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Employing phase modulation and second harmonic nulling to eliminate the interference fringes from the spectrum of a portable coherent frequency-domain THz spectrometer

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Outline

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- Approach
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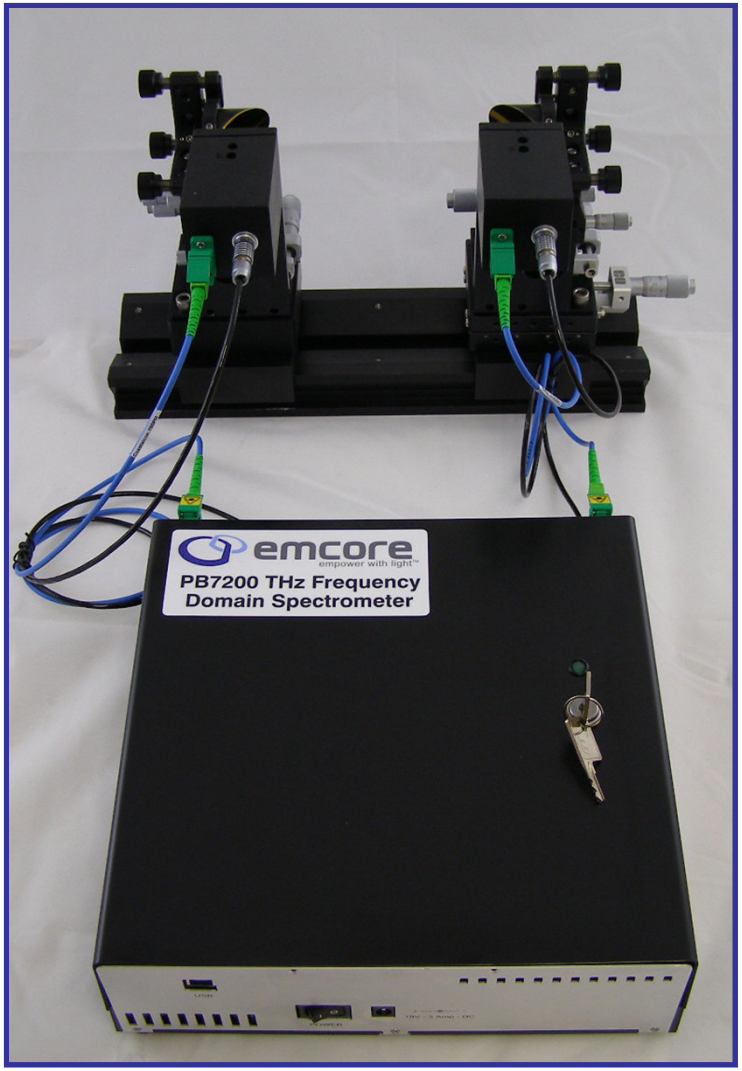
- Future work
- Summary

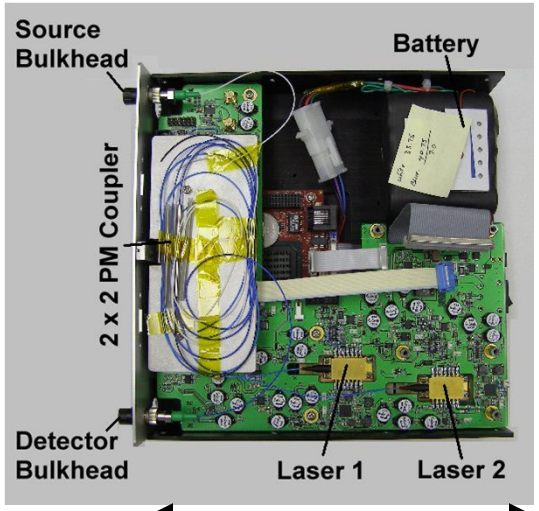


Motivation

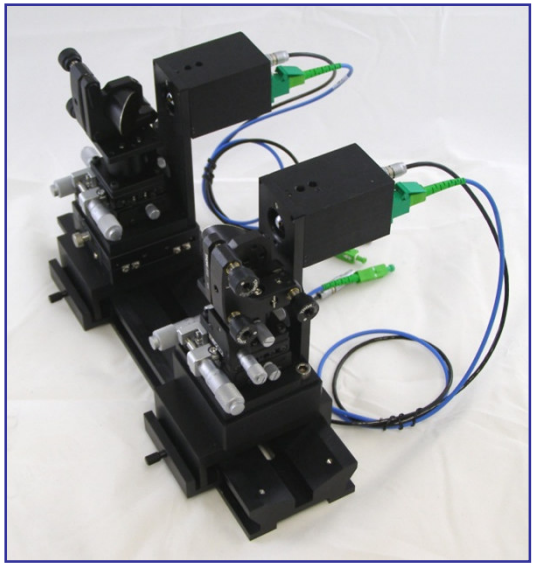
- **Develop a portable low-cost frequency-domain THz spectrometer**
  - Characterization of explosive and precursor materials in the field
  - Non-contact reflection modality
- **Investigate optical control of terahertz phase**
  - Mitigate the effect of interference fringes in data sets
  - Mitigate the effect of changing interference fringes in non-contact measurements
- **Design-for-cost approach**
  - Utilize telecom photonic packaging for low-cost and high reliability
  - COTS fiber-optic components and low-cost DSP-based electronics
  - Custom Lithium Niobate 850 nm optical phase modulator

Compact Spectrometer

- **Turn-key, high-performance system**
  - Two-piece design for maximum flexibility in wide range of applications
- **Fiber-coupled source/detector**
  - Transmission-mode system shown
  - Integrated detector pre-amp for low noise
  - Fully detachable for easy positioning
- **Laser / Processor unit**
  - Houses lasers and tuning/data collection electronics
  - Lithium Niobate phase modulator
  - Custom low-power DSP board
  - Weighs less than 4.5 kg (10 lbs)

