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Simultaneous Measurement of the 1st and 2nd Harmonics of a Phase-Modulated Coherent Frequency-Domain THz Spectrometer

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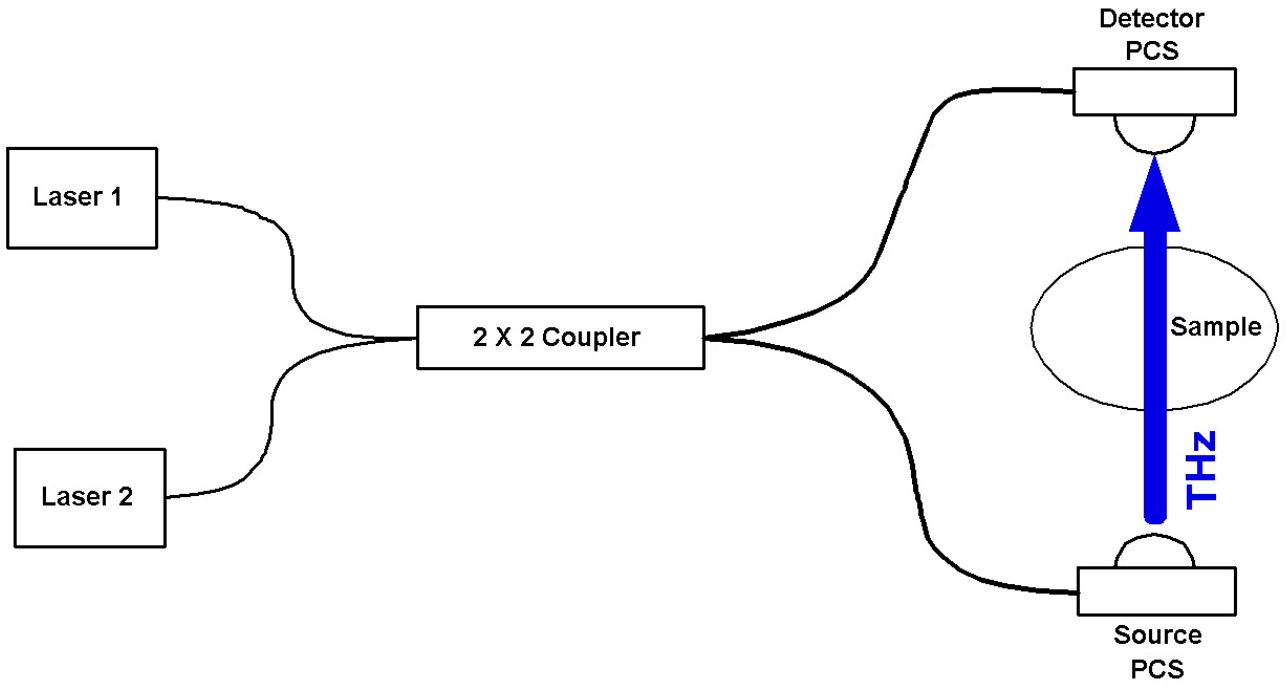
Outline

