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Integrated phase control on a portable coherent frequency-domain THz spectrometer

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Outline

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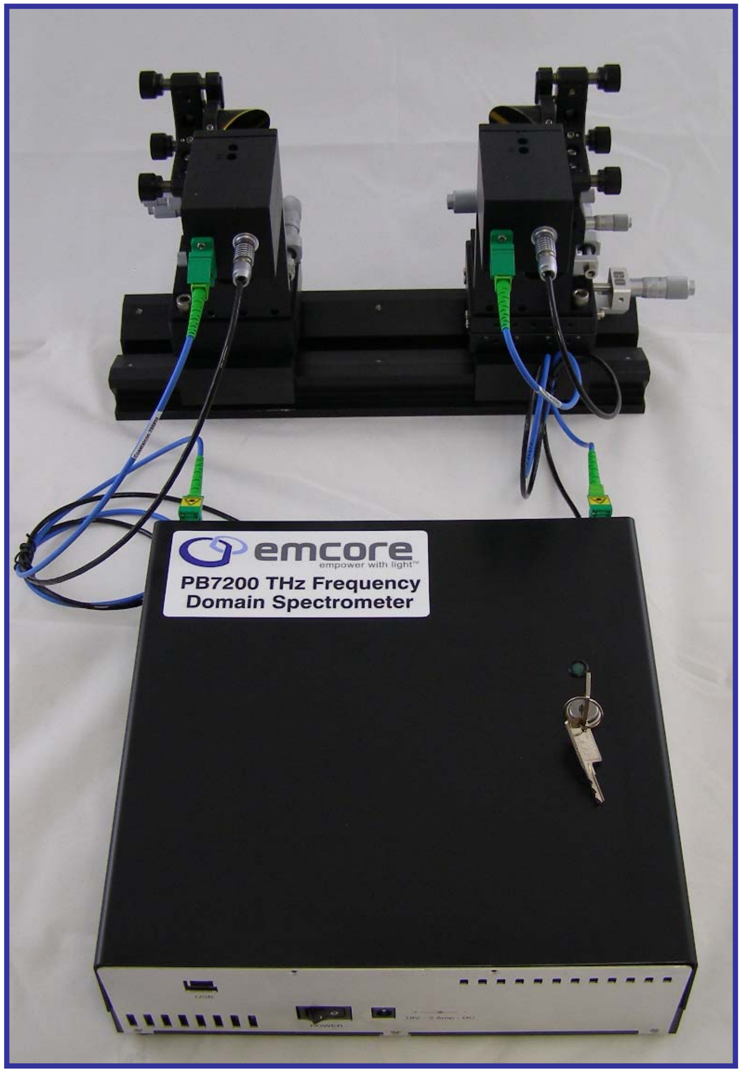
- Results
- Future work
- Summary



Motivation

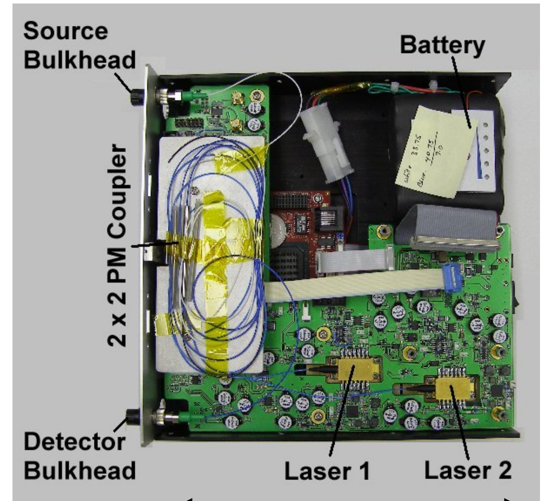
- **Develop and demonstrate a portable low-cost frequency-domain THz spectrometer**
  - Characterization of explosive and precursor materials in the field
  - Transmission-mode or Reflection-mode
  - Rechargeable battery, low-power electronics design
  - Utilize telecom photonic packaging for low-cost and high reliability

- **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
  - Enables collection of phase information and vector network analysis