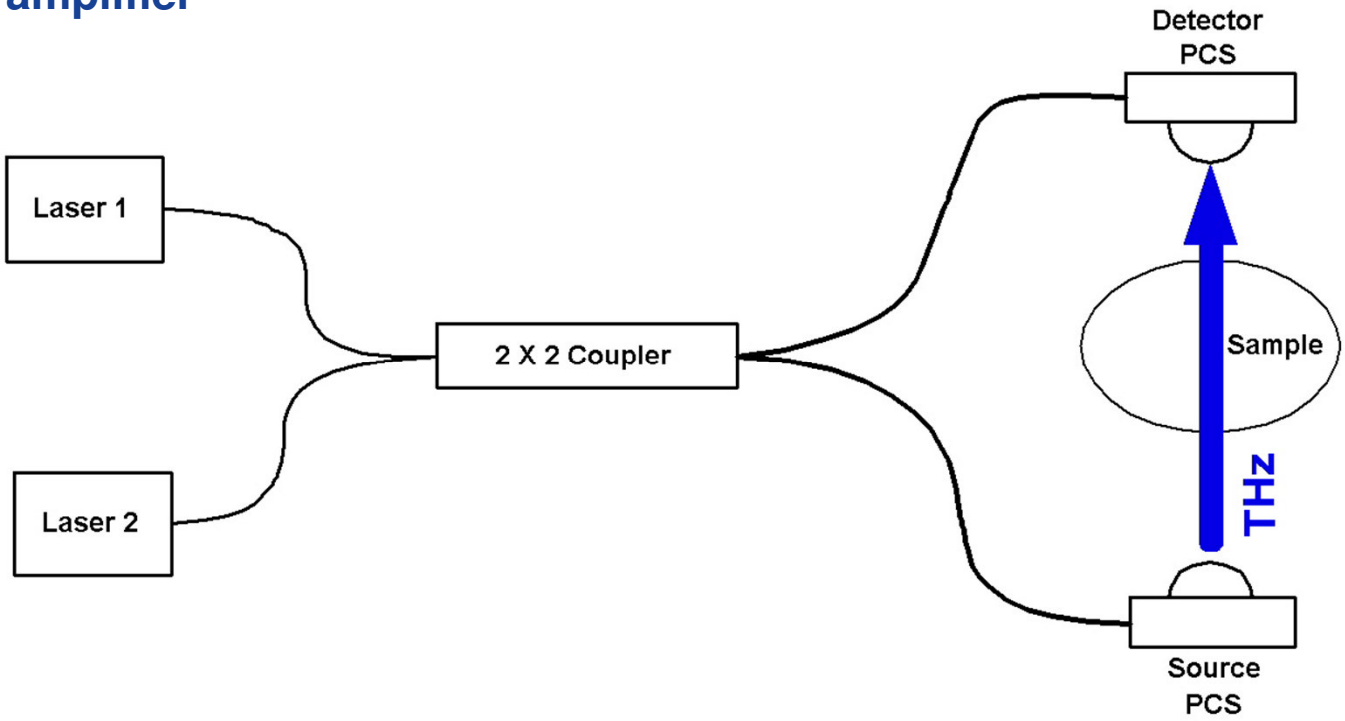


8 inches



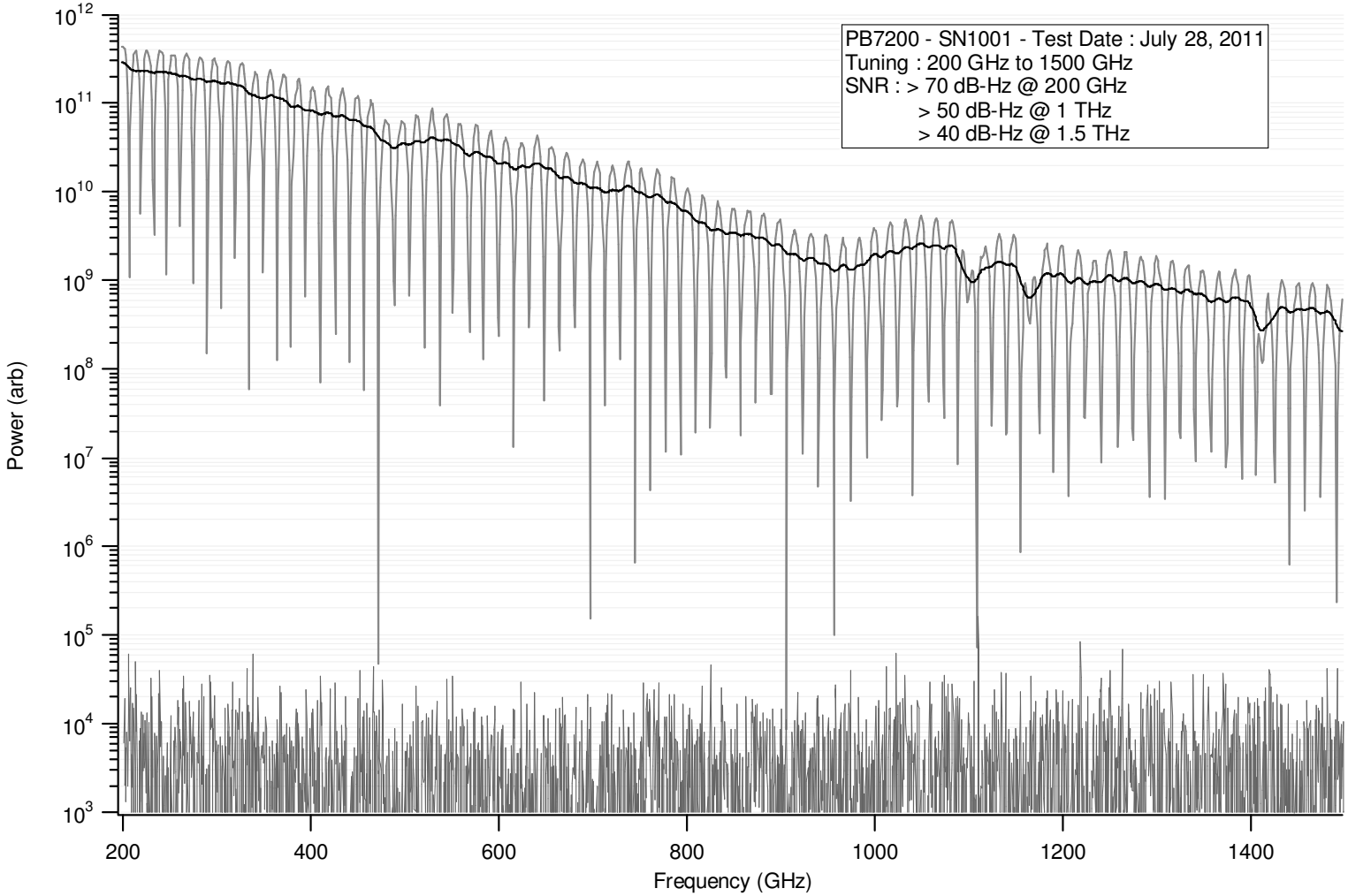
Approach

- Coherent spectrometer configuration using GaAs-based lasers and photomixers
- Heterodyned semiconductor DFB lasers (783 or 855 nm)
- Tuning range of over 2 THz (~480 GHz/nm at 783 nm)
- THz beat note modulates conductance of source and detector photomixers
- Low-cost fiber-optic packaging and single-mode polarization-maintaining fiber
- Source photomixer bias modulated at 6 kHz enabling homodyne detection with lock-in amplifier



