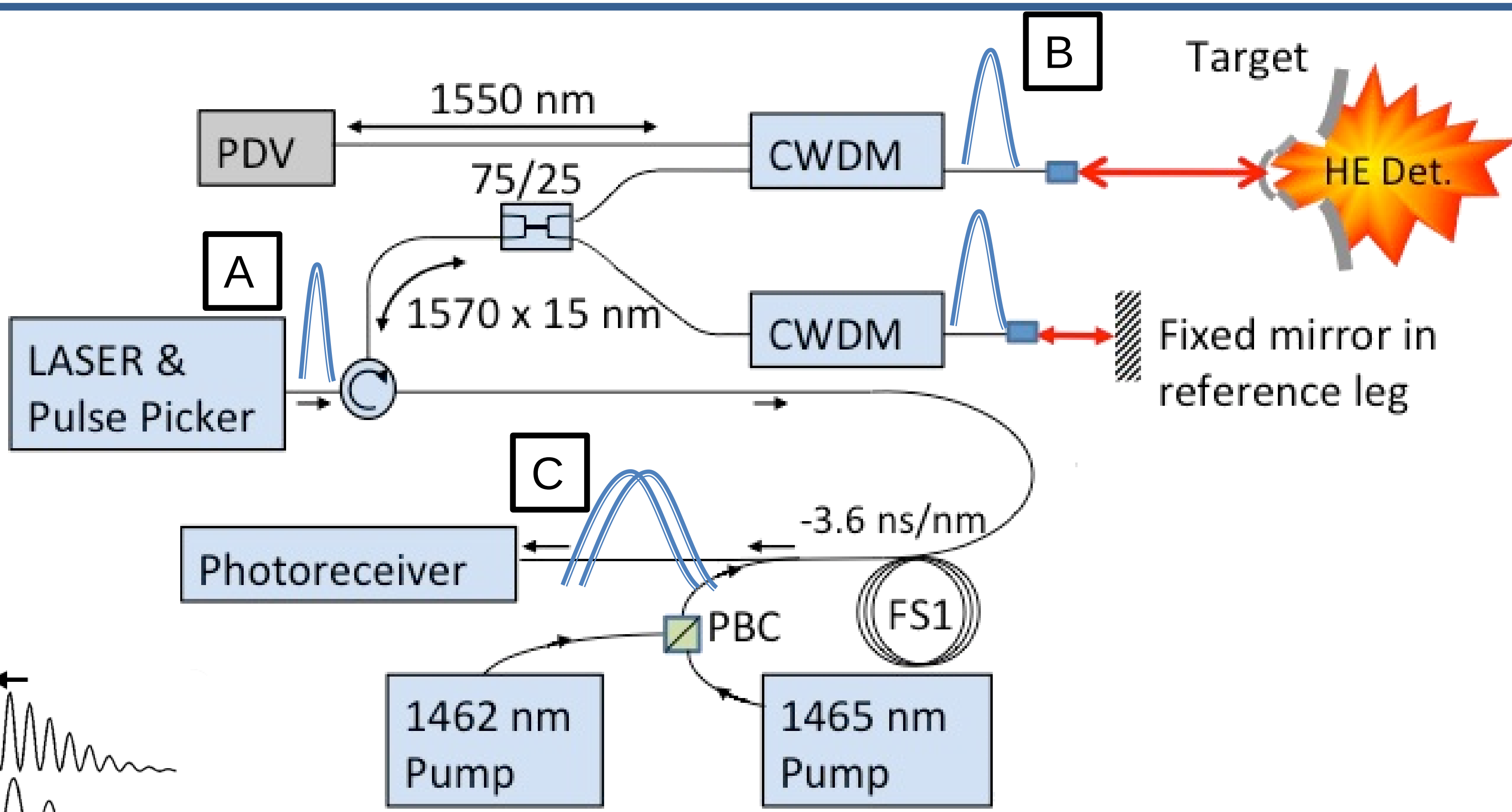


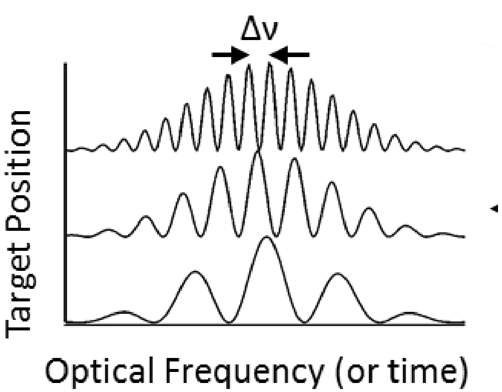
What is Optical Ranging (OR)?

- OR is a fast interferometric technique used to measure distance to a target at periodic intervals
- **Spectral interferometer**:
  - — light pulses in target and reference arms interfere
  - — chromatic dispersion in the fiber maps spectral information into the time domain (***real-time dispersive Fourier transformation)***
  - — beat waveform is recorded
- Also known as "Broadband Laser Ranging" (BLR)



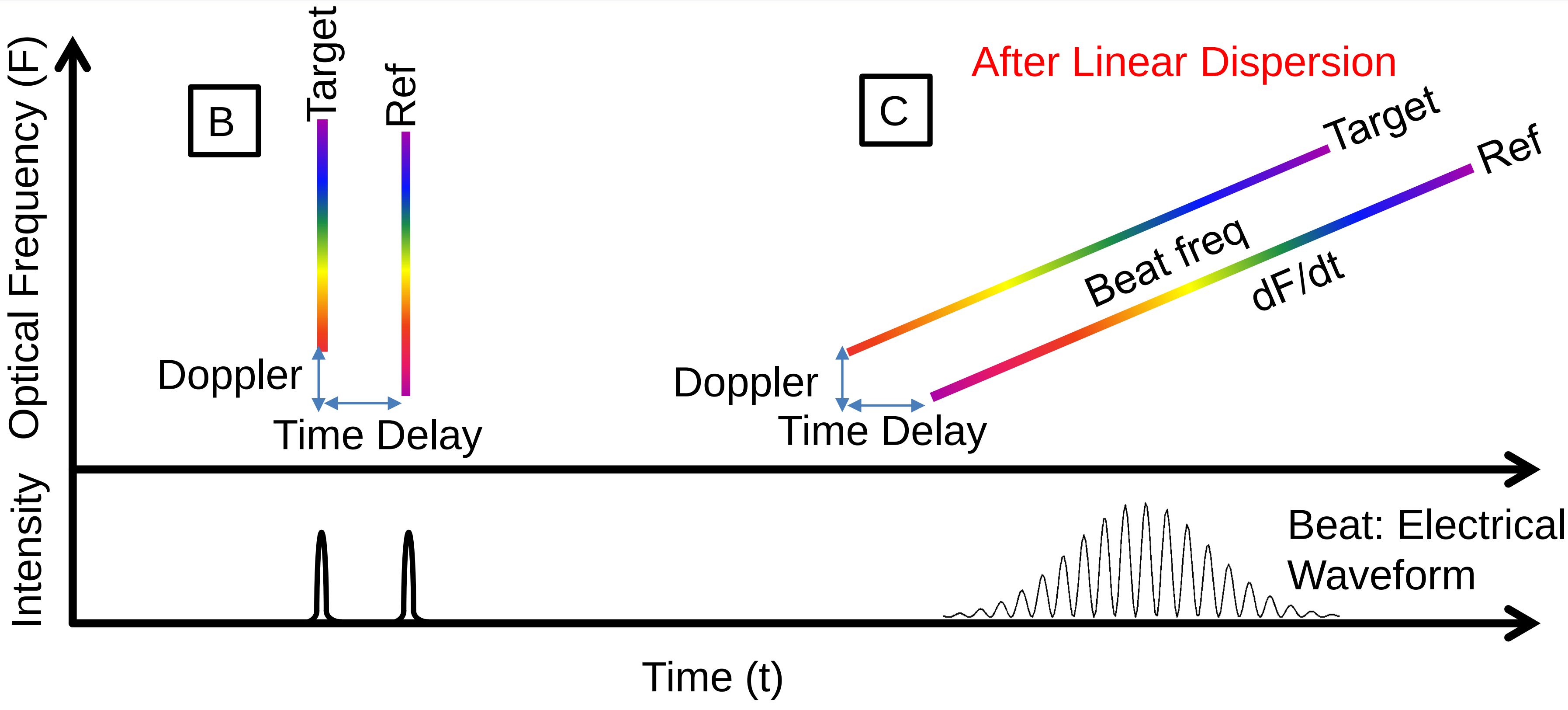
Schematic of current setup





Fiber converts the interference spectrum into the time domain via ***real-time dispersive Fourier transformation***