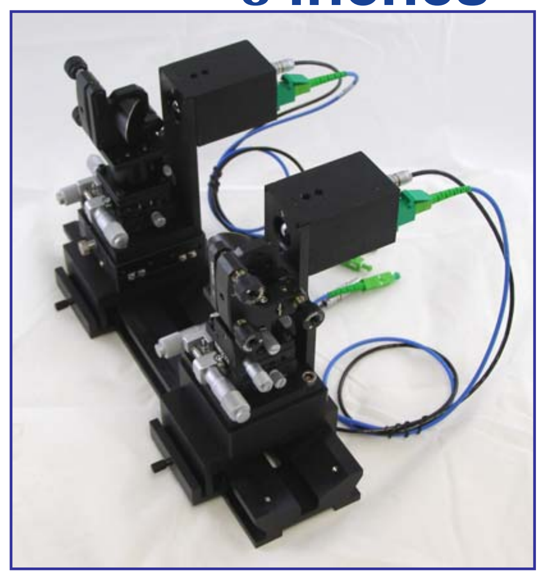
- **Design-for-cost approach**
  - Leverages volume telecom packaging processes
  - COTS fiber-optic components
  - COTS computer and low-cost DSP-based electronics

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
  - Integrated phase control
  - Custom low-power DSP board
  - Weighs less than 4.5 kg (10 lbs)