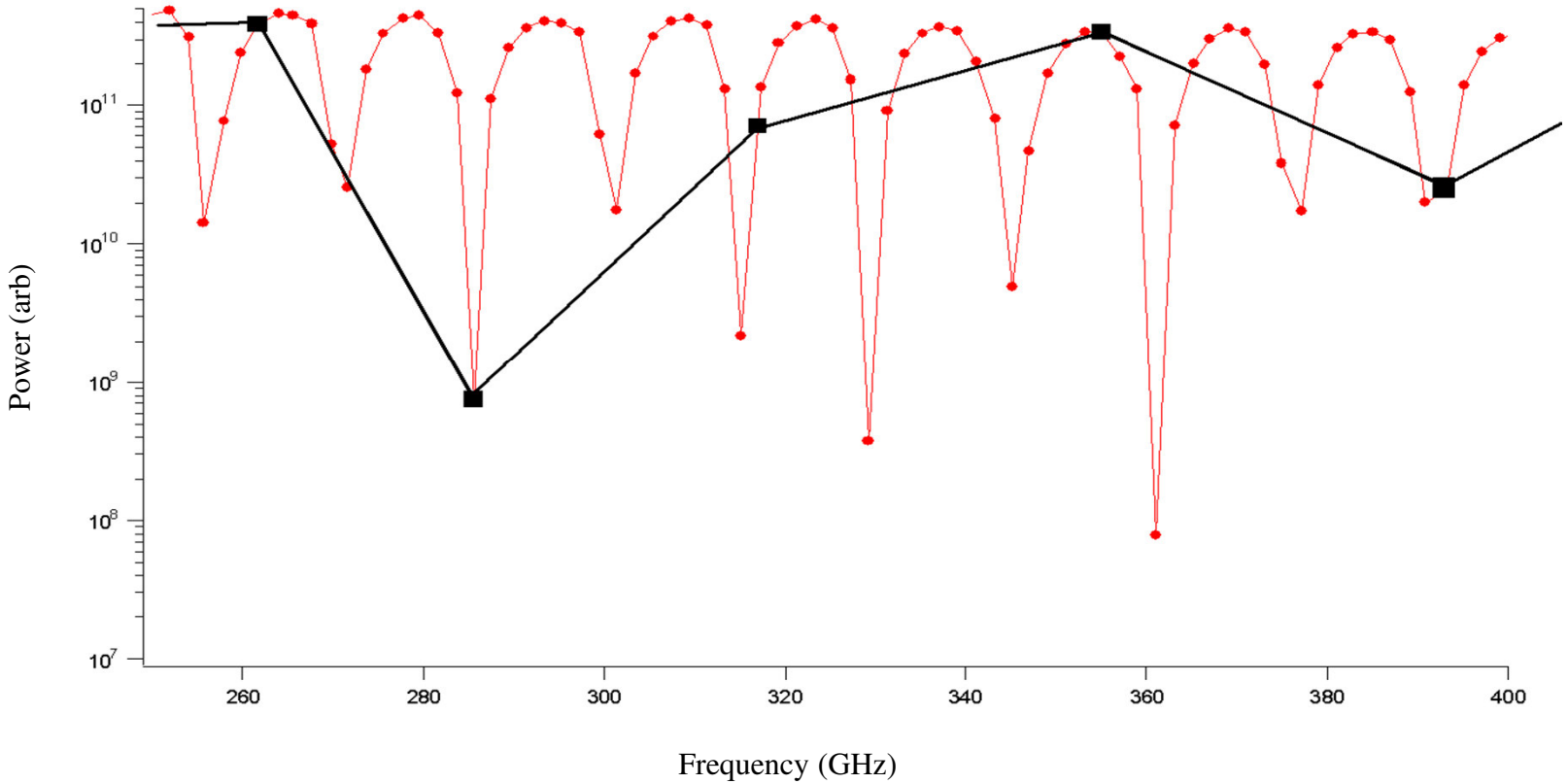
Spectrometer scan of lab air

- Interference pattern caused by coherent detection
- Smoothing eliminates fringe pattern, broad absorption features may be seen
- Smoothing reduces resolution and discards phase information and decreases resolution



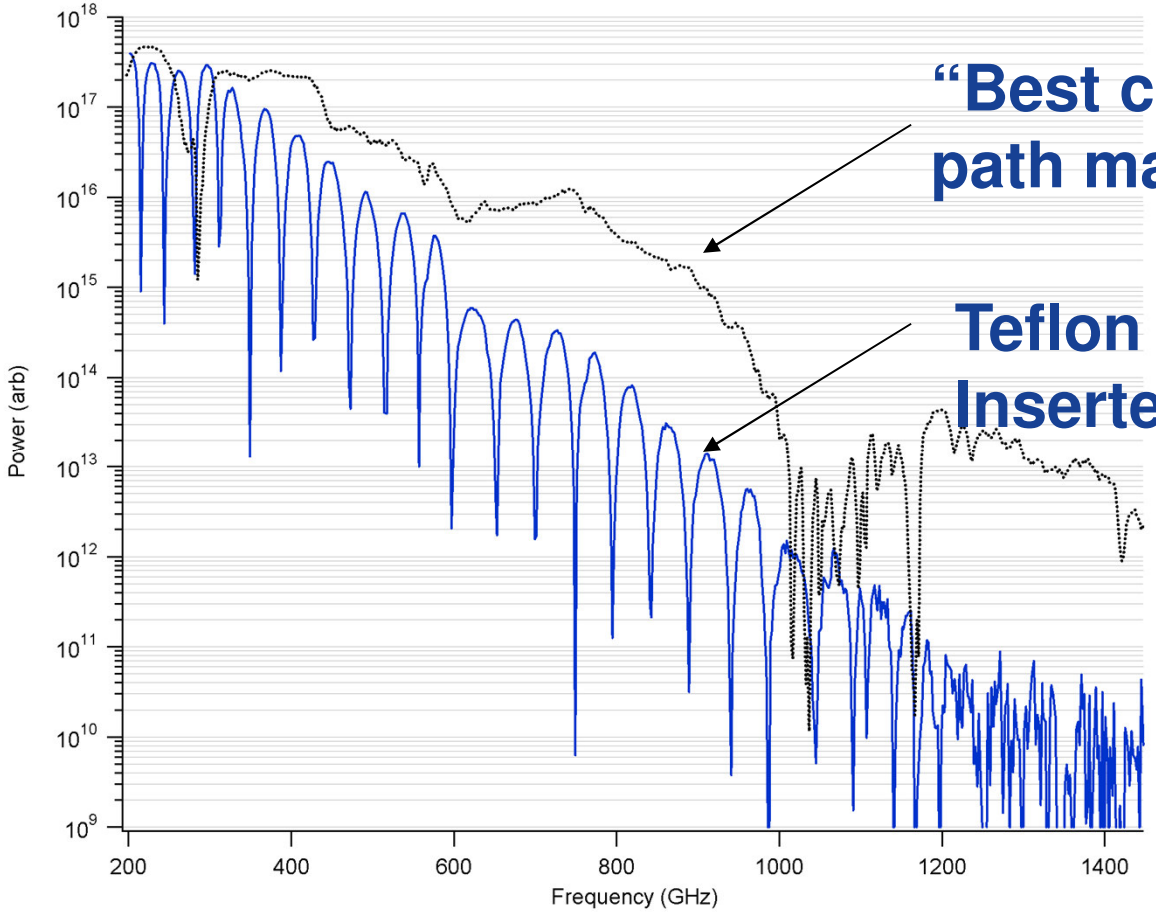
The problem with coherent detection

- Fringes negatively impact scanning speed and system performance
- Must completely resolve the fringes and therefore take high resolution scans when fringe spacing is short regardless of desired resolution
- Low resolution scans not possible without amplitude variation



Sample induces path-length changes

- Introduction of sample changes fringe spacing making background subtraction impossible