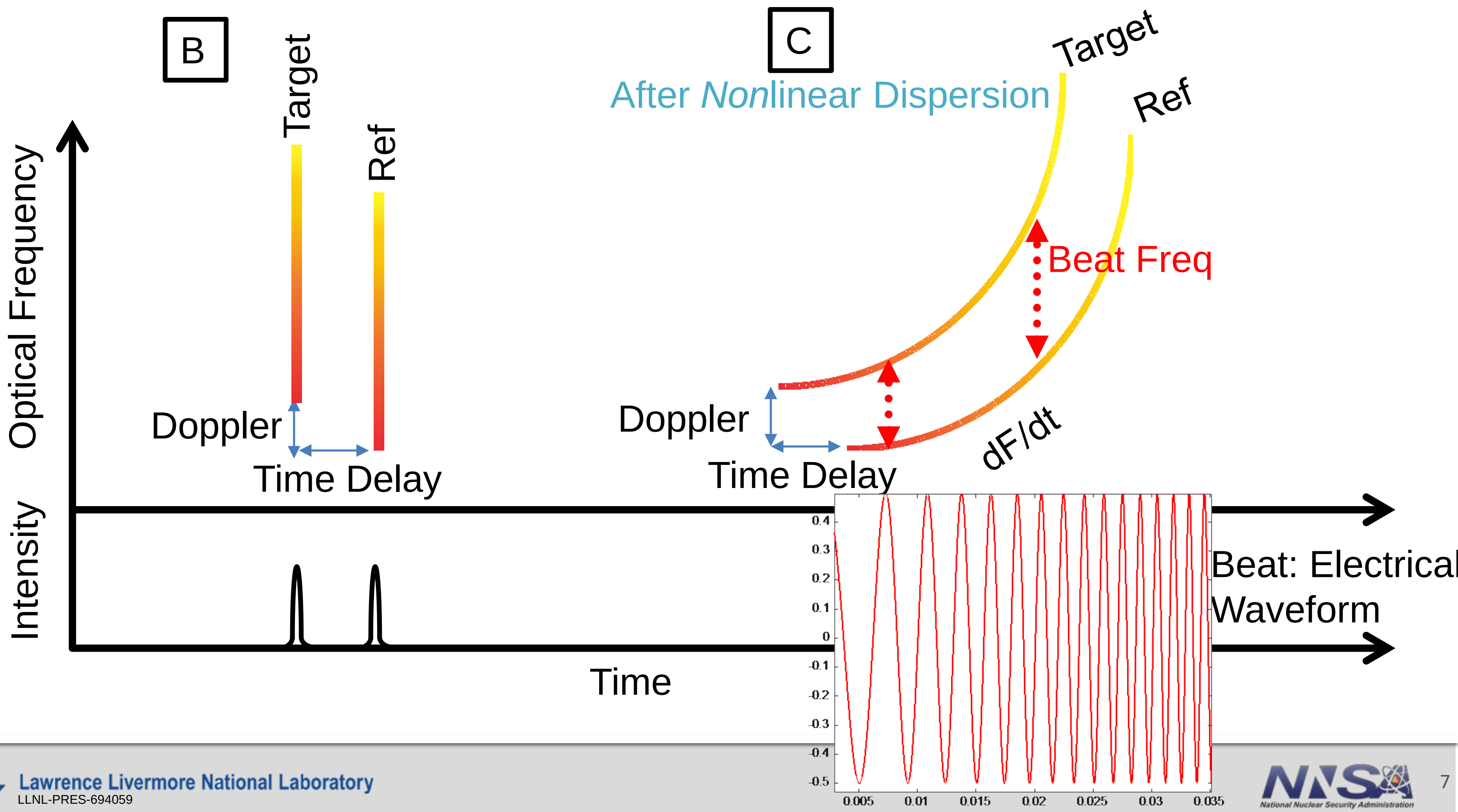
Idealized frequency domain description demonstrates the insensitivity to Doppler shift



Time Delay = Beat freq/(dF/dt)
Position = c*Time Delay/2

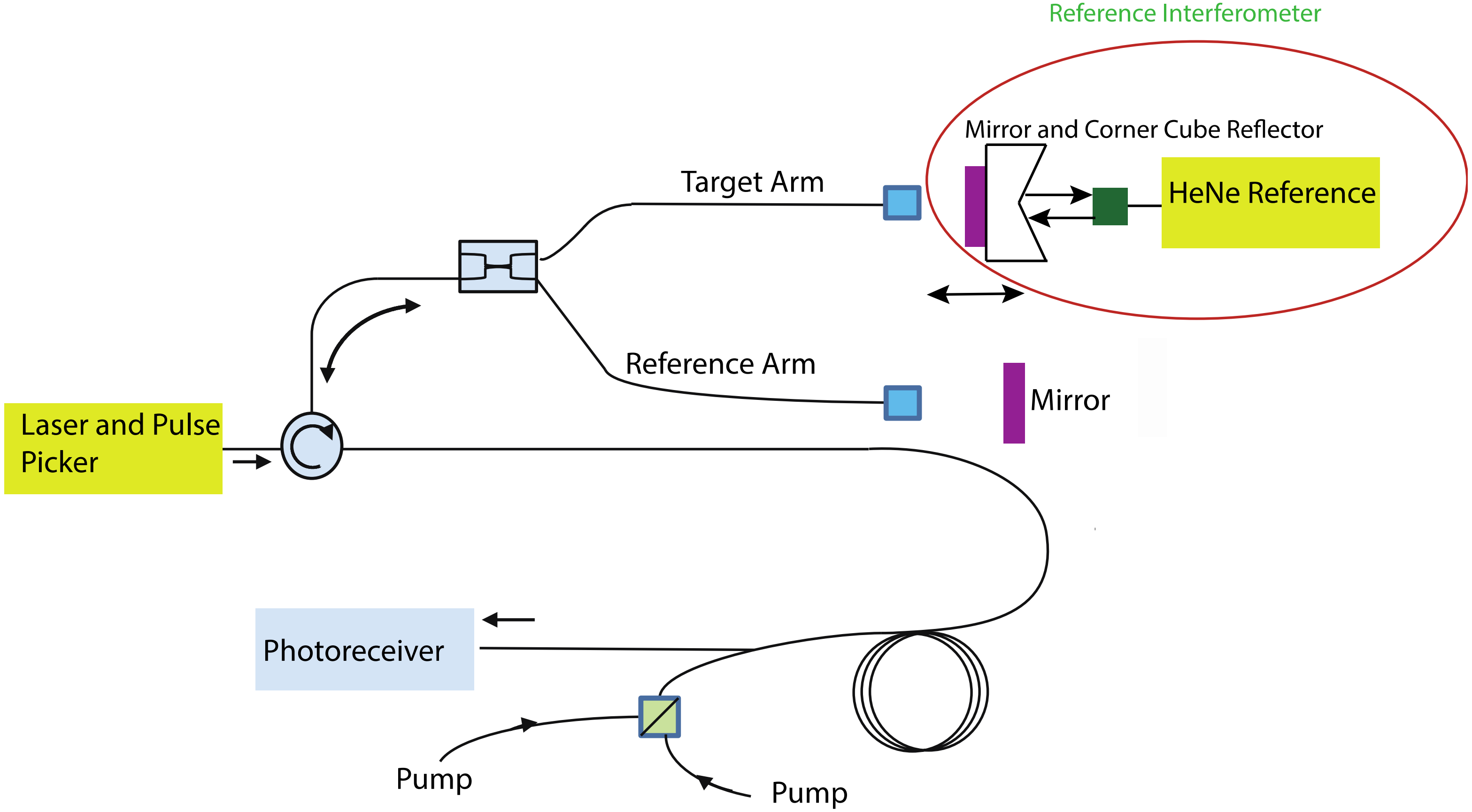
Chirped signals

- The chirp is due to Third Order Dispersion (TOD) in fiber



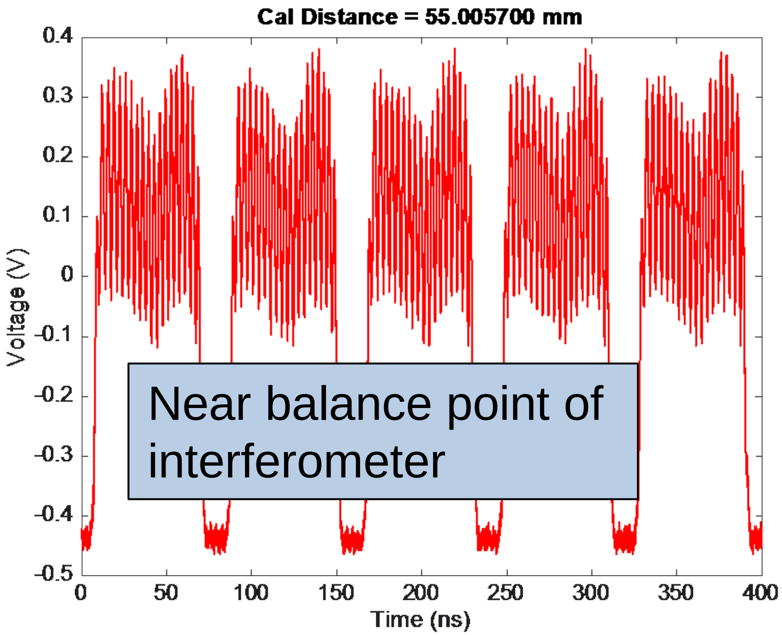
Calibration before experiment

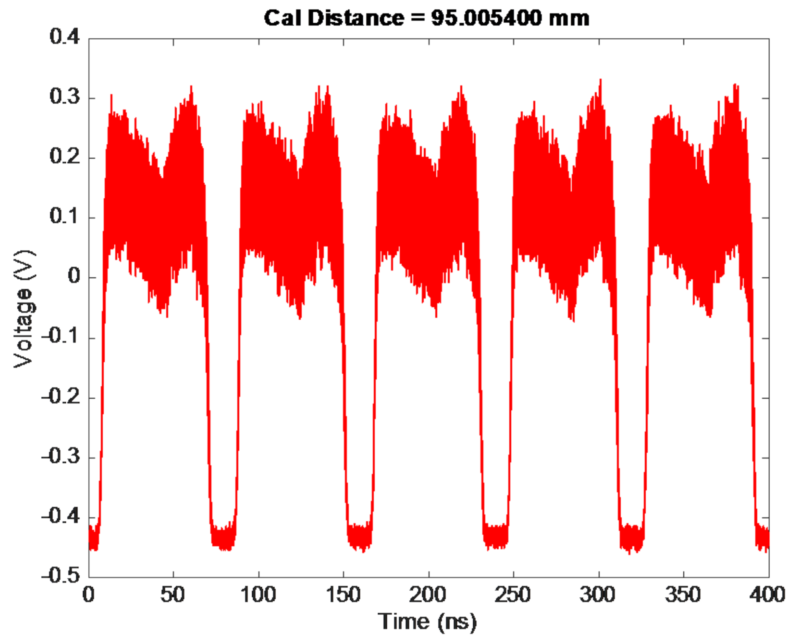
- The calibration establishes a correction for *dechirping* the beat waveform, and a relation between beat frequency and distance