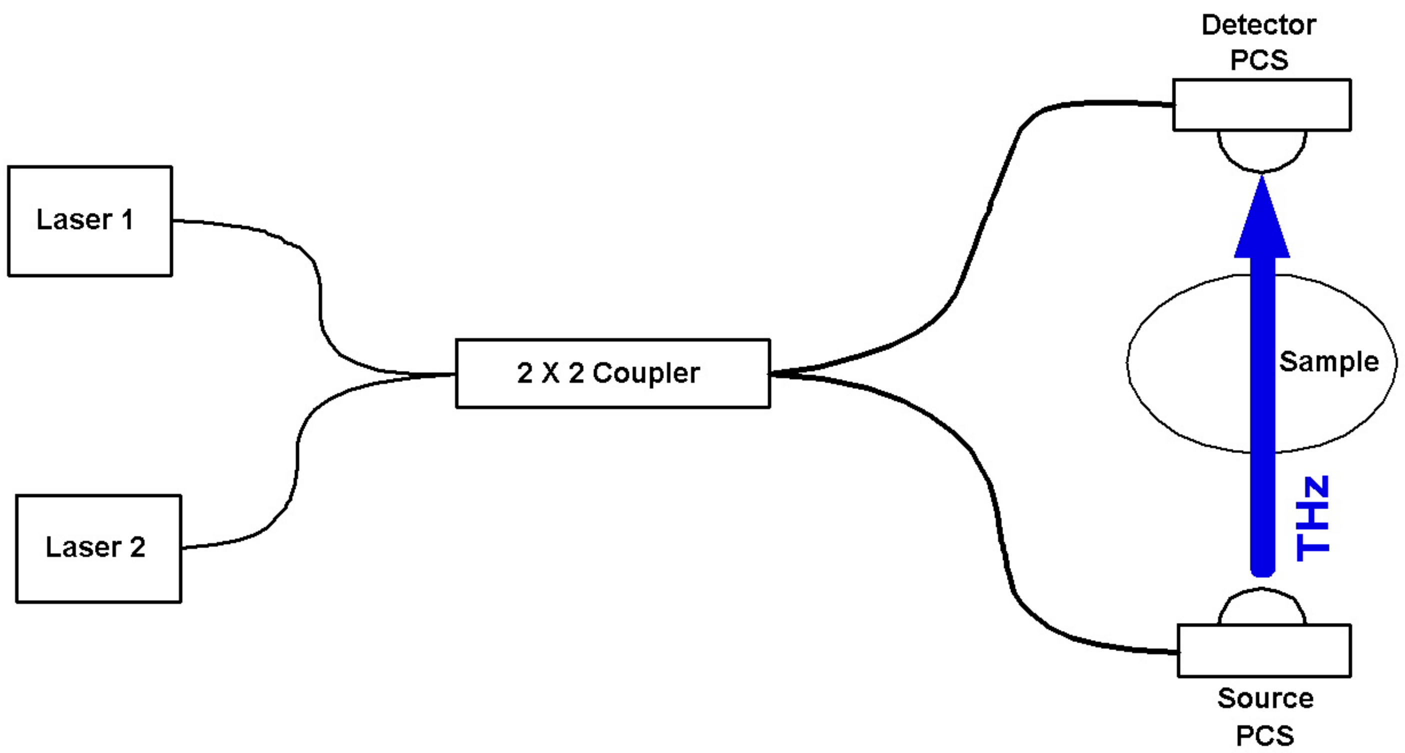


8 inches



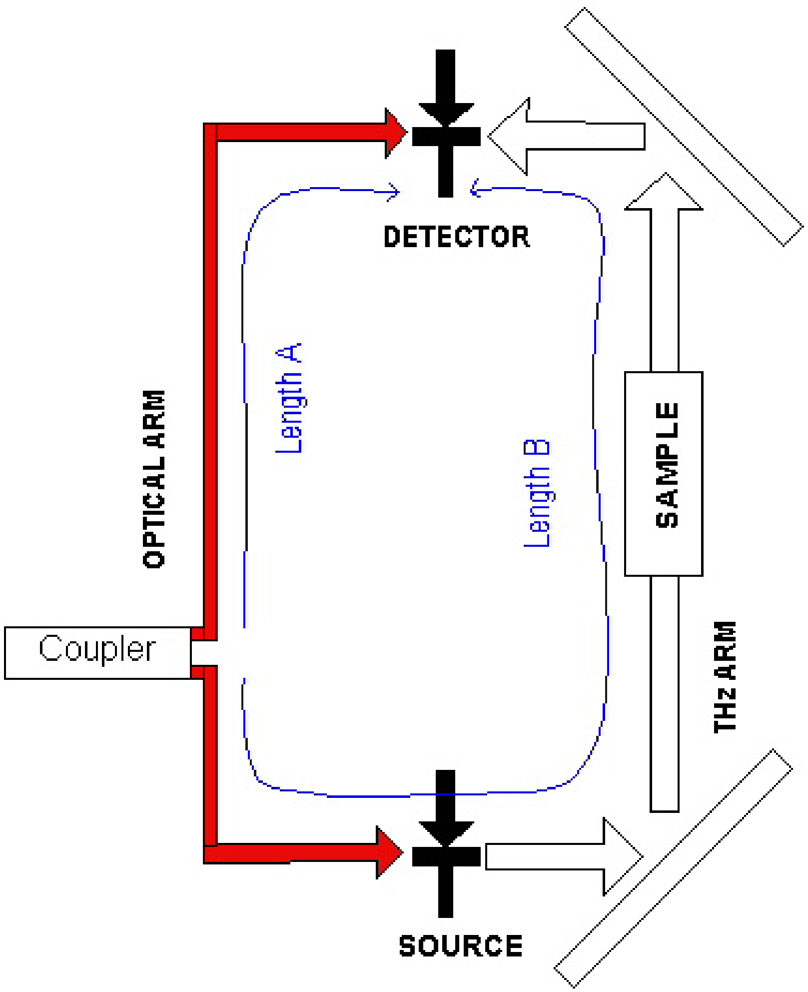
Approach

- **Coherent spectrometer configuration using GaAs-based lasers and photomixers**
  - Heterodyned semiconductor DFB lasers (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
  - Low-cost fiber-optic packaging and single-mode polarization-maintaining fiber



Coherent spectrometer is an interferometer

- **Interferometer is formed between output of heterodyne optical coupler and detector photomixer**