- Review
- Motivation
- Approach
- Results
- Summary

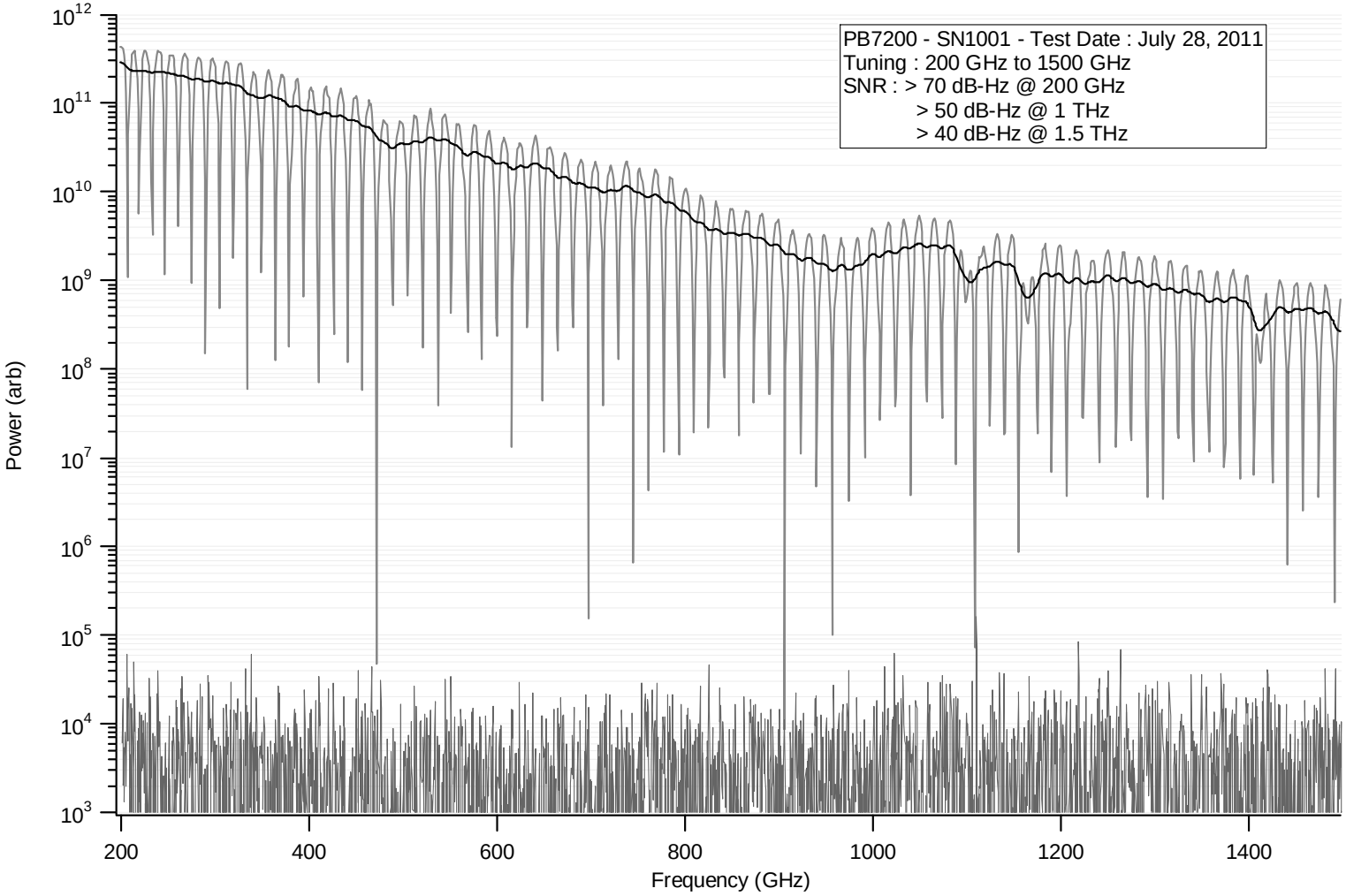
Review

- **Constant Wave Photomixing Terahertz Spectrometer**
  - Heterodyned semiconductor DFB lasers (785 or 853nm)
  - Precise temperature tuning range of over 2 THz (~480 GHz/nm at 785nm)
  - THz beat note modulates conductance of source and detector photomixer devices
  - Coherent homodyne detection with same optical signal used as local oscillator



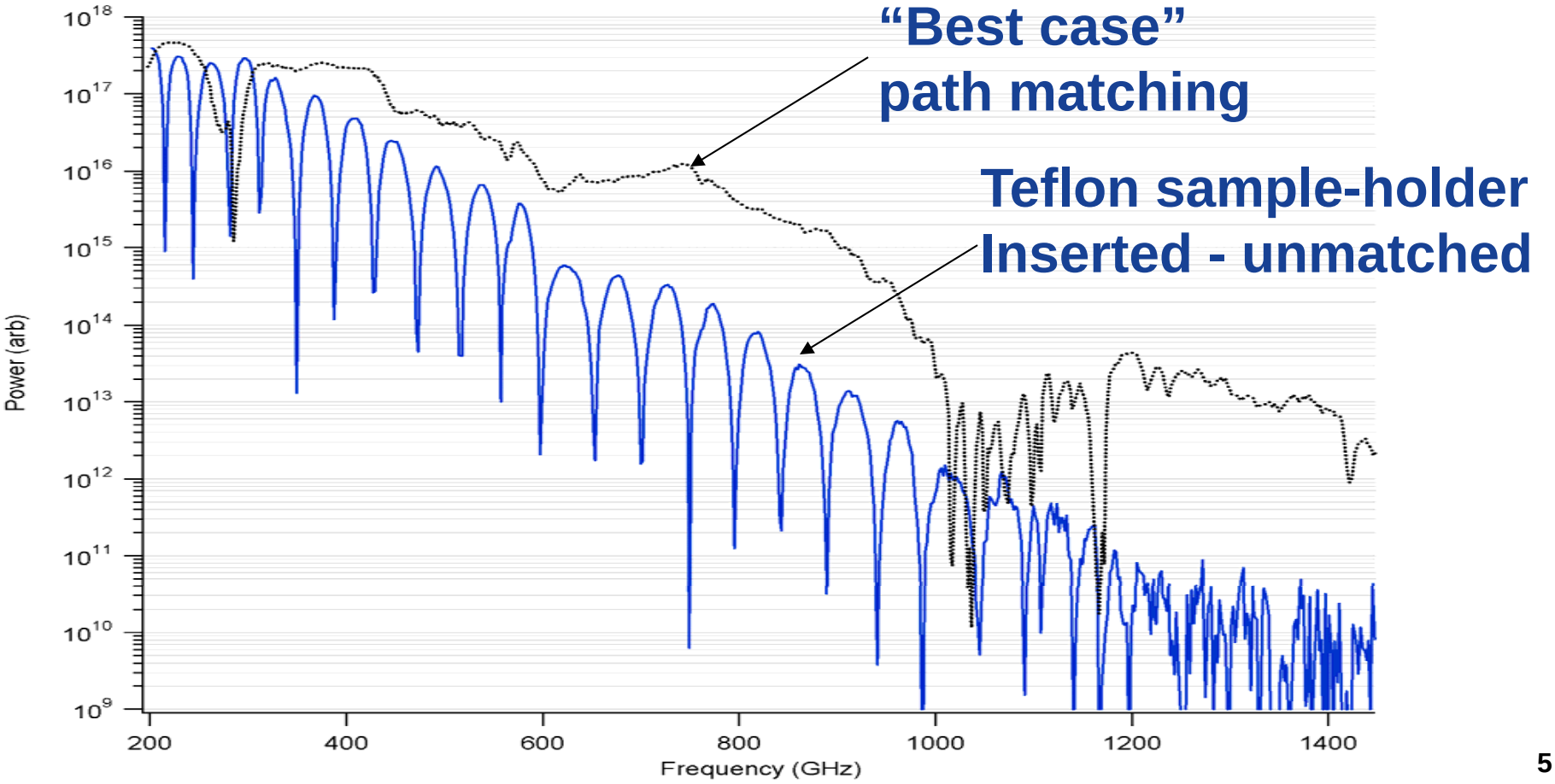
Spectrometer scan of lab air

- Interference pattern caused by coherent detection
- The fringes make resolving narrow features difficult if the absorption falls on a fringe. The heads can be moved, but this is time consuming and inconsisitent.