Example calibration files

- It is the **beat frequency** that we care about...this will correspond to a particular distance to target
- We also care about what we call the pulse edge or **start time**



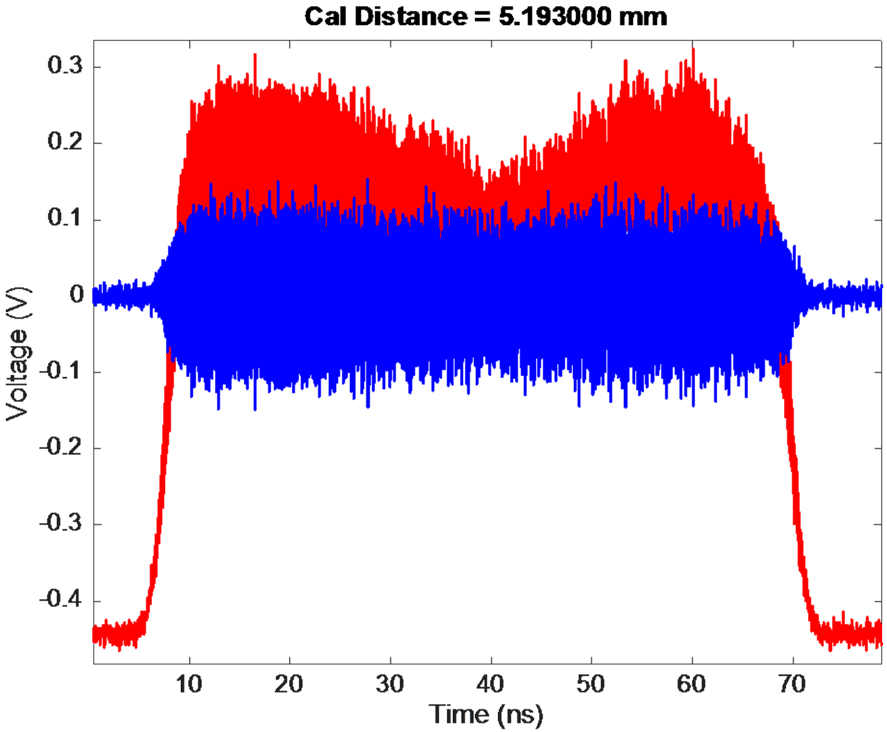


Analysis steps for calibration data

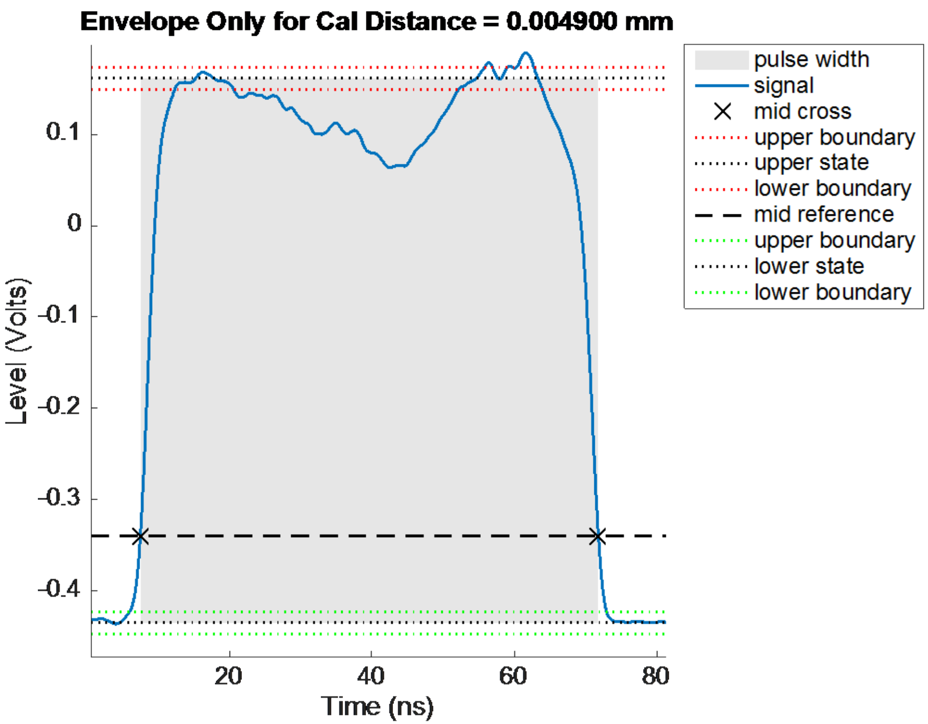
- Collect data at different distances (5 Pulses each at 41 distances)
- For every pulse,
  - Find envelope and subtract
  - Estimate the phase
  - Dechirp the signal
  - Find frequency of dechirped signal
- Do a linear least squares fit of signal beat frequency vs distance to get a slope – the *correction to be applied to experimental data*

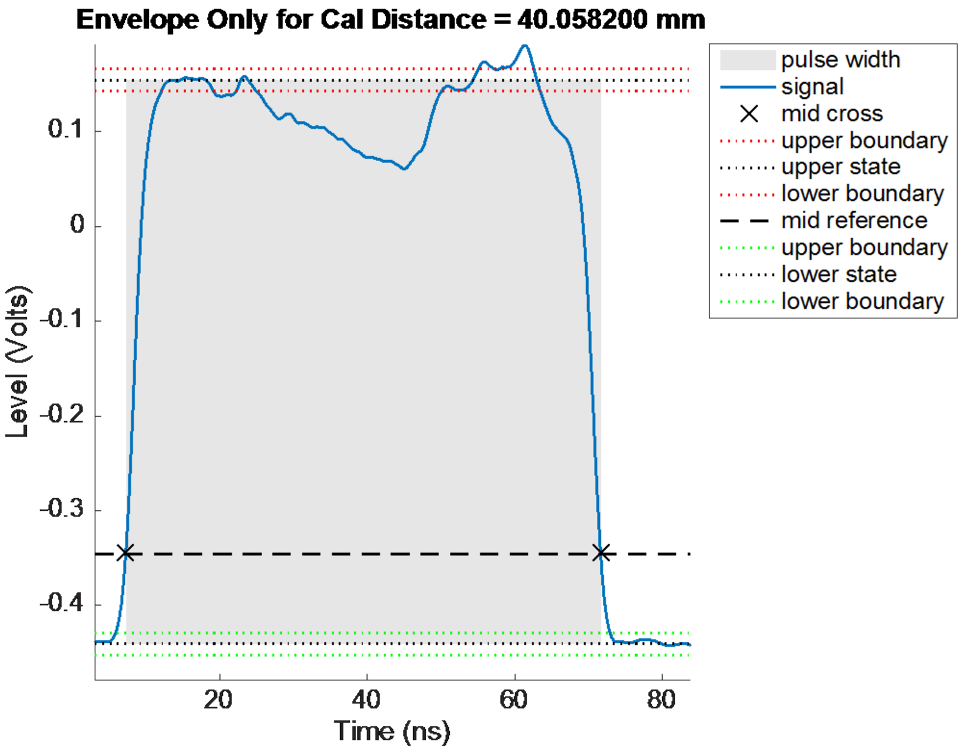
Envelope detection

- For a particular distance file
  - Find the envelope and subtract from original signal