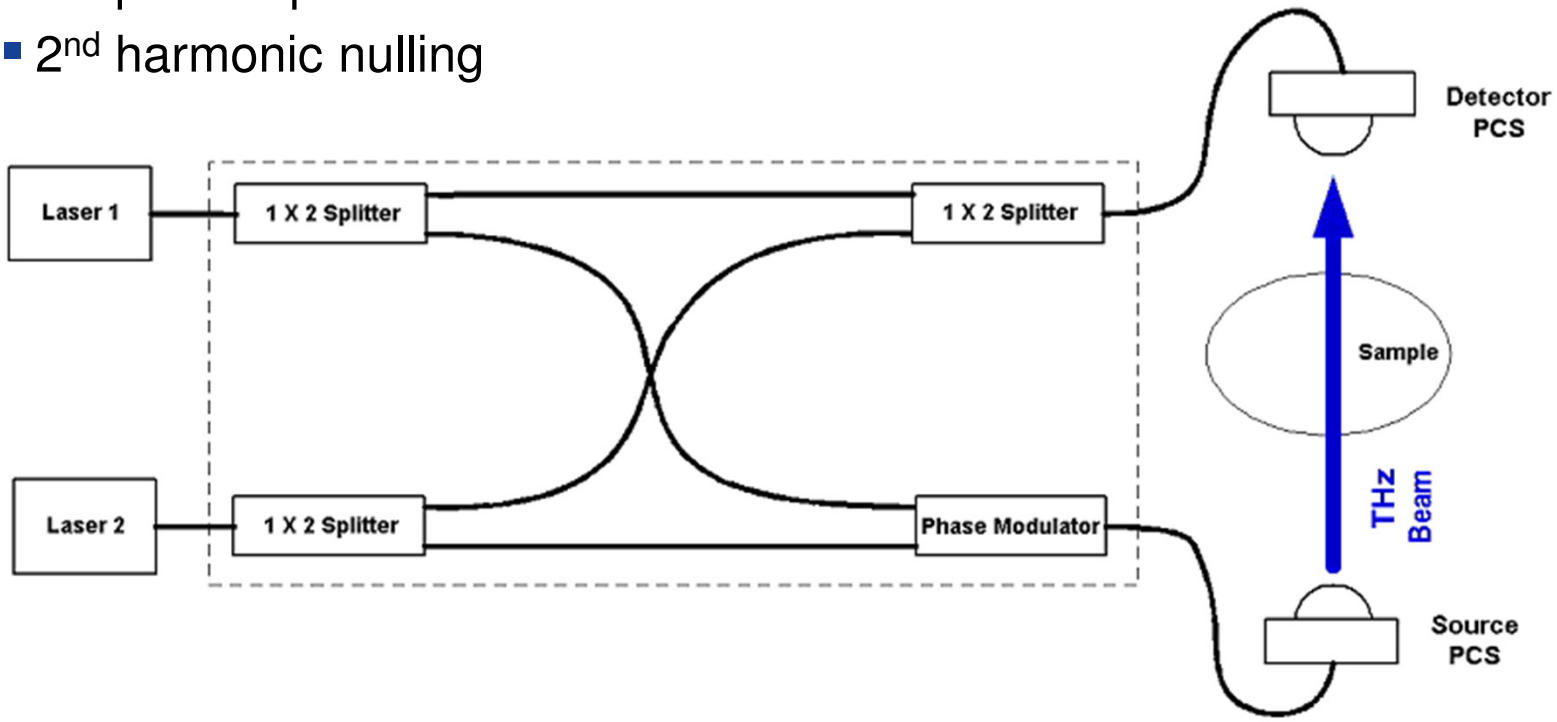


"Best case" path matching

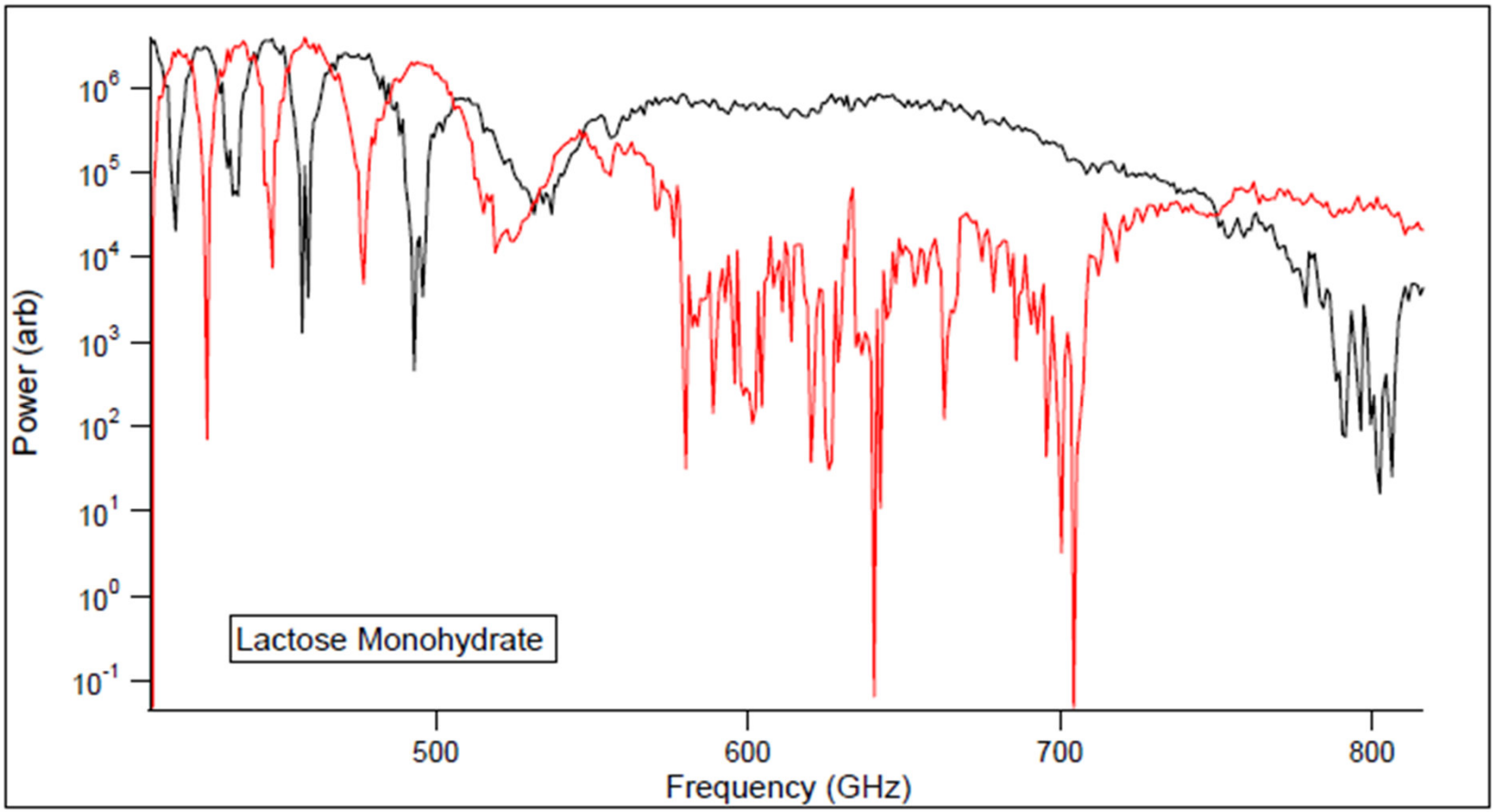
Teflon sample-holder Inserted - unmatched

Optical phase control

- Use 1 x 2 lithium-niobate optical phase modulator to control relative optical phase prior to heterodyne combination
- Differential phase shift between the lasers on the source photomixer results in an equivalent terahertz phase shift
- Two techniques for fringe removal
  - Sequential phase shift
  - 2nd harmonic nulling