$$\left|L_A - L_B\right| = \partial L$$

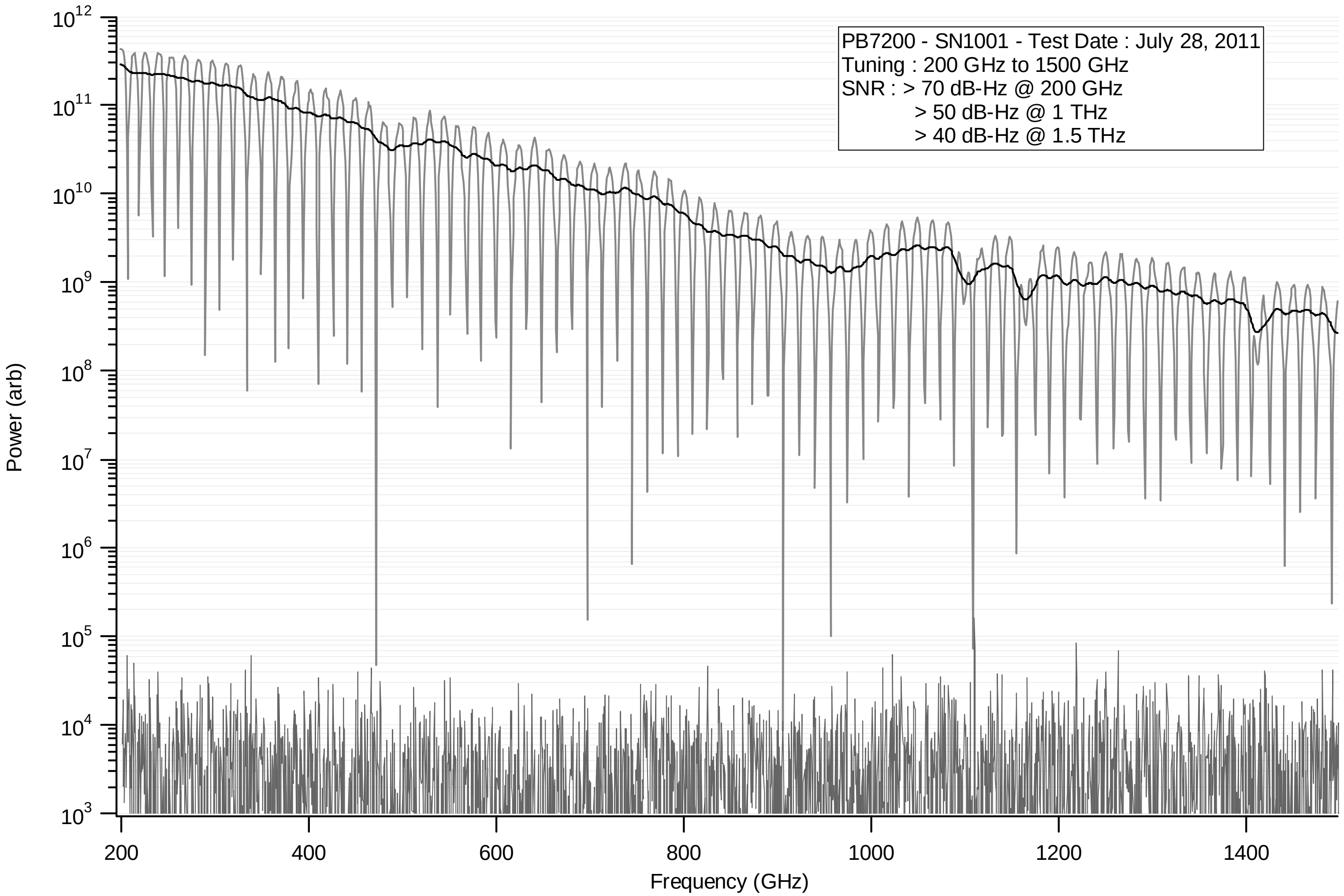
$$I_{out} \propto 1 + \cos(k \cdot \partial L)$$