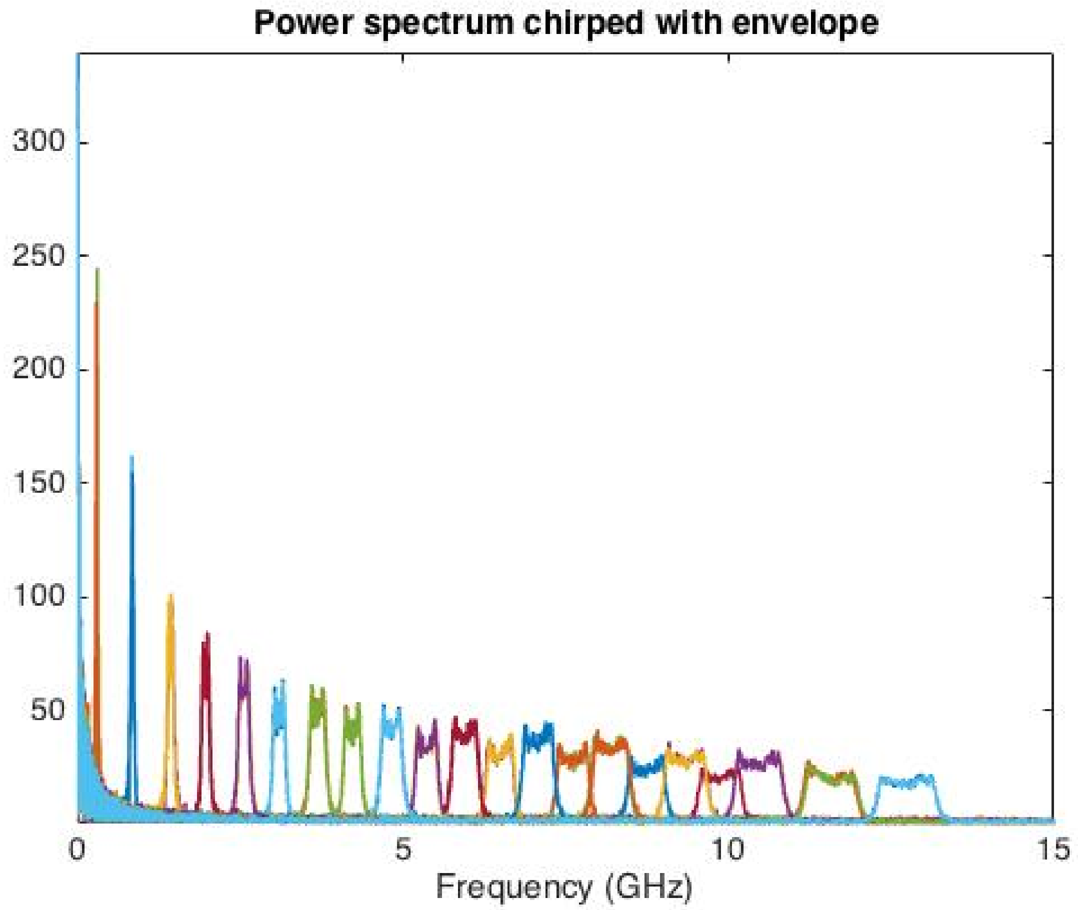
Finding the envelope with Loess smoothing





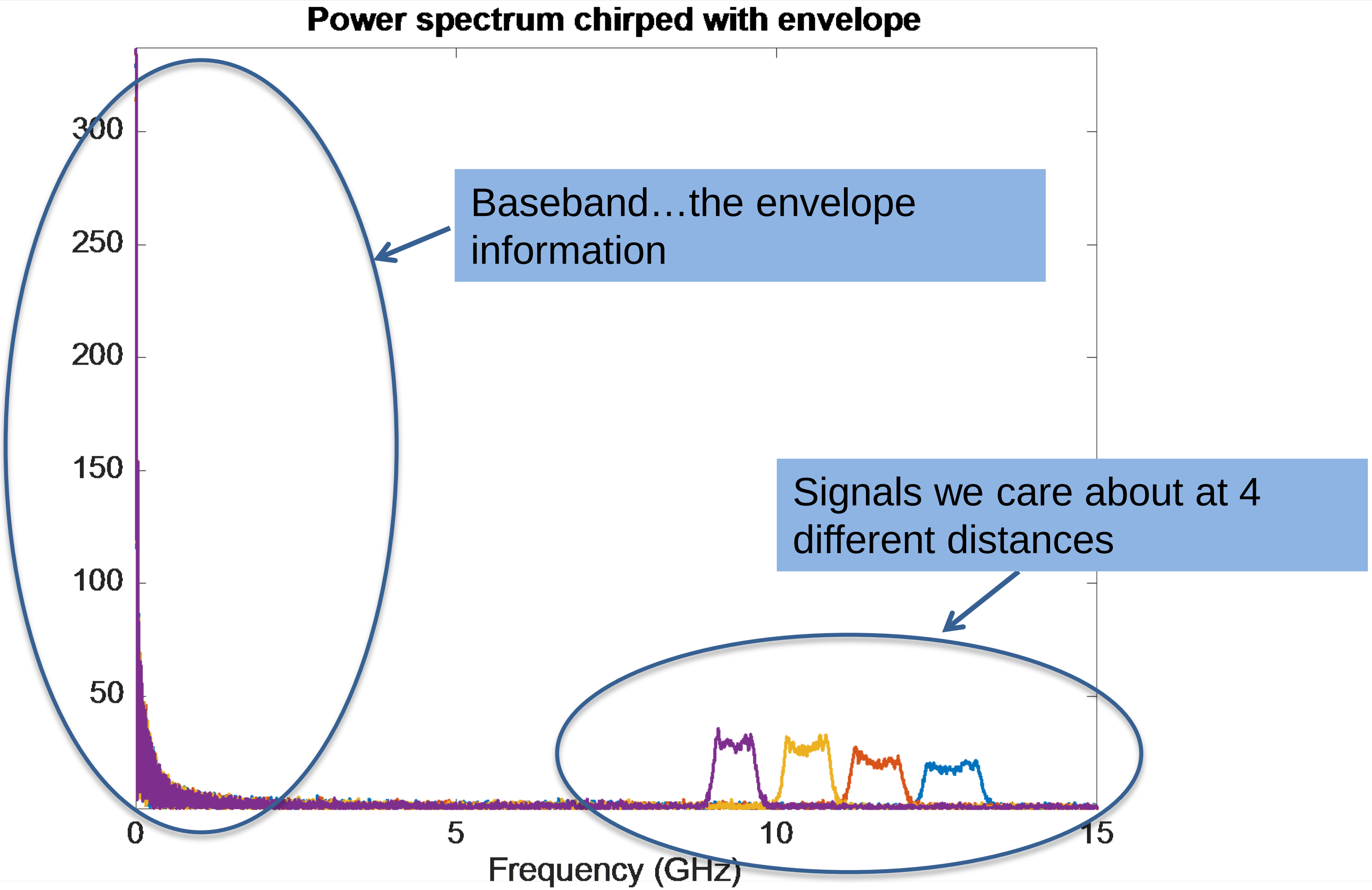
Using 200 point Loess smoothing
Mean pulse width: 64.351 ns ± 96 ps
Pulse to pulse there is variability in the envelope structure…so we find the envelope for each pulse