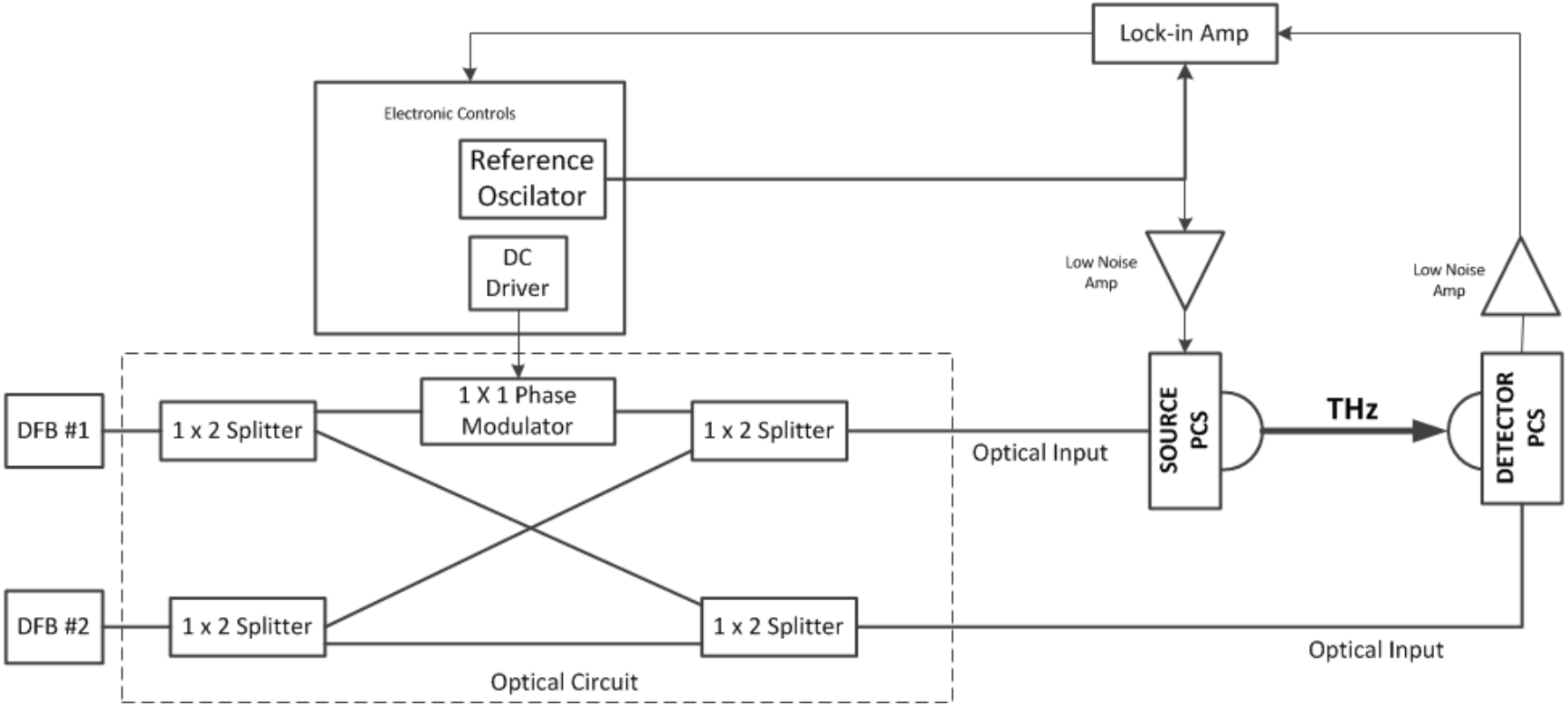
Sample induces path-length changes

- Fringe spacing is dependent upon the effective distance between the source and the detector and may be adjusted by changing the spacing.
- The interference pattern makes it difficult to perform background subtraction because when a sample is inserted into the path the fringe spacing changes.