$$k = \frac{2\pi\upsilon}{c} n_{eff}$$

Combined sample, photomixer, antenna and system path dispersion term

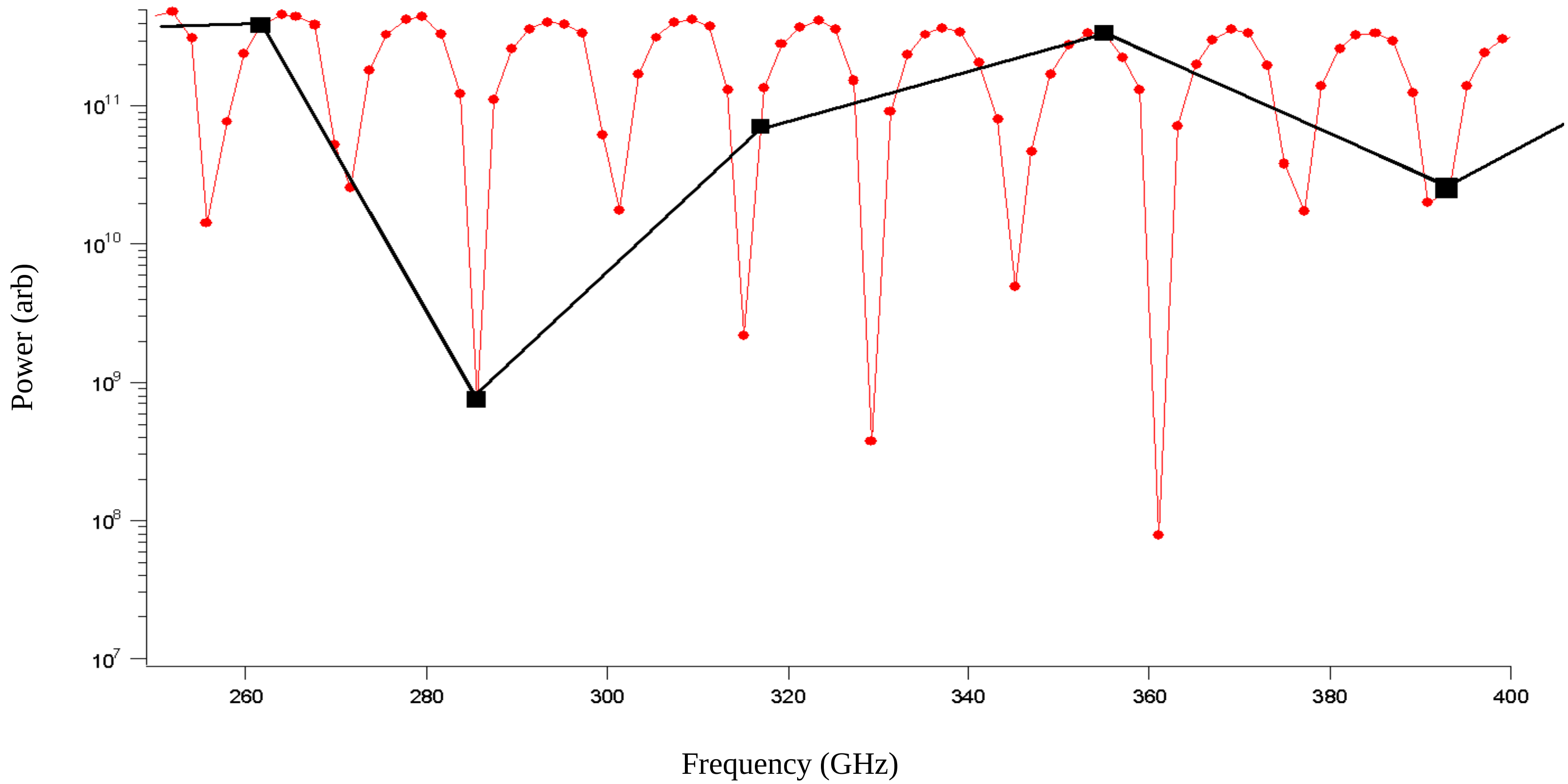
Spectrometer scan of lab air

- **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**