Before removal of envelope

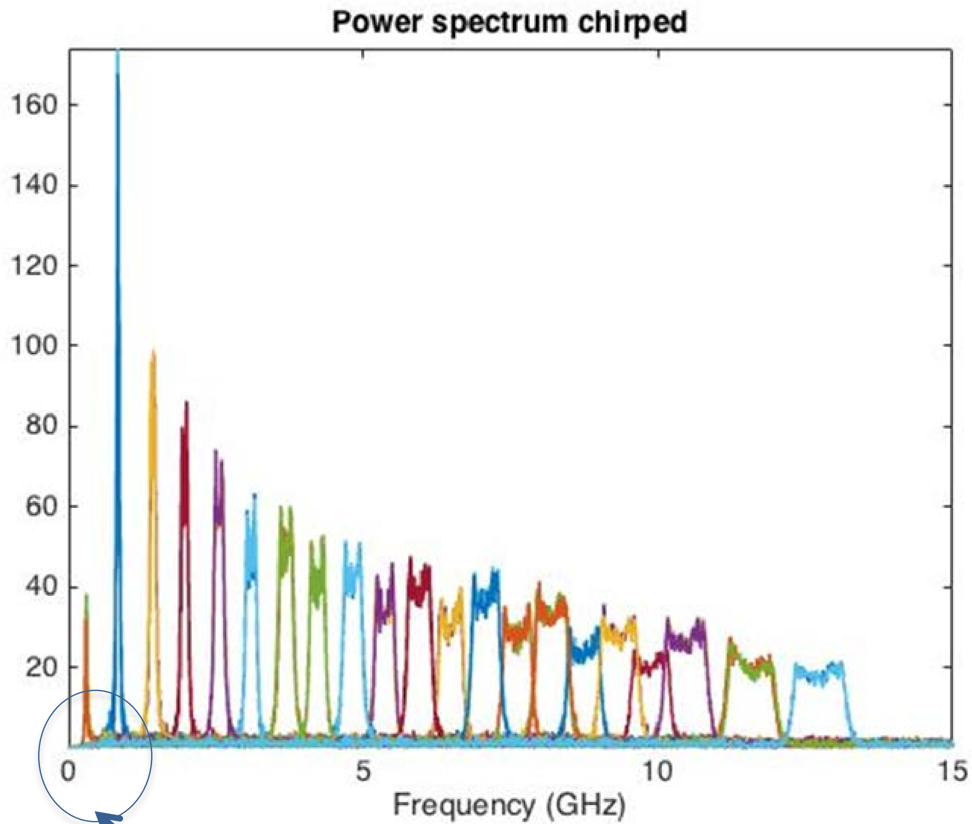


FFT of a single pulse per distance

Before removal of envelope: a closer look

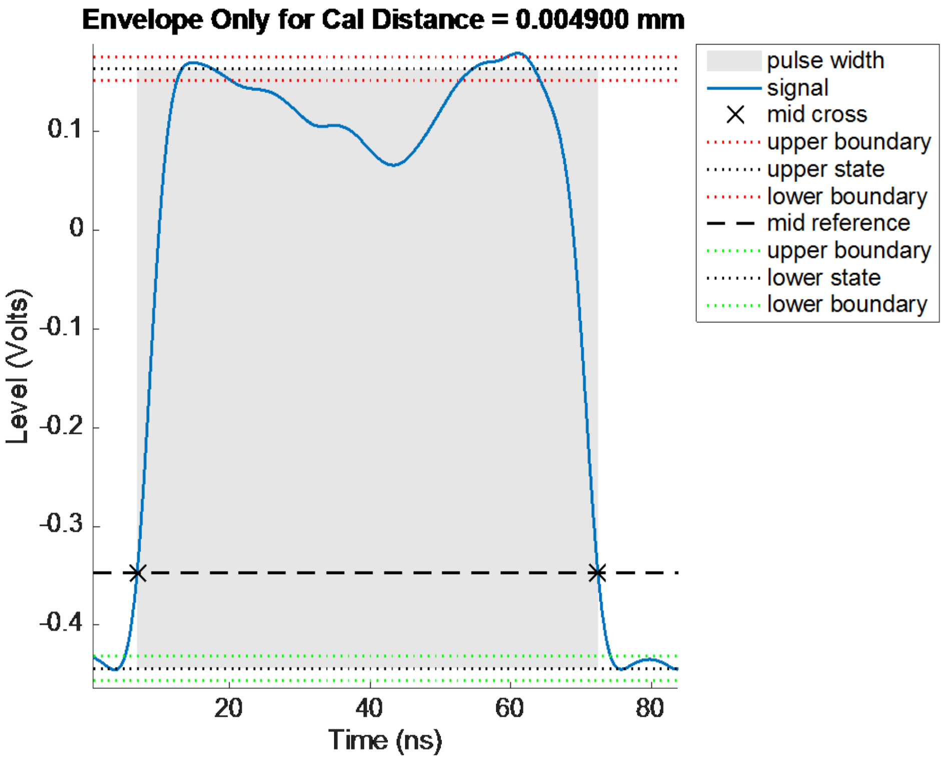


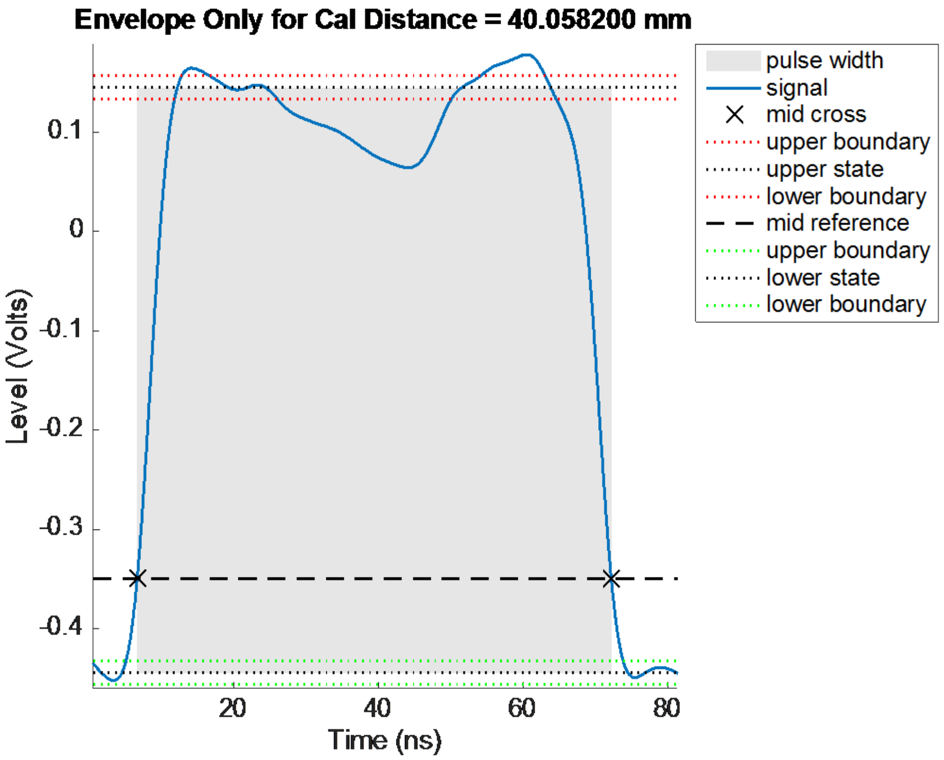
After removal of the envelope



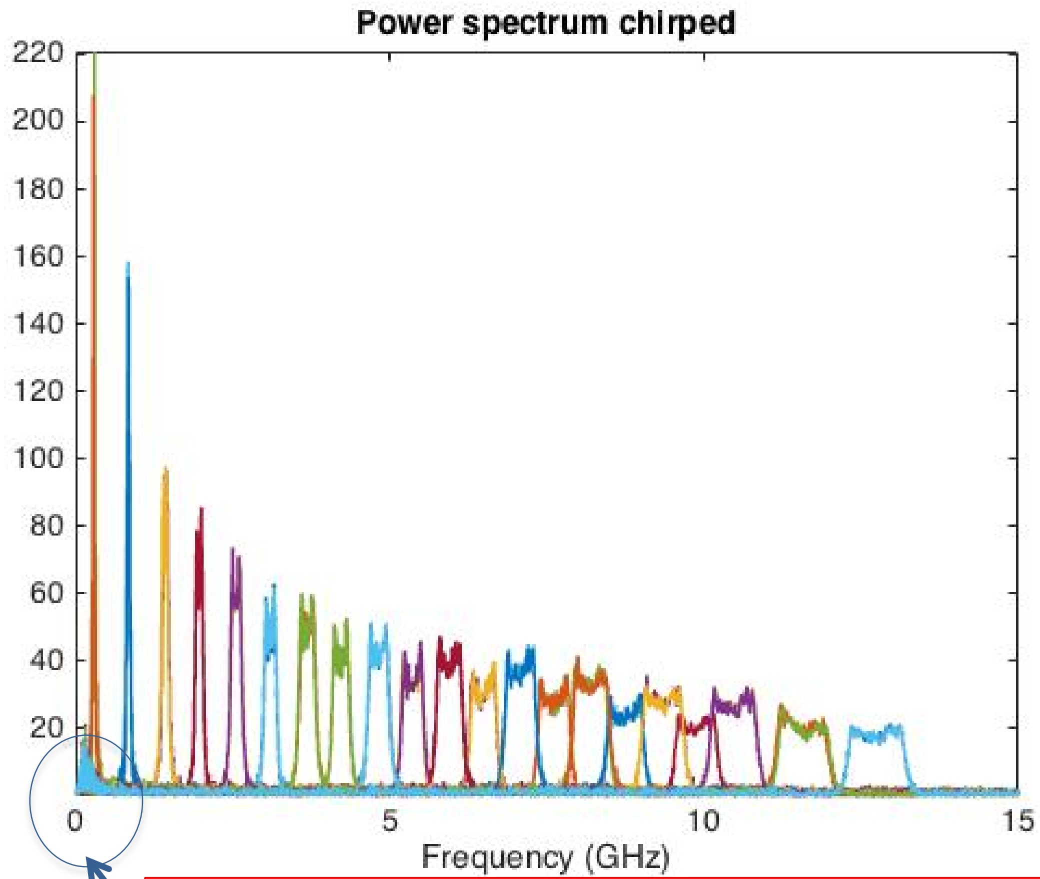
Envelope removed

Finding the envelope with a 2nd order Butterworth lowpass filter





After envelope removal



Residual power near dc (imperfect envelope detection)..overlap of spectral content near the balance point

After envelope subtraction…phase estimation

- Estimate the phase $\varphi(t)$
- Methods tried include:
  - Zero crossings
  - Hilbert Transform
  - Local Oscillator
- Fit phase vs time to a quadratic function and then linearize
- Resample and interpolate data to dechirp