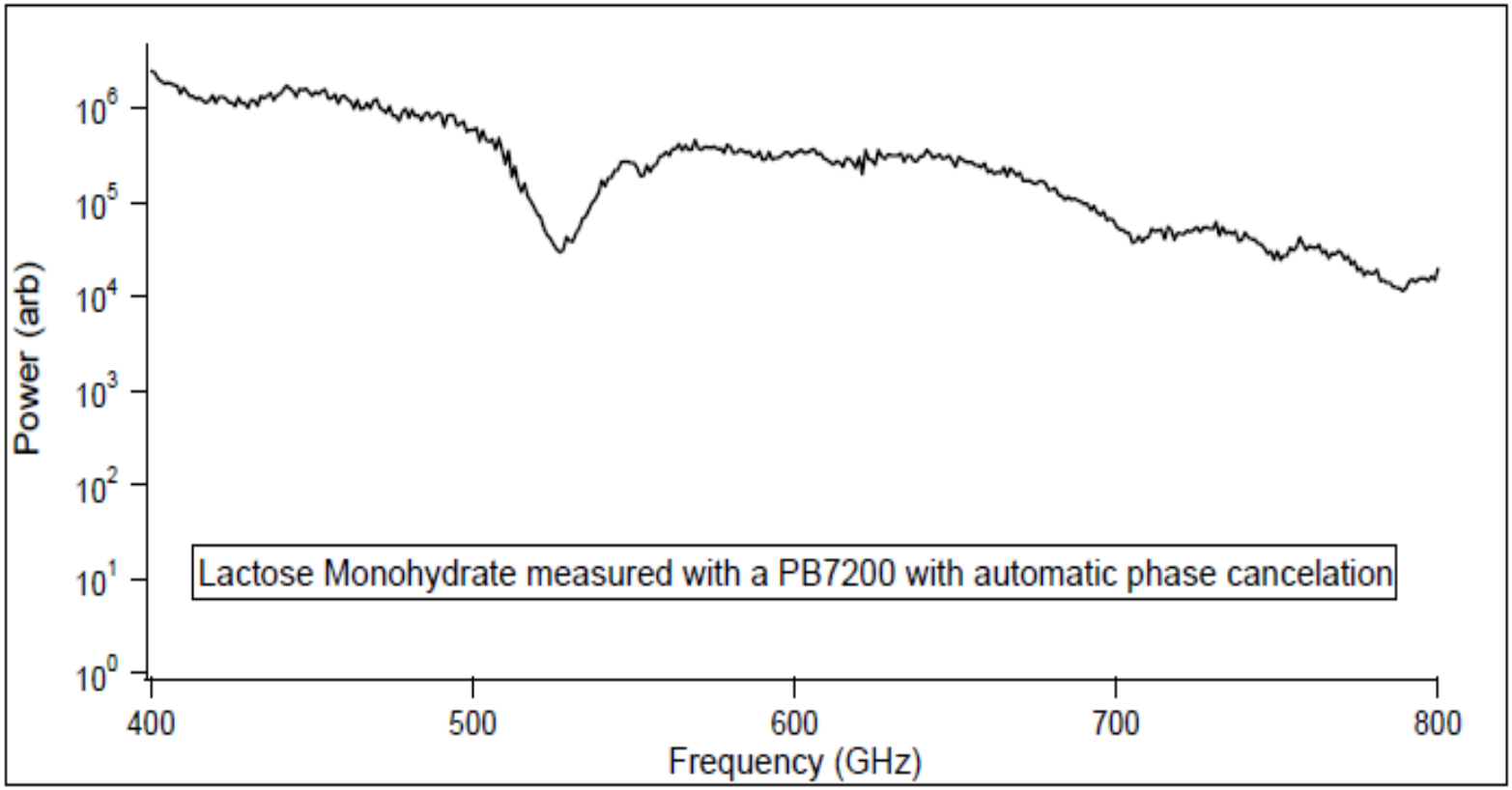


Optical terahertz phase control

- **Use 1 X 1 lithium-niobate optical phase modulator to control relative optical phase between source and detector**
- **Optical phase shift results in equivalent terahertz phase shift**
- **Previously demonstrated data acquisition with sequential phase shifting**
  - 0º data recorded then 90º data point recorded at the “same” frequency