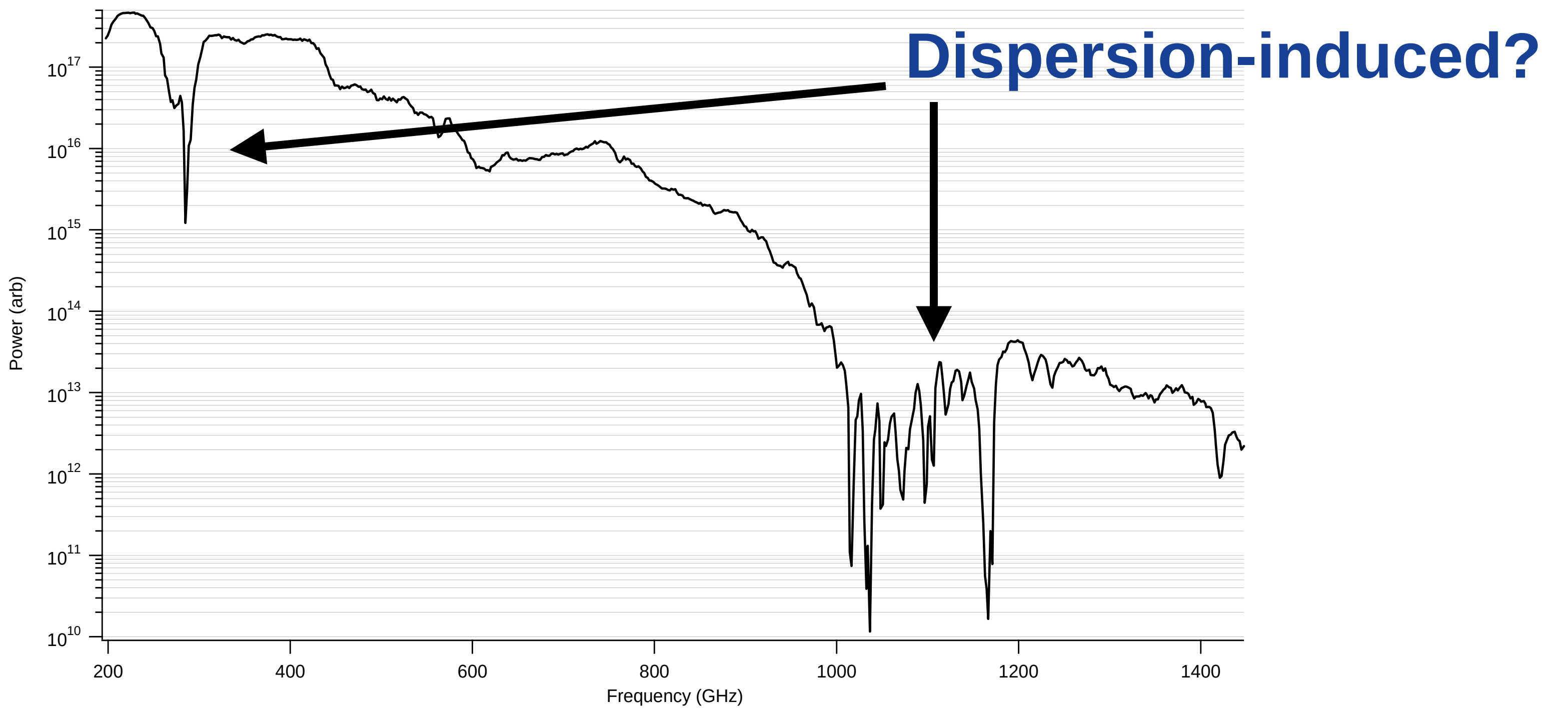
The problem with coherent detection

- Historically the fringe spacing has had a negative impact on 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
- Fast, low resolution scans not possible without significant amplitude variation