$$y(t) = \sin(\varphi(t))$$

$$\phi = k_0 + k_1 t + k_2 t^2$$

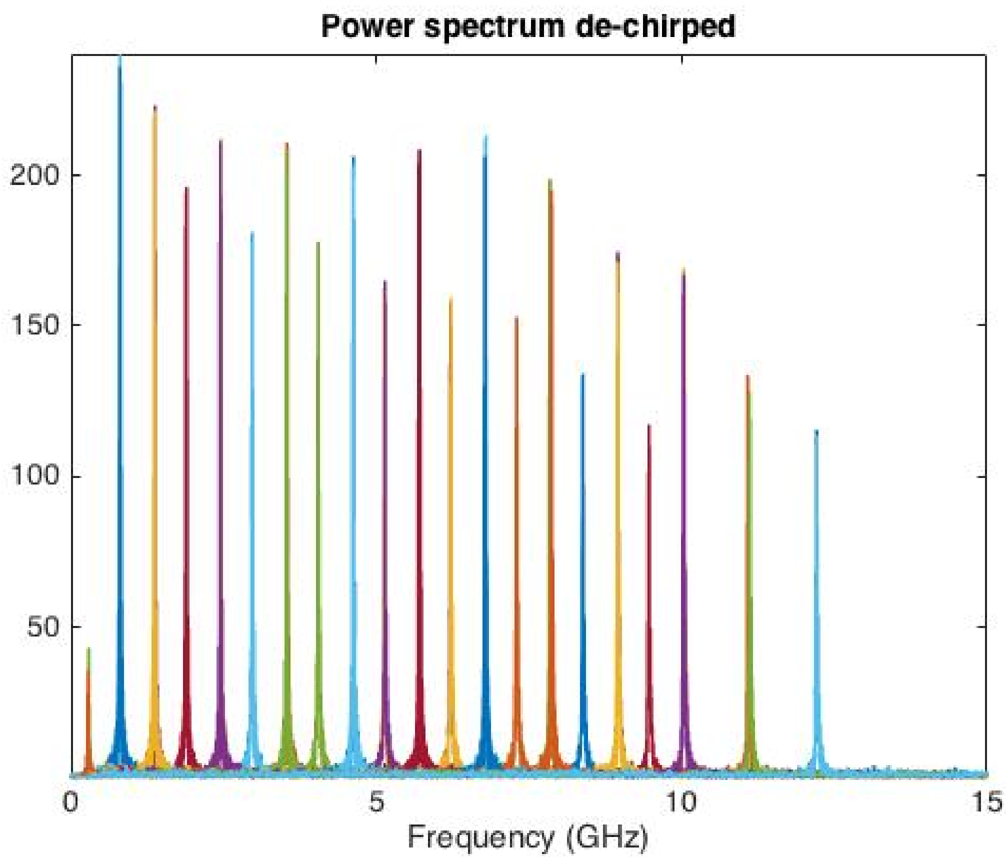
$$\phi = k_0 + k_1 t'$$

$$t' = t + \frac{k_2}{k_1} t^2$$

$$\text{Let } a = \frac{k_2}{k_1}$$

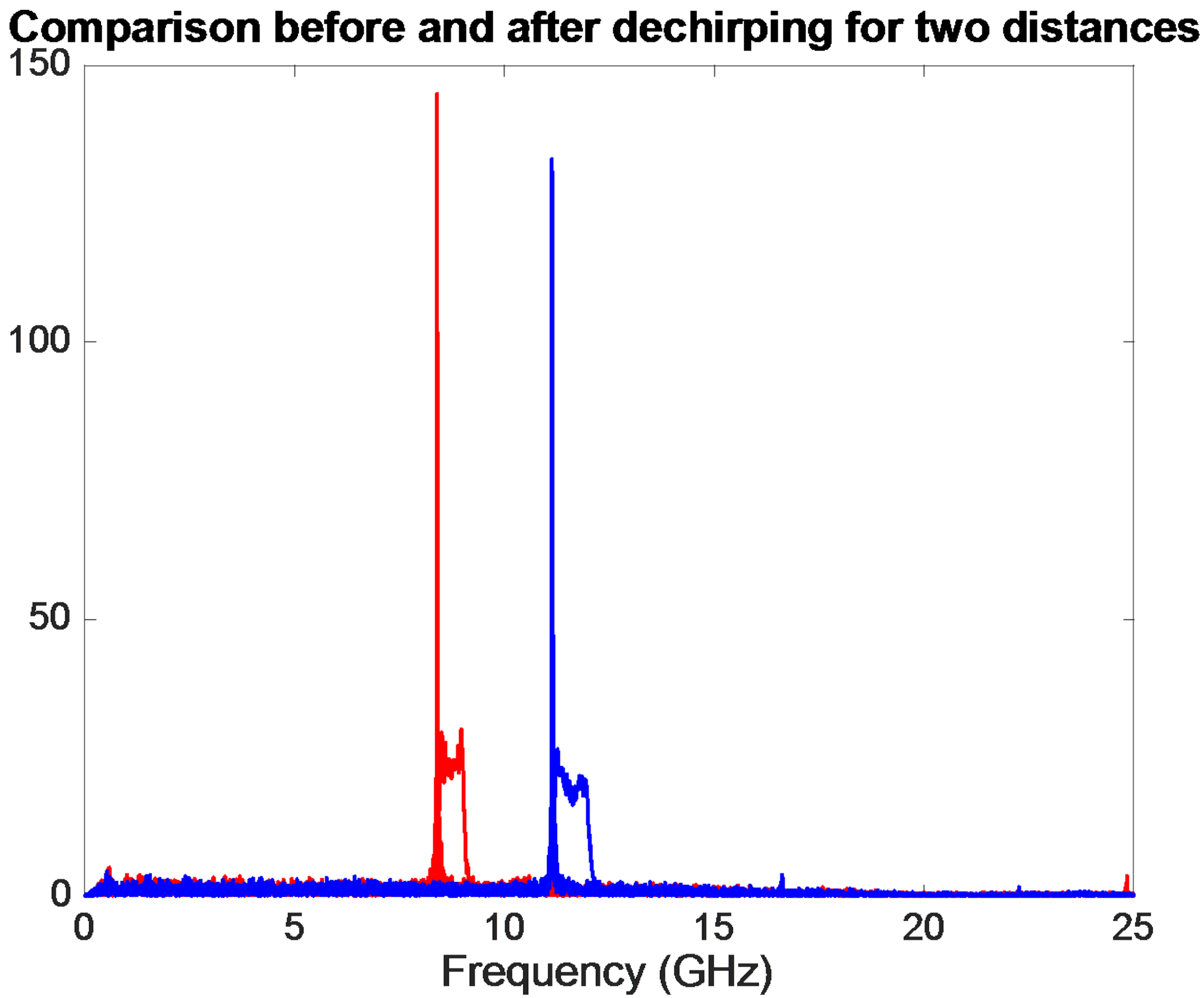
$$t = \frac{1}{2a}\left(\sqrt{4at'+1} - 1\right)$$

After dechirping

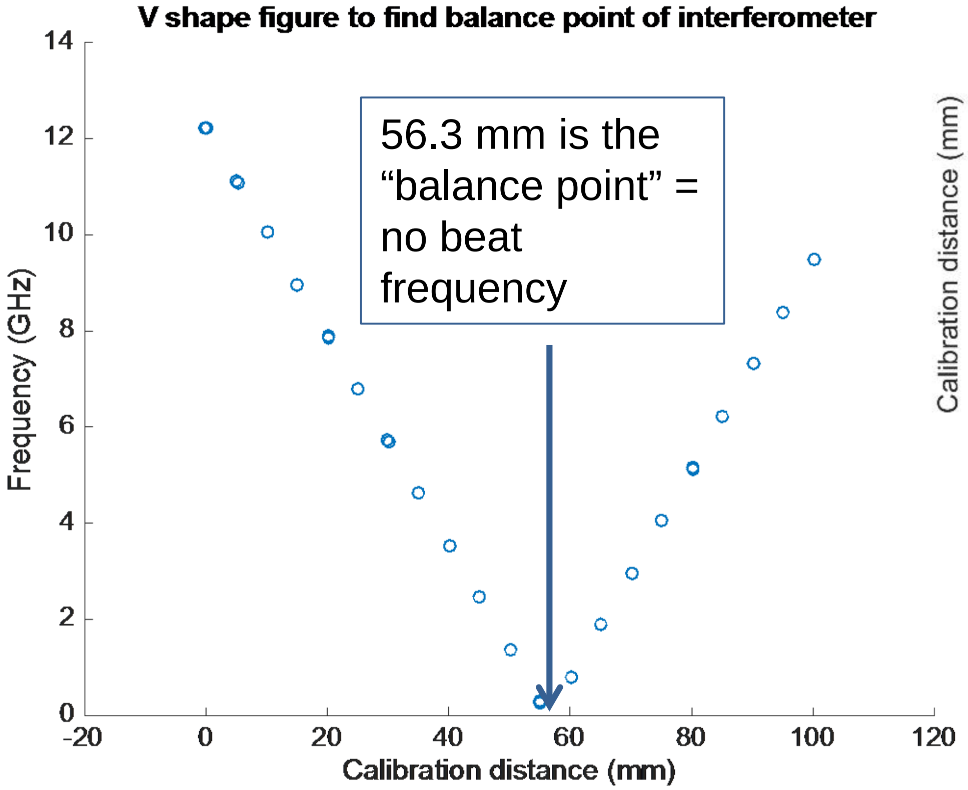


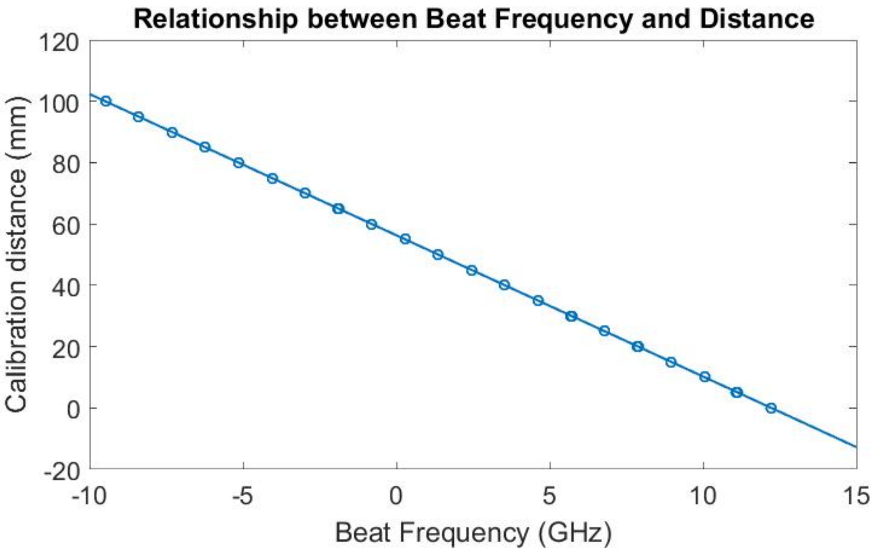
Envelope method: 200 point Loess smoothing
Phase method: Zero crossings