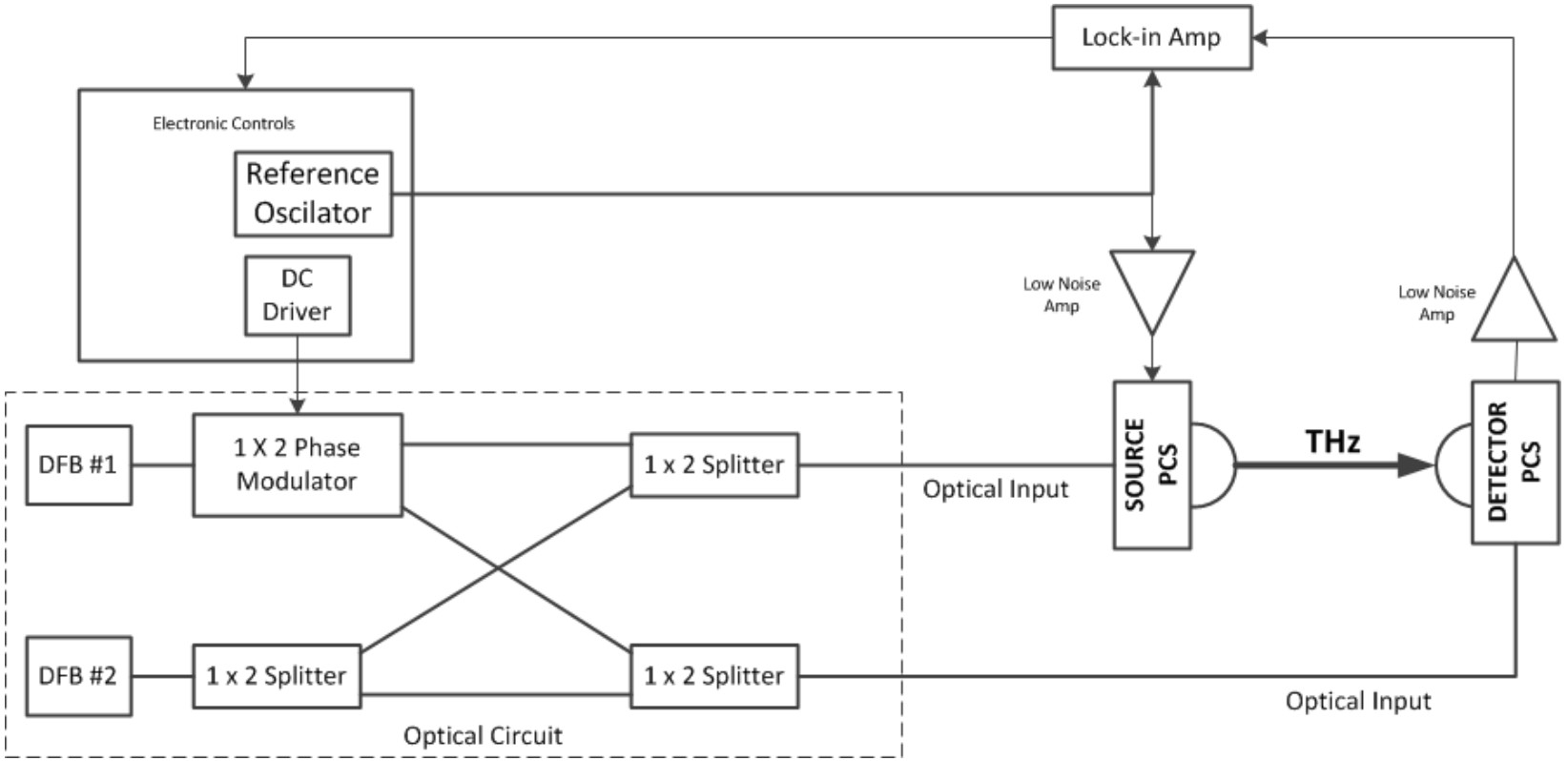
Lactose Monohydrate 0 and 90 combined



- Technique worked but it was twice as slow (twice as many points recorded)
- Issues with the phase drifting during a scan (temperature dependent)
- Slight differences in the frequencies between the 0° and 90° data acquisition required fully resolving the fringes (still!)

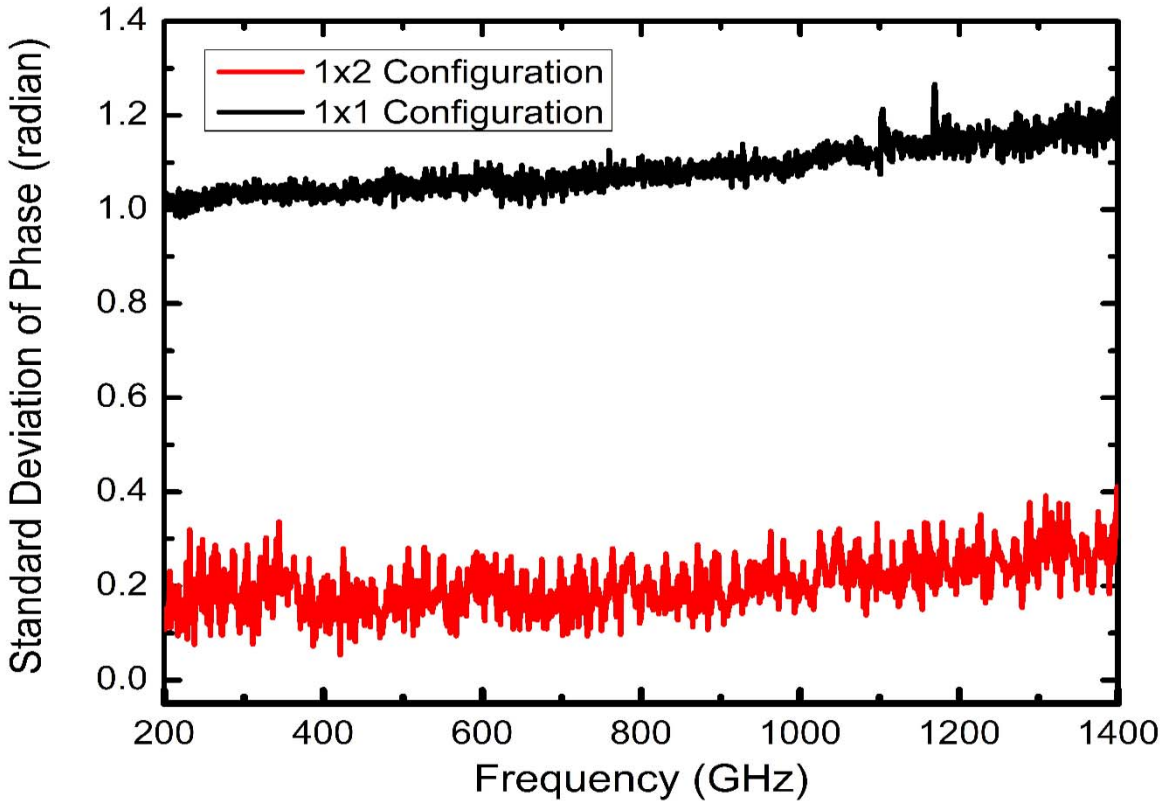
Common-mode phase drift rejection

- Developed a 1 X 2 lithium-niobate optical phase modulator to control relative optical phase between source and detector
- Phase drift due to temperature changes was present on both the source and the detector and therefore rejected via “common-mode.”
- This solved the phase drift issues; still had to resolve the fringes and slow scans