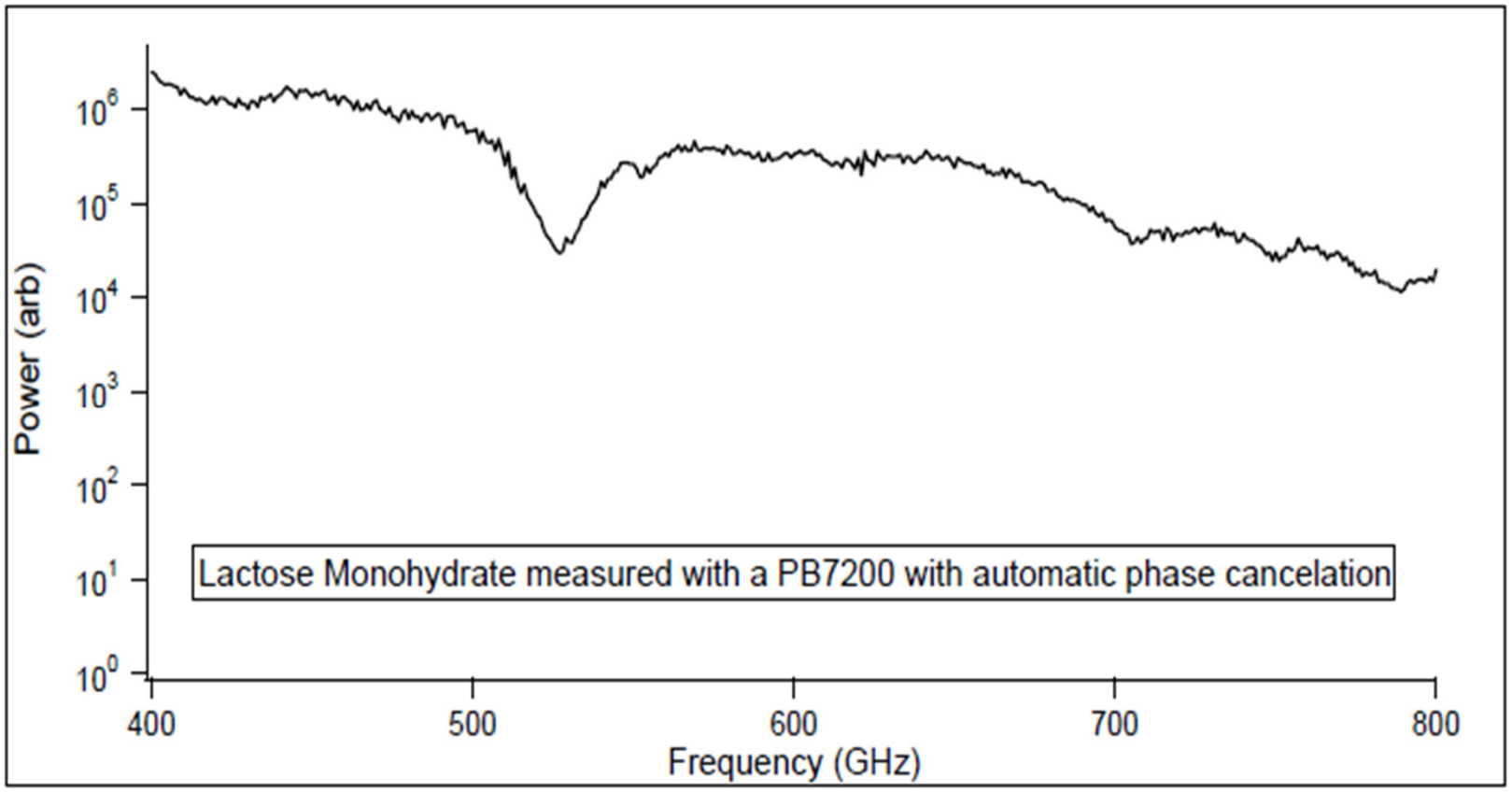


Lactose monoydrate : sequential



- A single scan of lactose monohydrate.
- Black trace is 0° phase offset while the red trace is 90° offset. Each data-point was taken sequentially switching between phases.

Lactose monoydrate : sequential



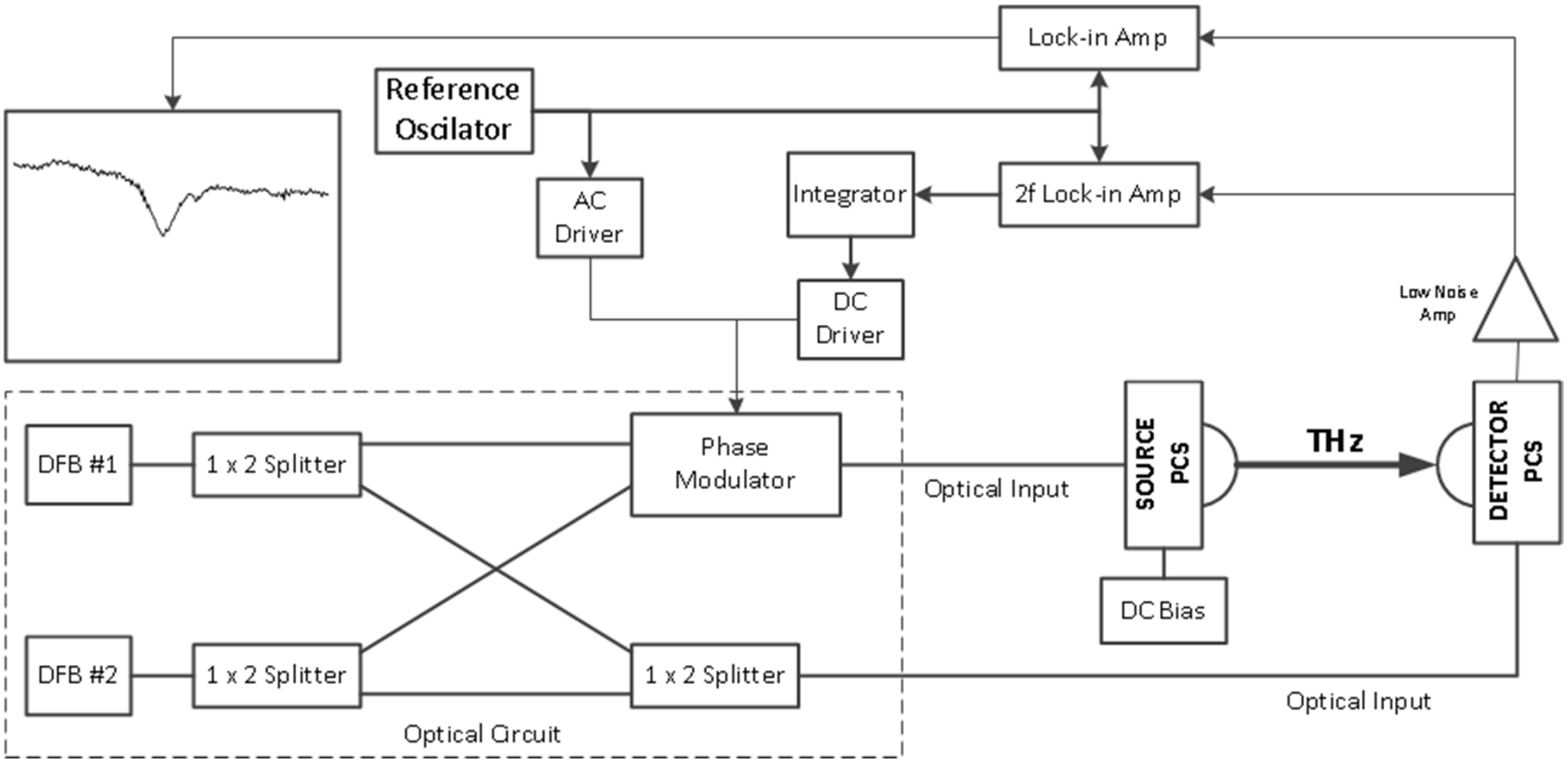
- The summation of the 0° phase offset and the 90° offset results in the almost complete removal of the interference pattern.
- No smoothing

Sequential 90 Degree Phase Shift Technique

- **Summation of the 0 and 90 phase shifted power results in fringe-free power**
- **Benifits:**
  - Removes interference pattern
  - Easy to implement with current system
  - Easy to determine bias corresponding to 90 degree
  - Take data point with modulator off, take data point with it on
- **Limitations:**
  - Not as effective with tight fringes
  - Still can't effectively do the large step, low resolution scans
  - Scans take twice as long