Before and after dechirping



Distance to beat frequency calibration slope

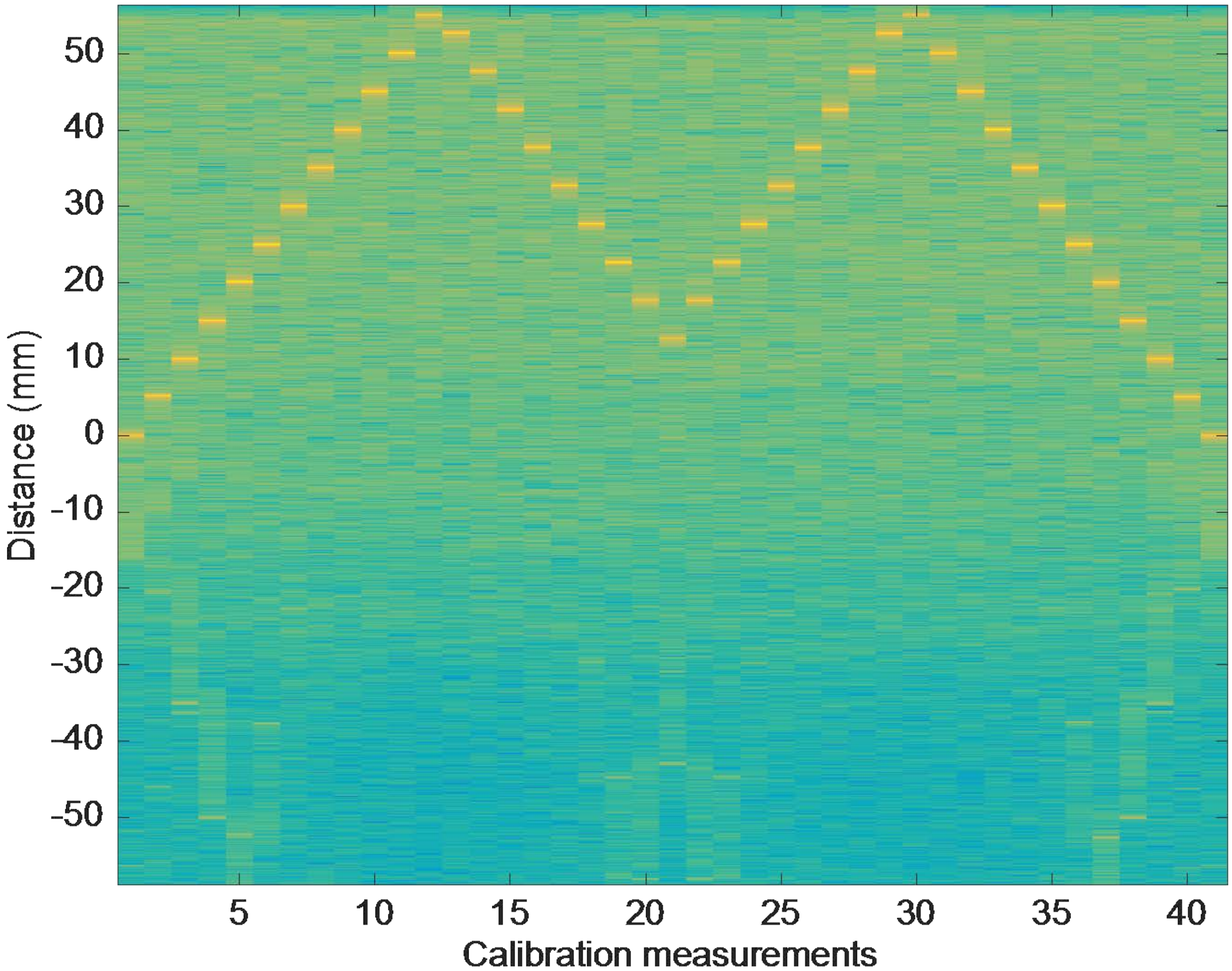




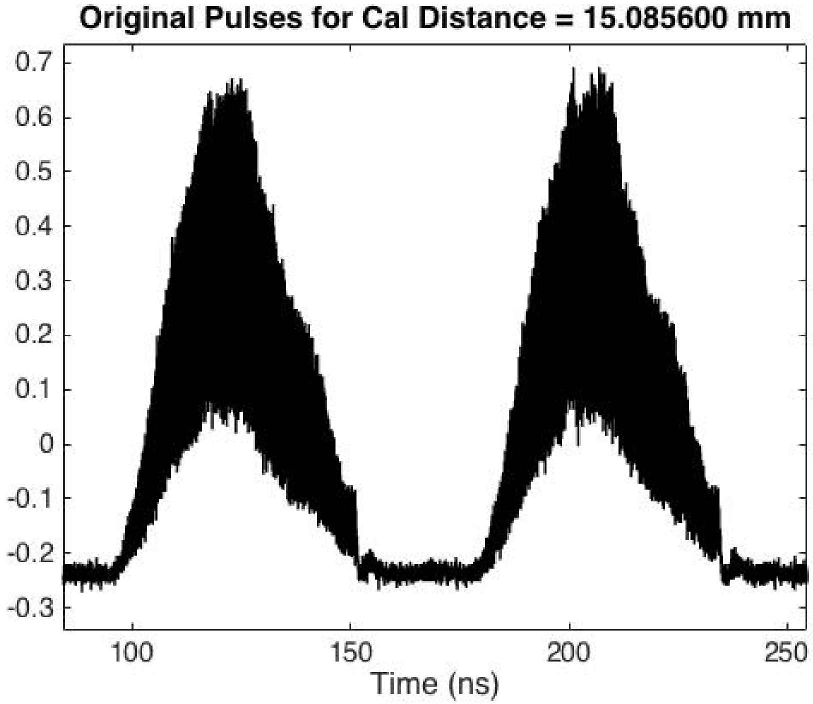
Fit frequency to calibration distance to get the slope to use to correct future experimental data

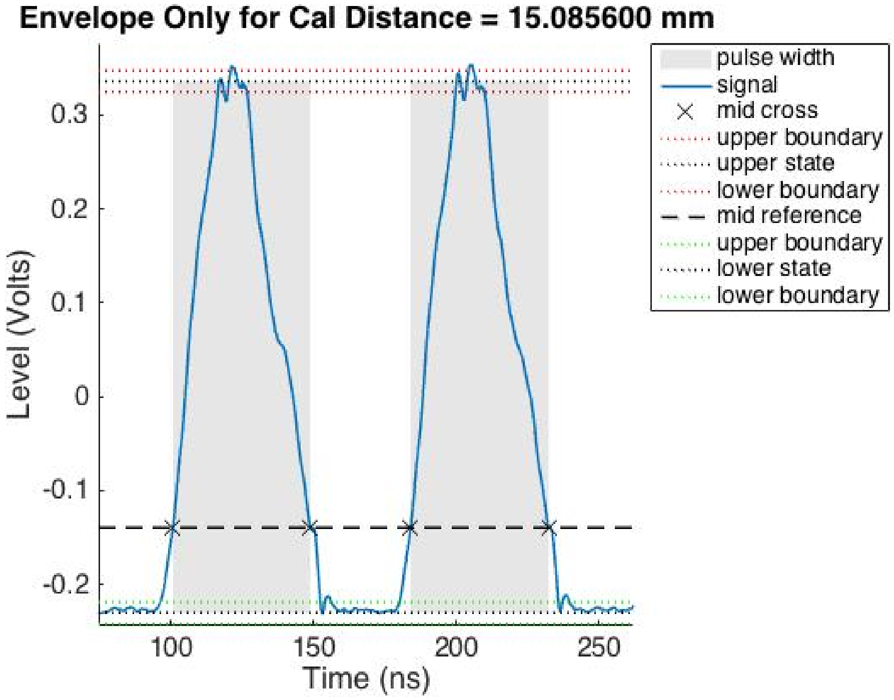
Conversion is .217 GHz/mm or 4.607 mm/GHz

Spectrogram of calibration measurements



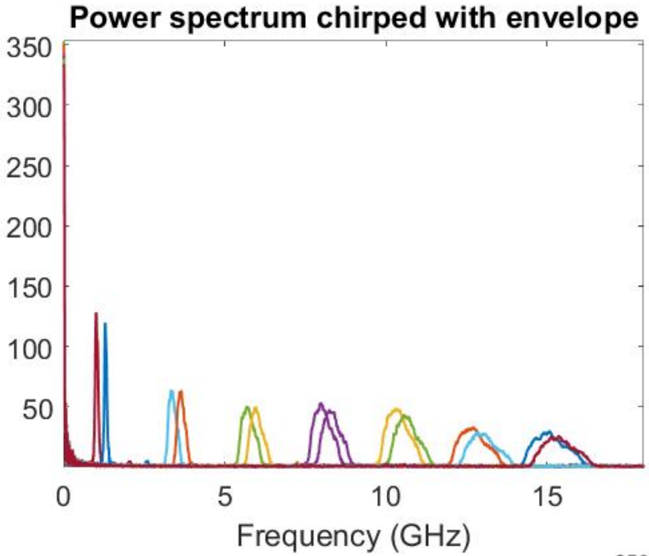
Another example: Sagebrush calibration measurements