Common-mode phase drift rejection results

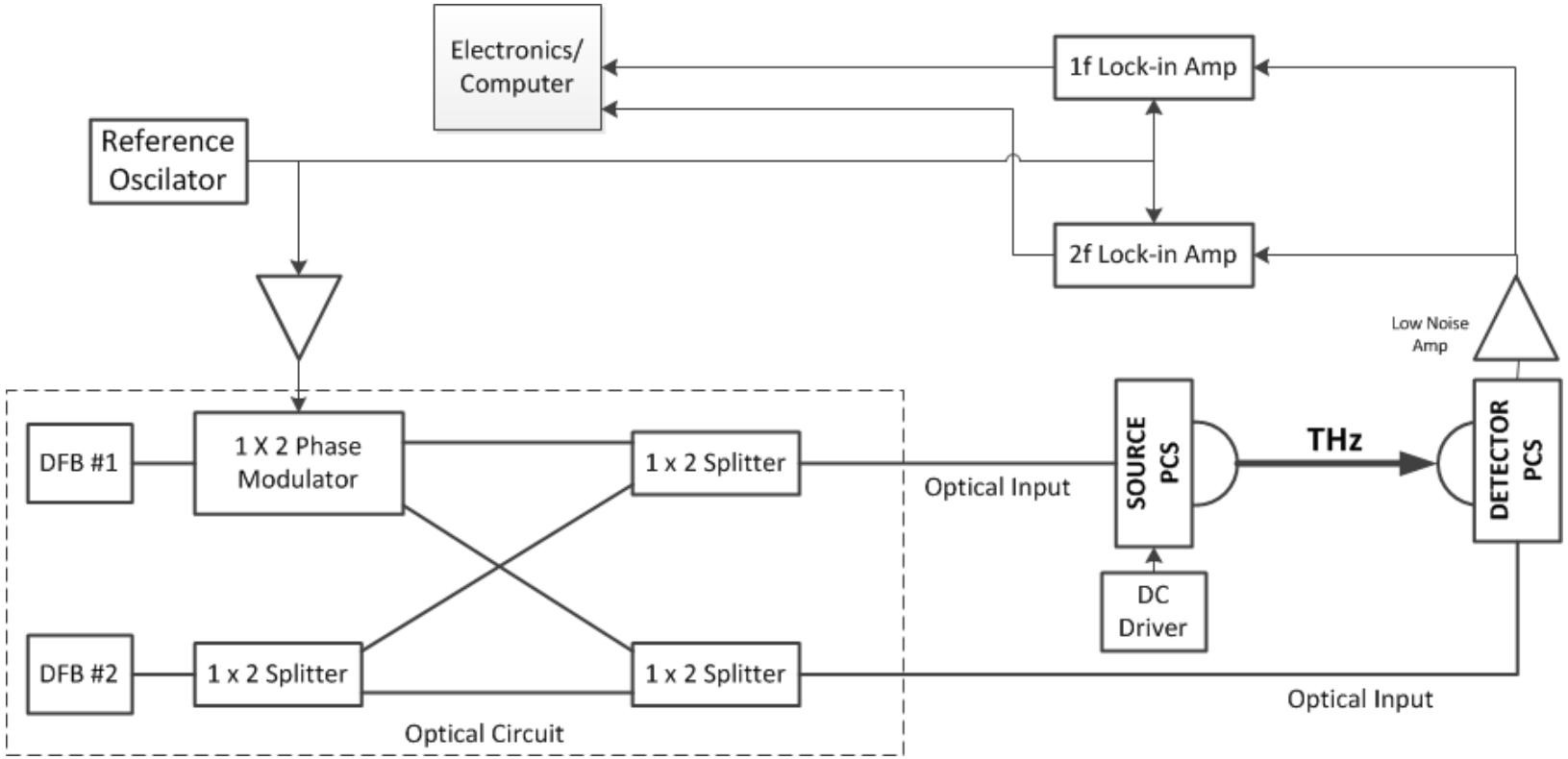
- Perform a scan with the optical circuit within a temperature controlled “oven”
- Apply DC bias to phase modulator for 90° shift and re-scan
- Compare the phase drift of the two systems



- This improved the phase drift issues; still had to resolve the fringes and slow scans

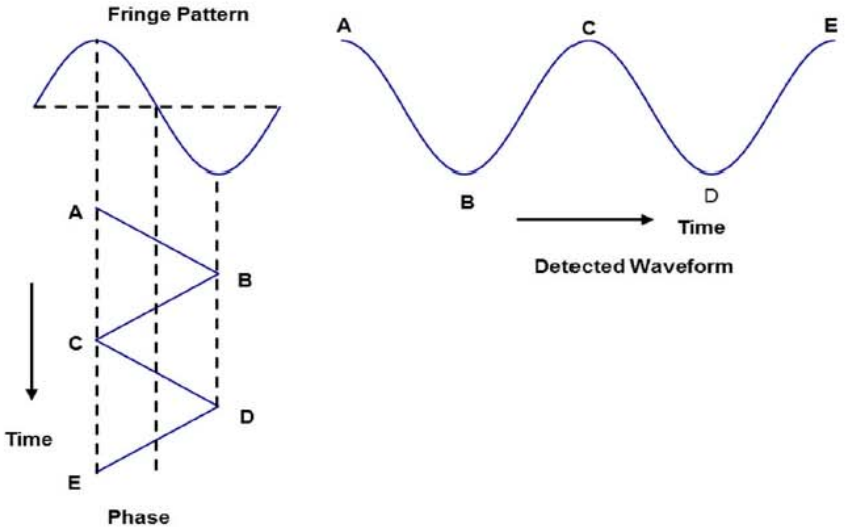
A system employing direct phase modulation