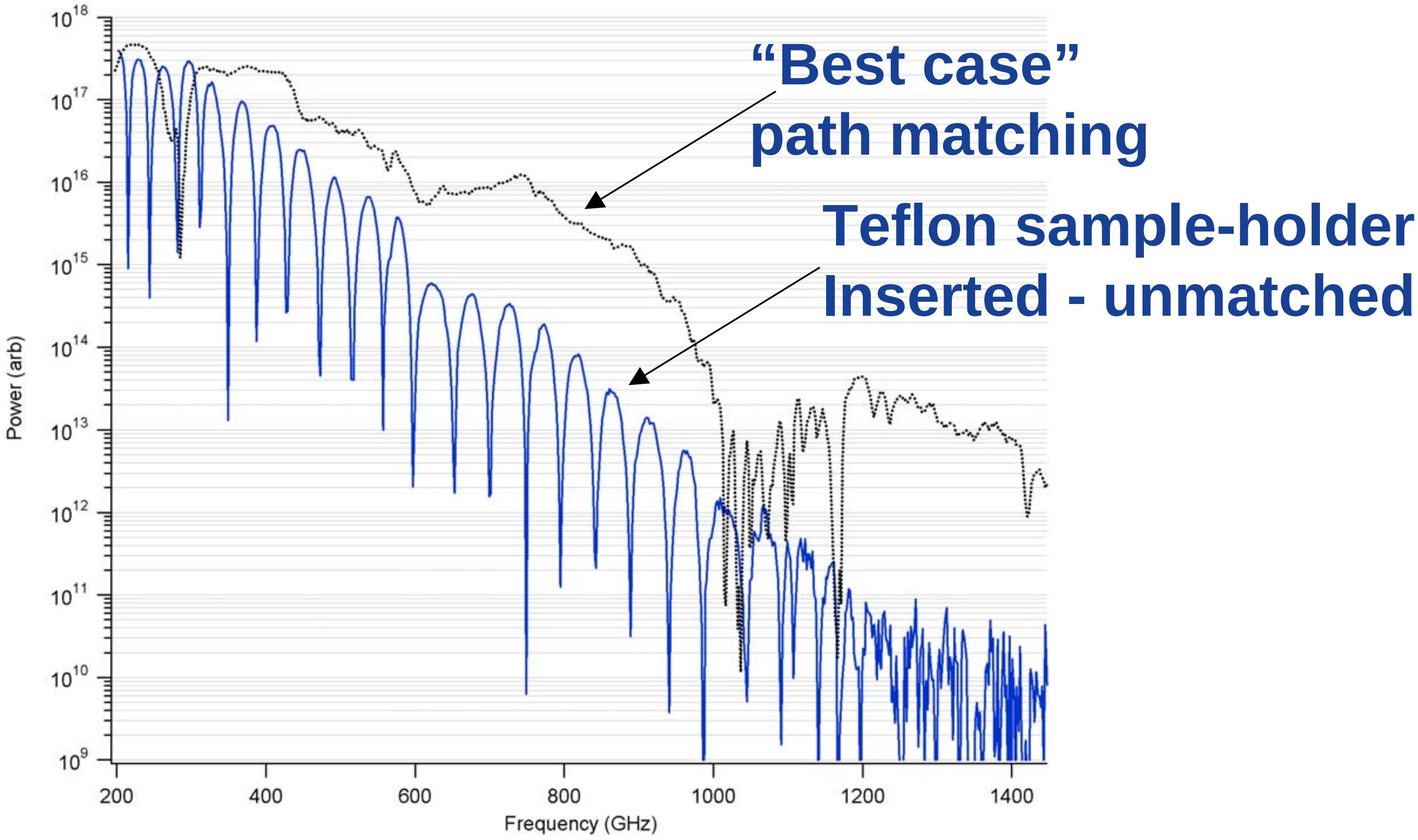
Solution 1: Matching pathlengths

- **Fringe pattern may be altered by physically changing relative path lengths**
- **Exact path matching should result in no interference fringes, but not achievable in practice**
- **Limited by dispersion?**
  - photomixers (antenna and material) and path (air)