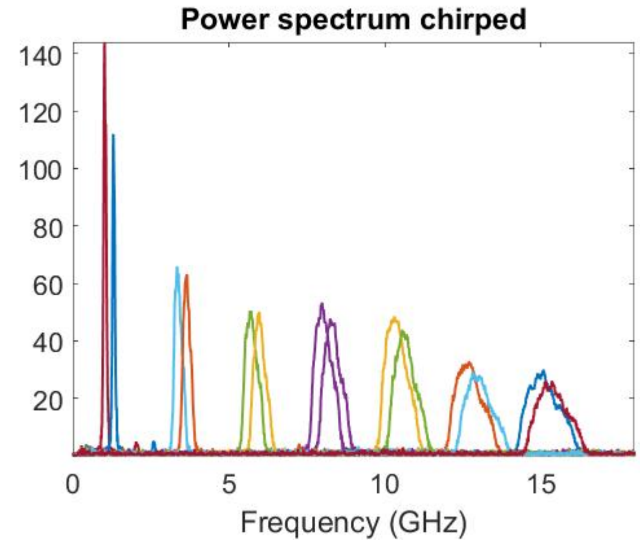


Find envelope with Savitzky-Golay 220 point smoothing window

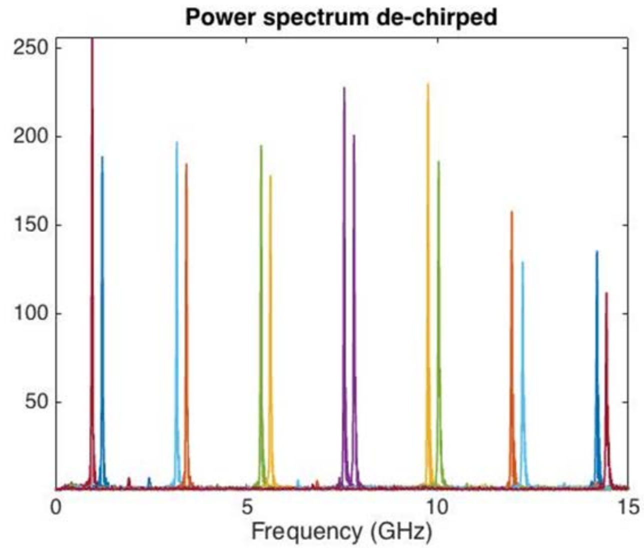
Sagebrush power spectra



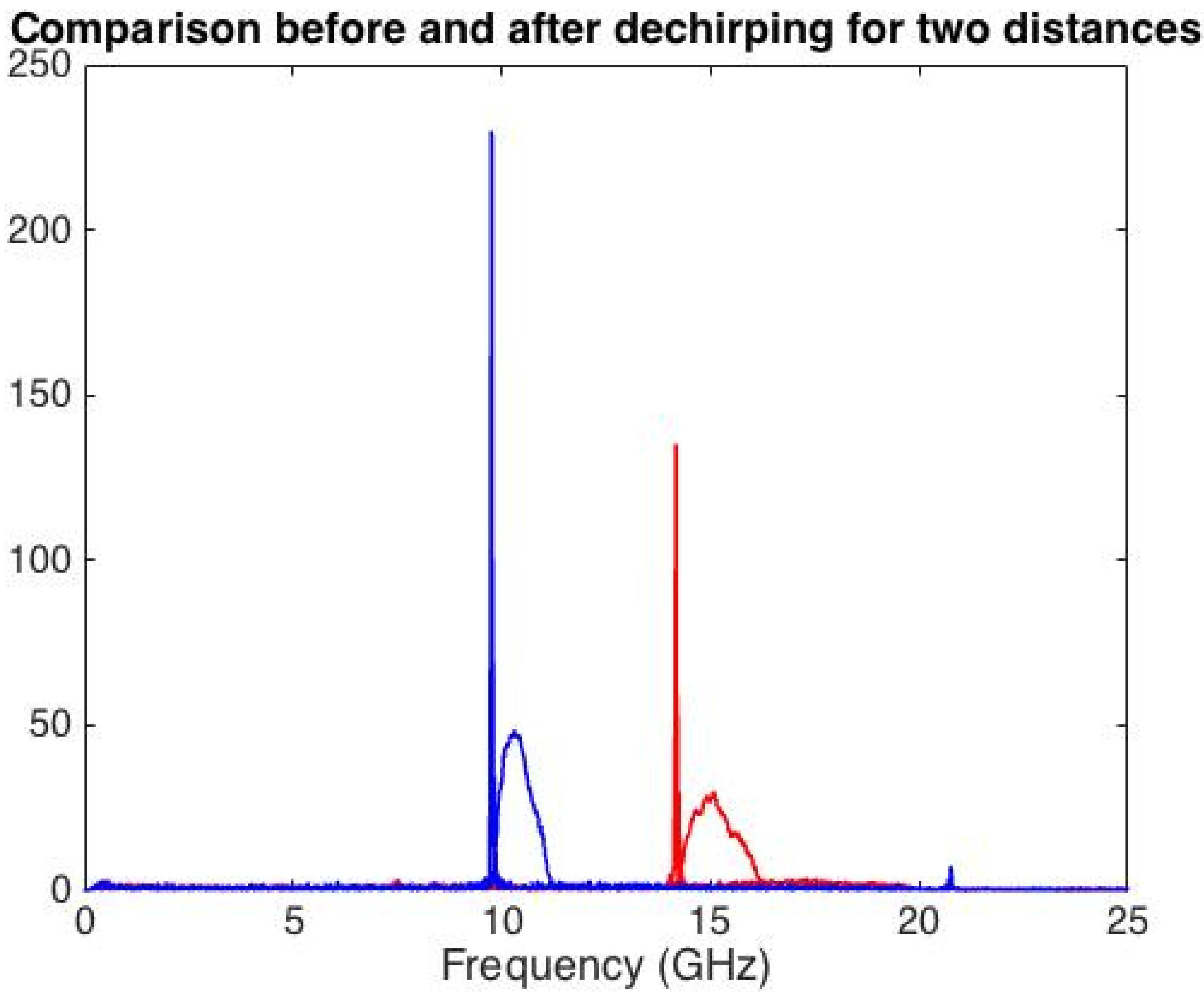
Remove envelope



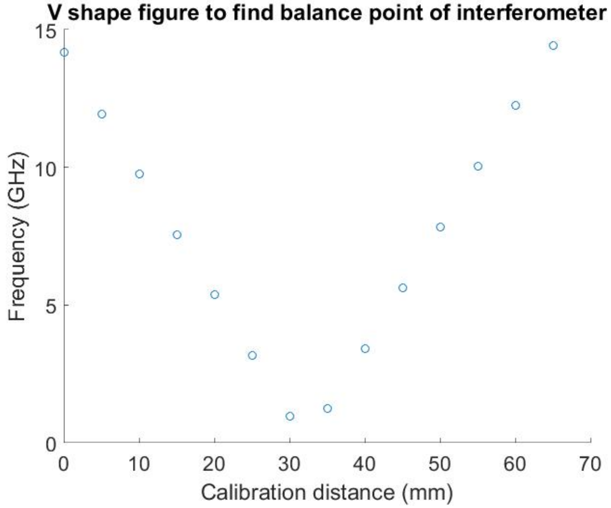
Apply dechirping

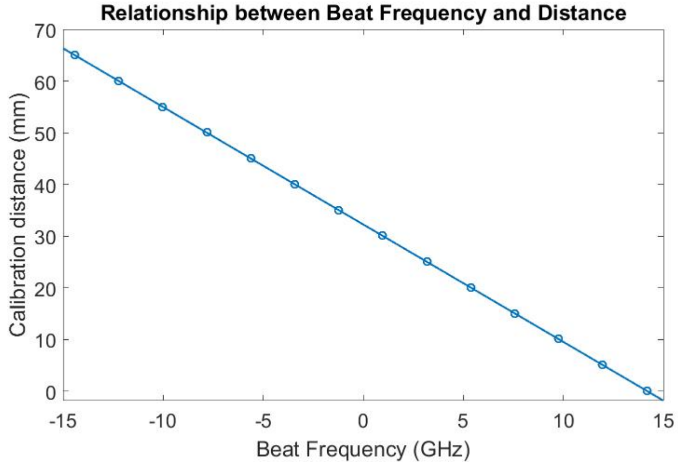


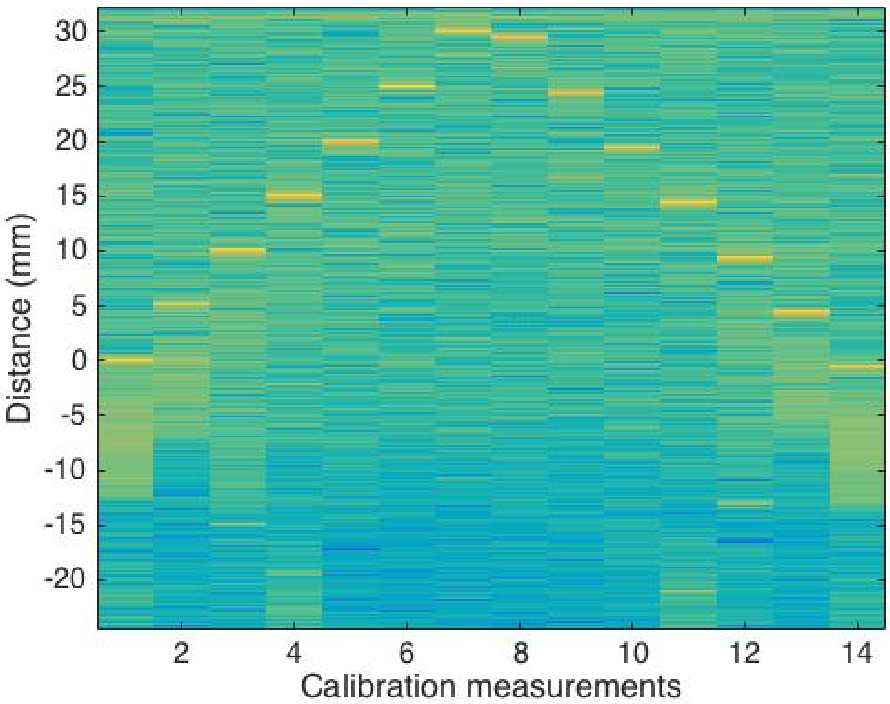
Sagebrush: A closer look



Sagebrush calibration analysis summary







Savitzky-Golay 220 points smoothing window
Zero crossing phase estimation
Conversion: 2.271 mm/GHz

A look at real data: explosive-driven aluminum test