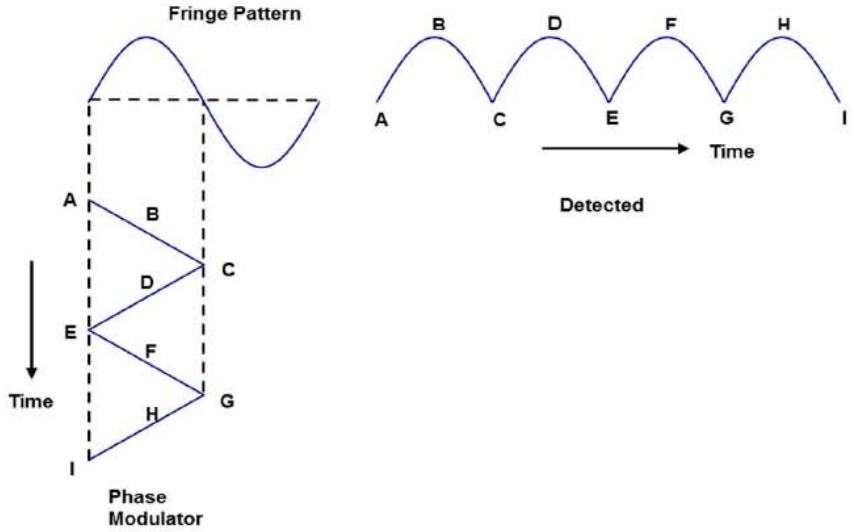
- The coherent detection and presence of a fringe pattern makes it possible to detect the direct phase modulation of the optical phase
- Apply DC bias to source photomixer and 6kHz triangle wave to the phase of the optical radiation on the source fiber
- We recently released a two channel THz spectrometer which made it easy to convert one channel for the detection of a second harmonic of



Direct modulation of phase

- **Applying a constant 6 kHz triangle wave to the phase modulator**
  - Voltage was adjusted to produce balanced response from harmonics
- **Frequencies with 90° phase difference at detector 1st harmonic is maximum**
- **Frequencies with 0° phase difference at detector 2nd harmonic is maximum**