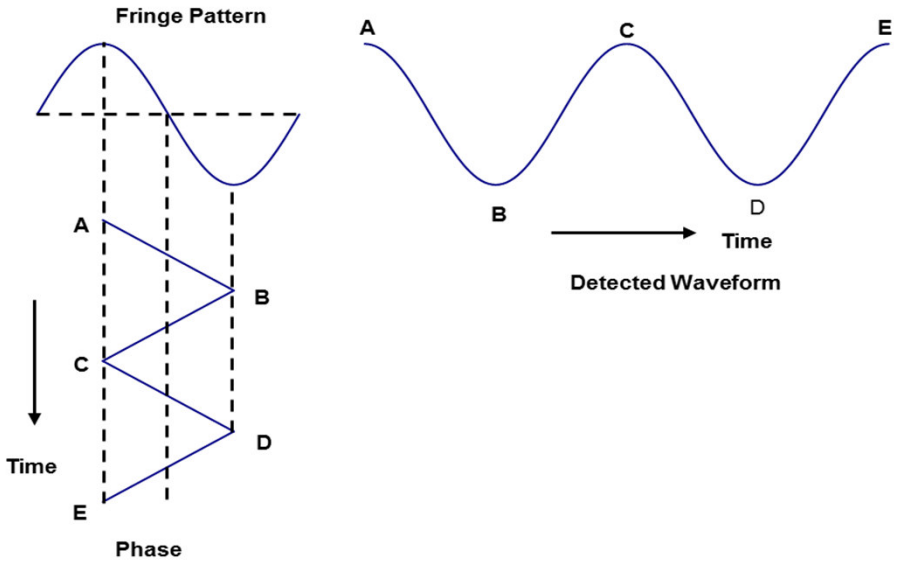
Schematic for 2nd Harmonic Nulling

- Required revision to the electronics and custom DSP programing
- DC bias on the source PCS
- Triangle wave bias on the phase modulator

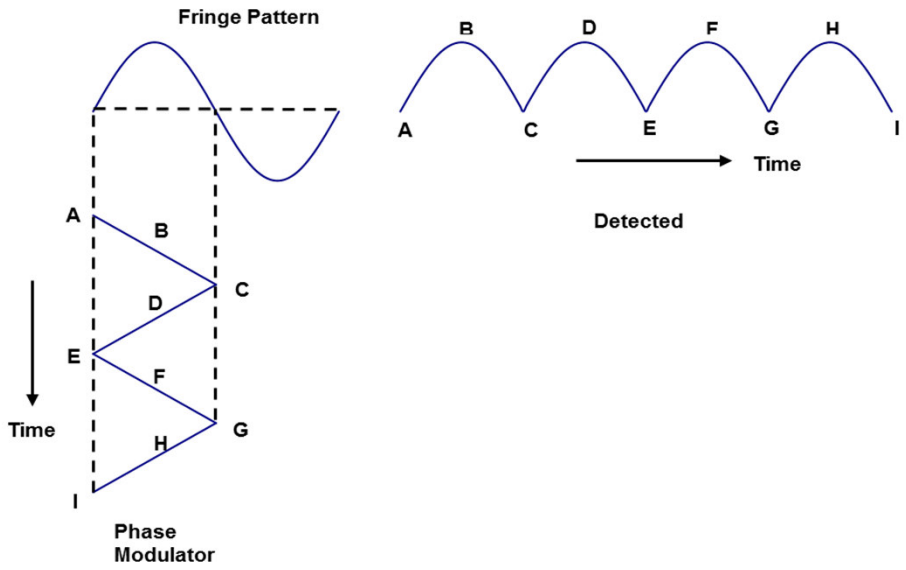


The Source of the 2nd Harmonic

- Balanced condition results in no second harmonic
- Un-unbalanced condition results in second harmonic

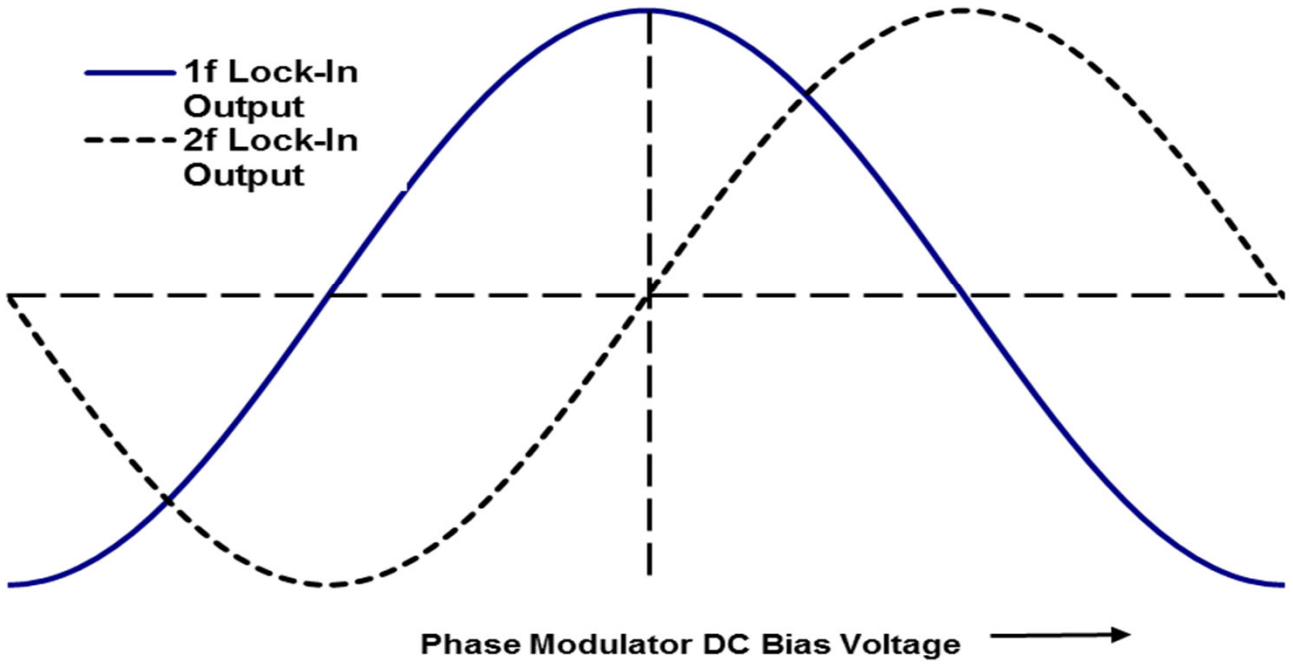


Balanced condition



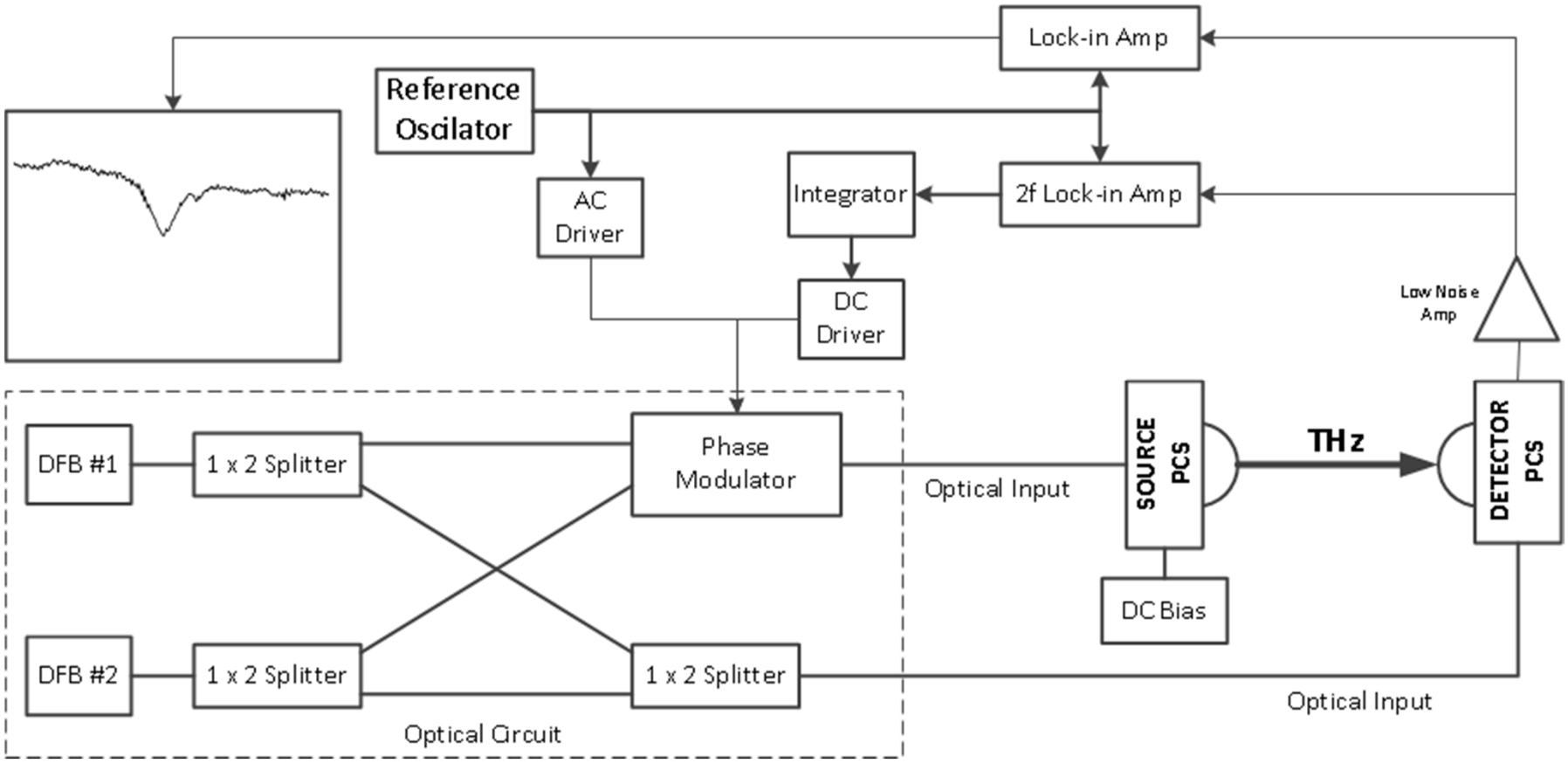
Un-balanced condition

Maintaining balance



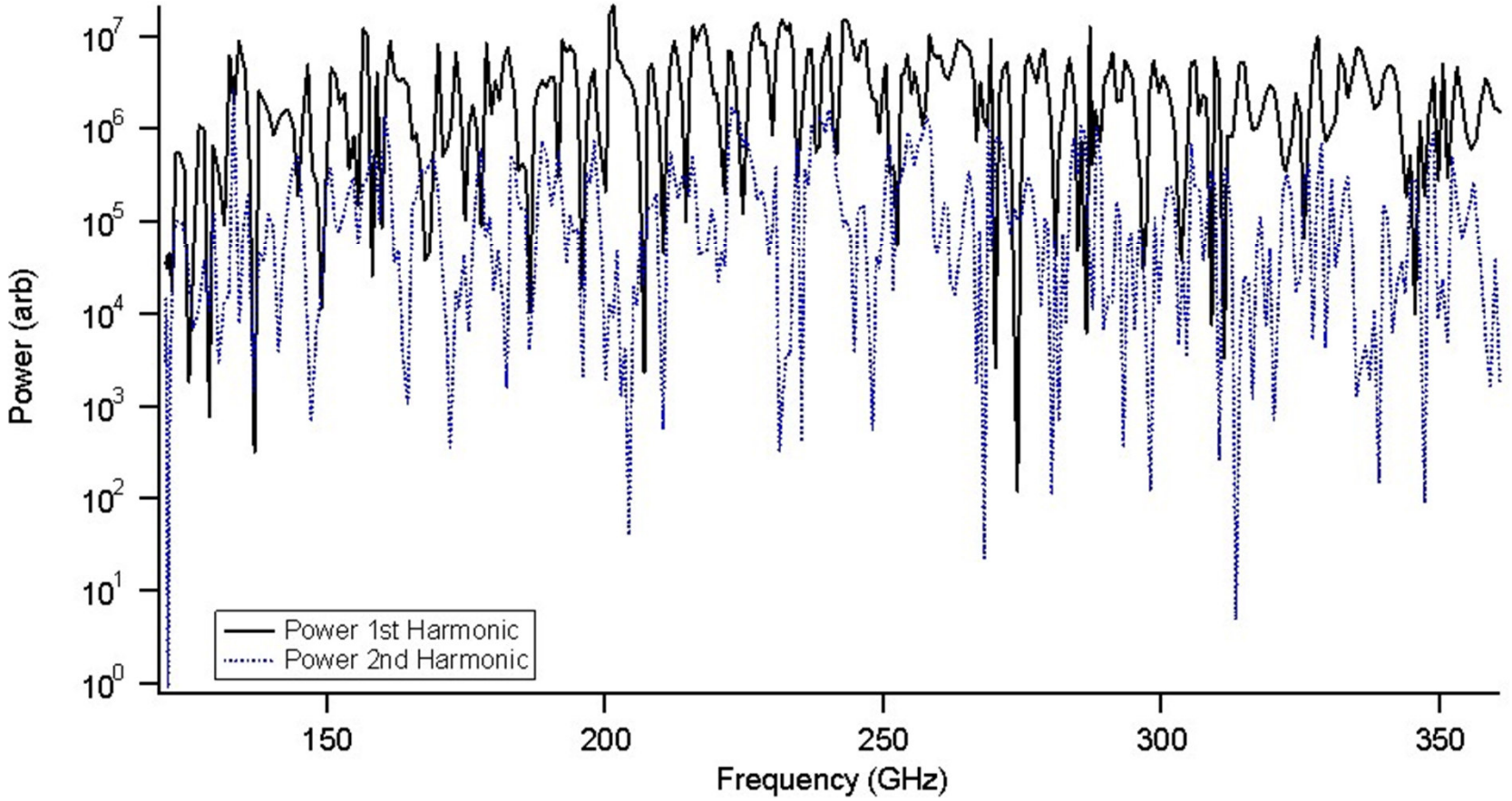
- The first and second harmonics as a function of bias voltage on the optical phase modulator