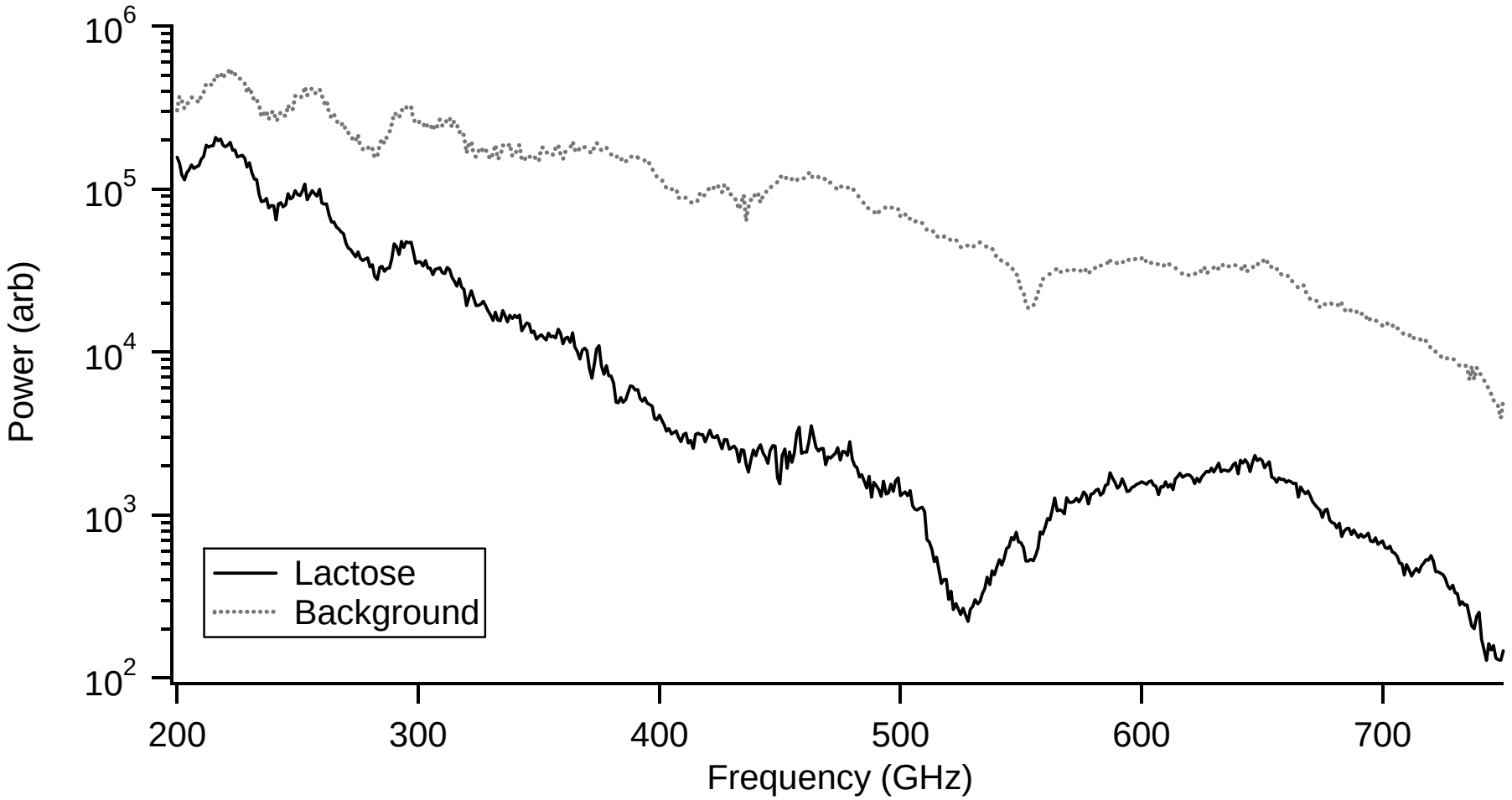


At 3dB point of fringe

At peak or null of fringe

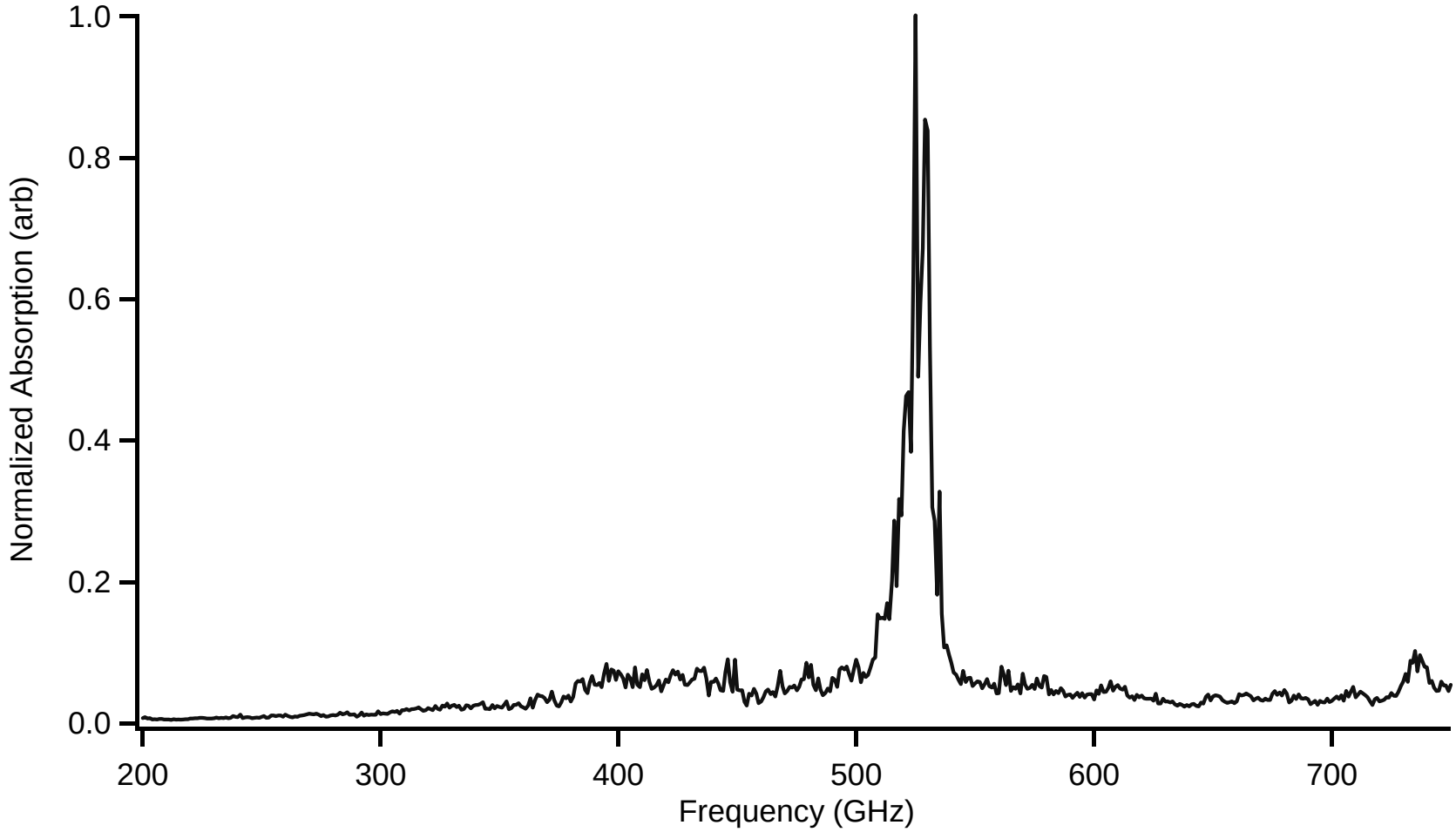
Spectrum of background and lactose sample

- System was employed to measure the spectrum of lactose powder (2 mm thick)
- 1st and 2nd harmonics were measured simultaneously and summed
- Single scan with 1 GHz resolution and 100 ms time constant ~ 1 min duration



Normalized spectrum of lactose

- No smoothing was performed
- Average of a single scan up in frequency and down in frequency
- Normalization eliminated the water line



Summary

- Demonstrated a CW THz spectrometer with integrated direct phase modulation and 1st and 2nd harmonic detection
- Demonstrated a CW THz spectrometer with a 5X decrease in the phase drift from scan to scan
- Demonstrated that the scan took the same amount of time as a normal scan with the same resolution and time constant
- Future work to decrease lithium niobate phase modulator insertion losses and thereby increase optical/THz power levels
- Demonstrate in the future that technique will work with a 1 X 1 PM
- Demonstrate in the future that measurements are independent of fringe spacing and resolution

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