Schematic for 2nd Harmonic Nulling



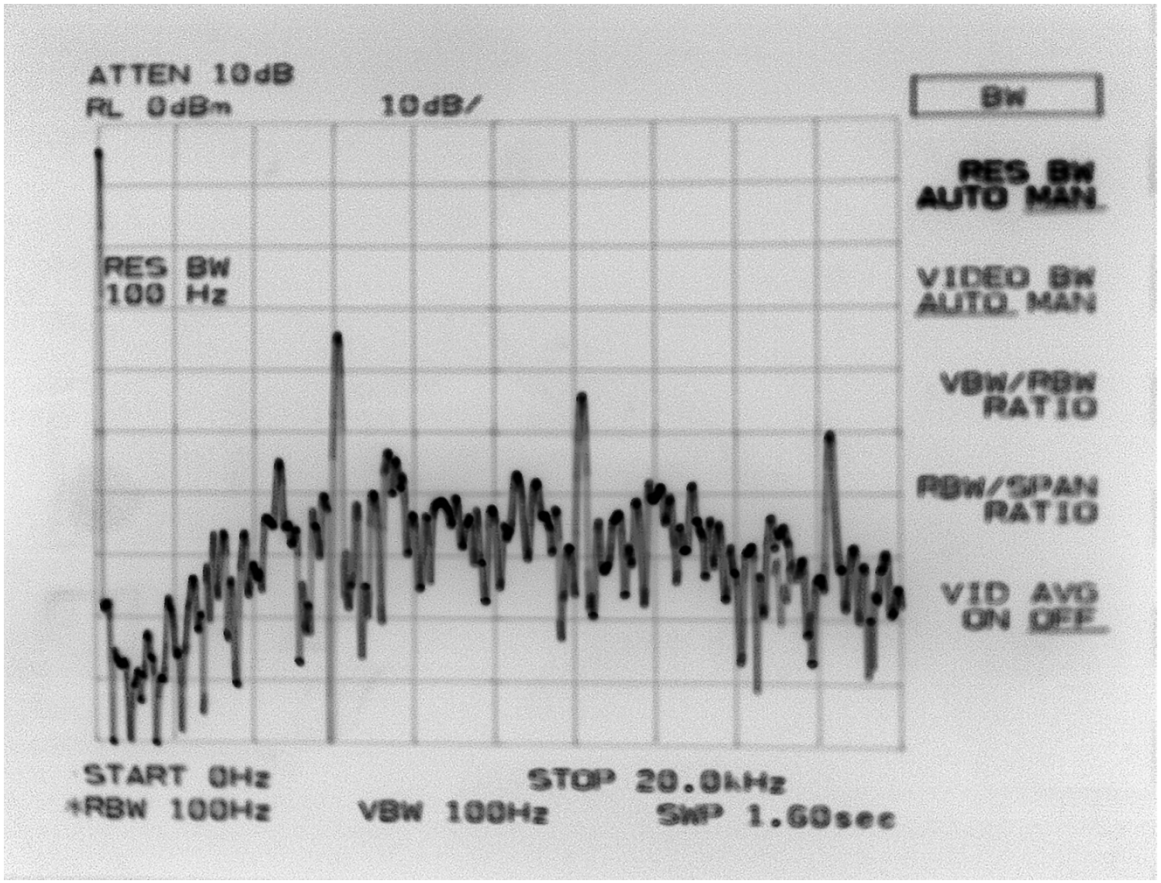
2nd Harmonic Nulling Results

- Plot 1st harmonic and 2nd harmonic
- Expected similar results as with sequential phase shifting
- Noise



Frequency Modulation

- Detach source PCS from optical input and connect to photodiode
- Multiple FM terms present – shouldn't be there!
- Back reflections from photomixers + phase modulation = frequency modulated lasers



Summary/Future Work

Summary

- Successfully demonstrated sequential phase shifting as a method to remove the interference fringes
- First attempt and 2nd harmonic nulling resulted in frequency modulating the lasers

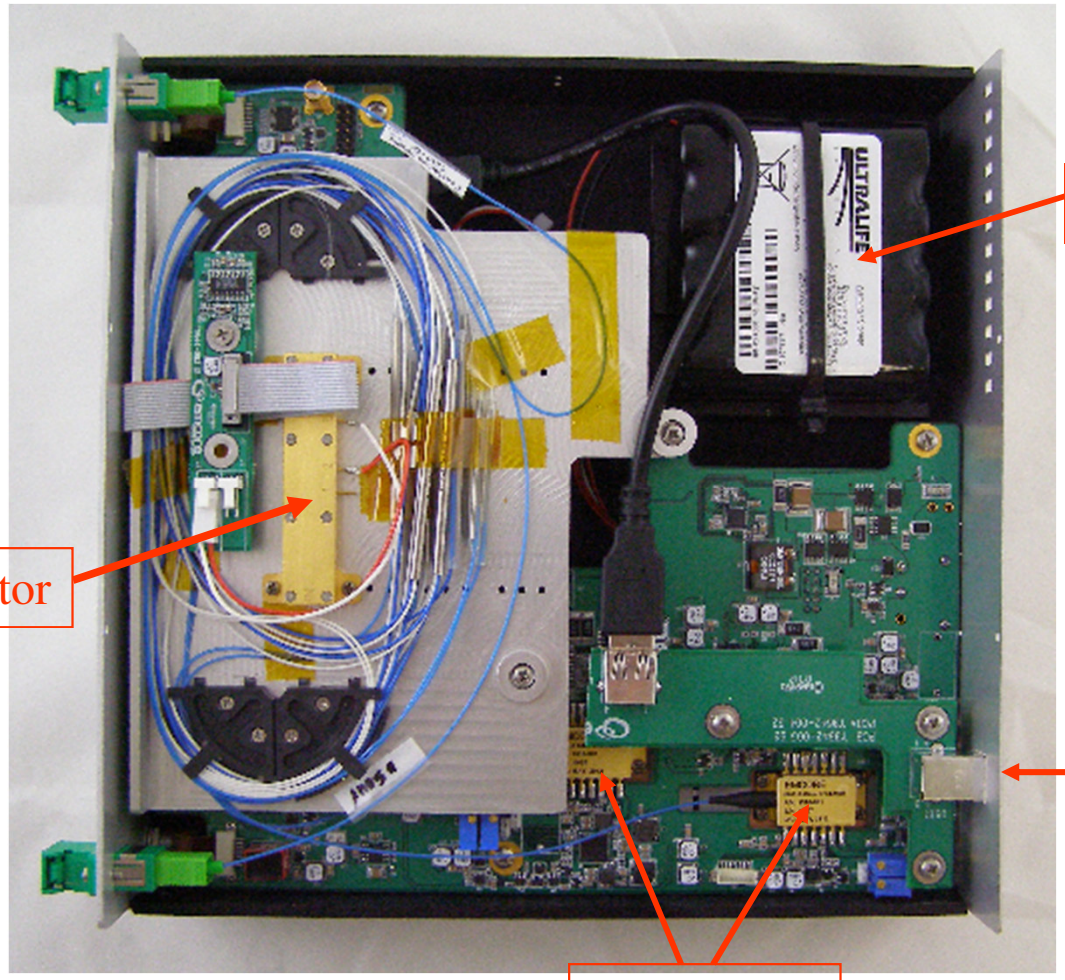
Future

- Improve optical isolation in the lasers and implement 2nd harmonic nulling
- Improve phase modulator insertion loss from 5 dB to less than 3 dB
- Transfer software from the computer to the DSP making system faster

- Acknowledgements:
  - NAVEODTECH, Indian Head MD

- For more information, visit EMCORE booth:
- Joseph R. Demers joe_demers@emcore.com

PB7200 picture



Issue with technique

- System changes frequency by temperature tuning lasers
- Integration happens during settling
- With current method greater frequency change occurs during un-shifted integration
- Likely an issue with large frequency steps

Exaggerated for illustration