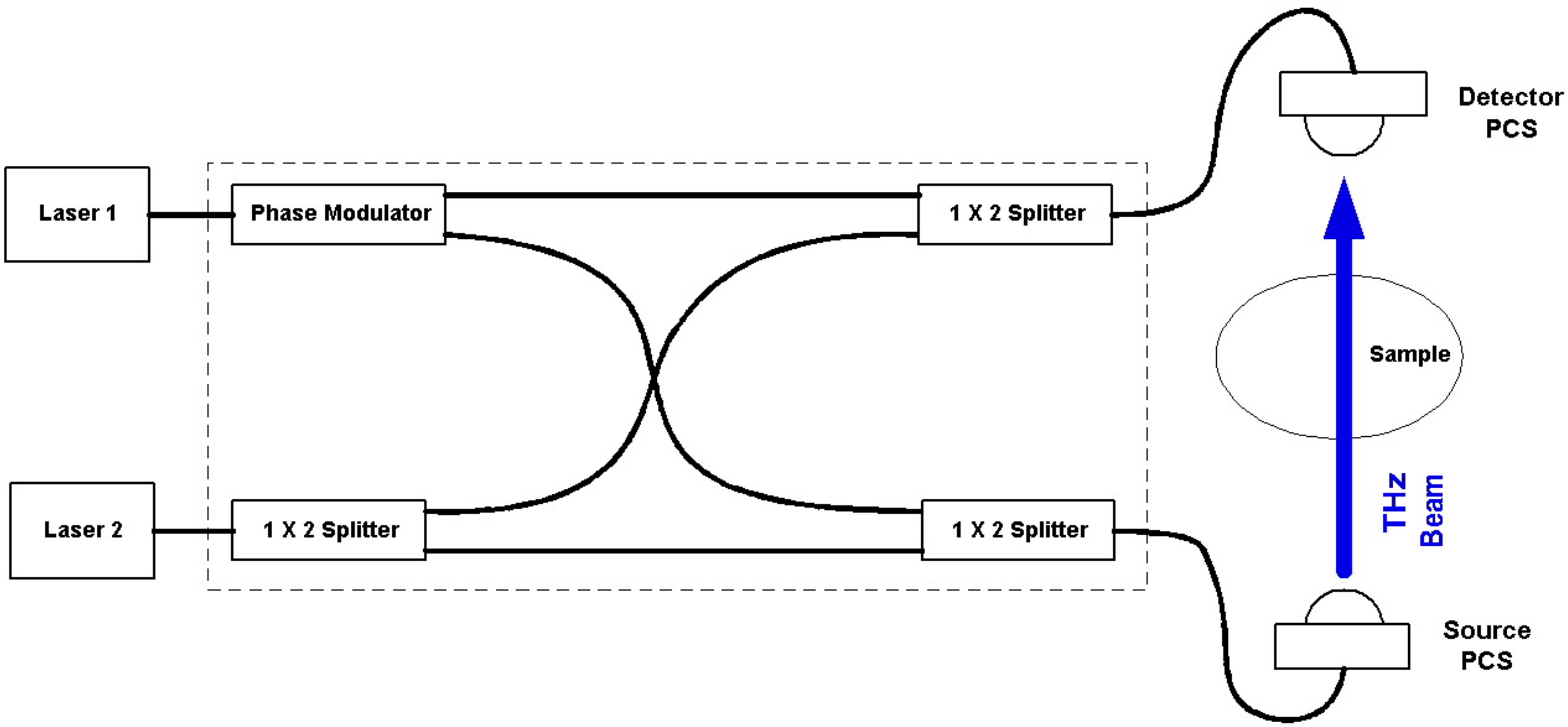
Sample induces path-length changes

- Insertion of empty Teflon sample cell results in path imbalance and interference fringes



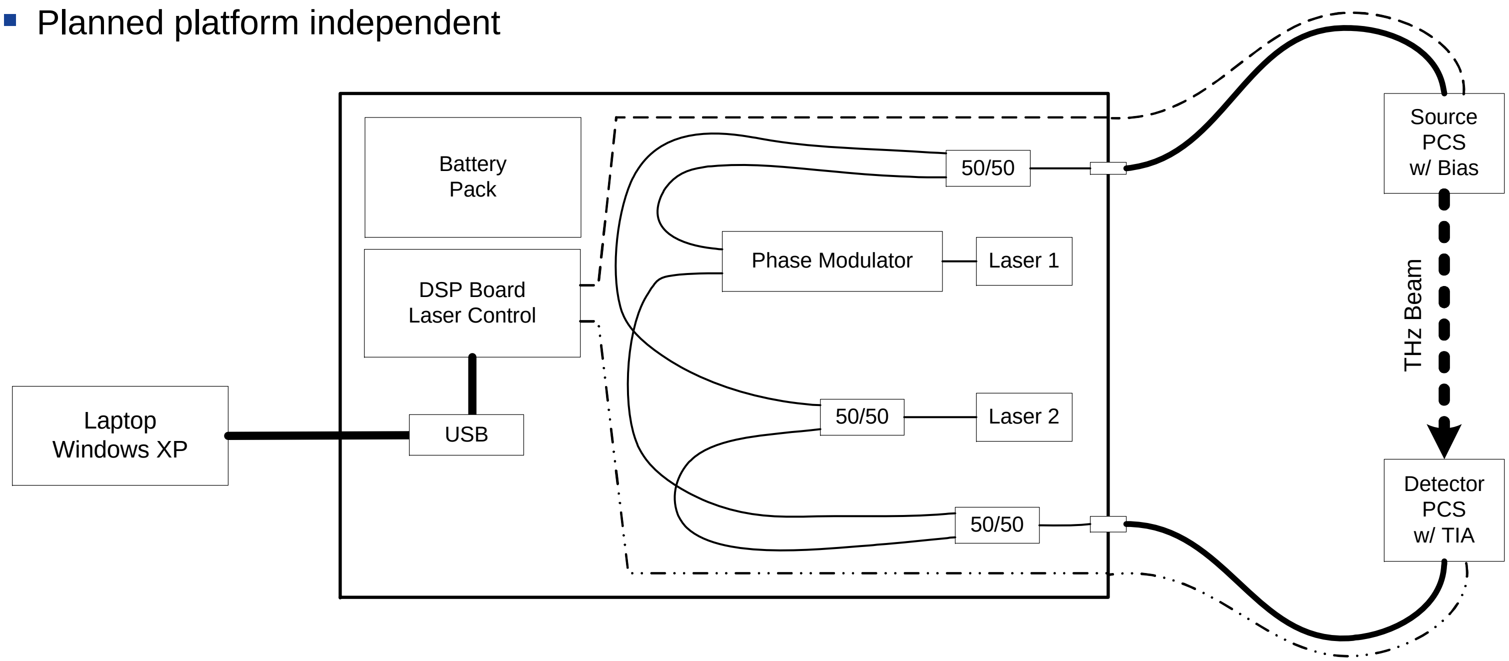
Solution 2 : Optical phase control

- Use 1 x 2 lithium-niobate optical phase modulator to control optical phase prior to heterodyne combination
- Laser phase shift causes terahertz phase shift
- Bias voltages less than 5 Volts
- Wideband operation with no moving parts or high-power components

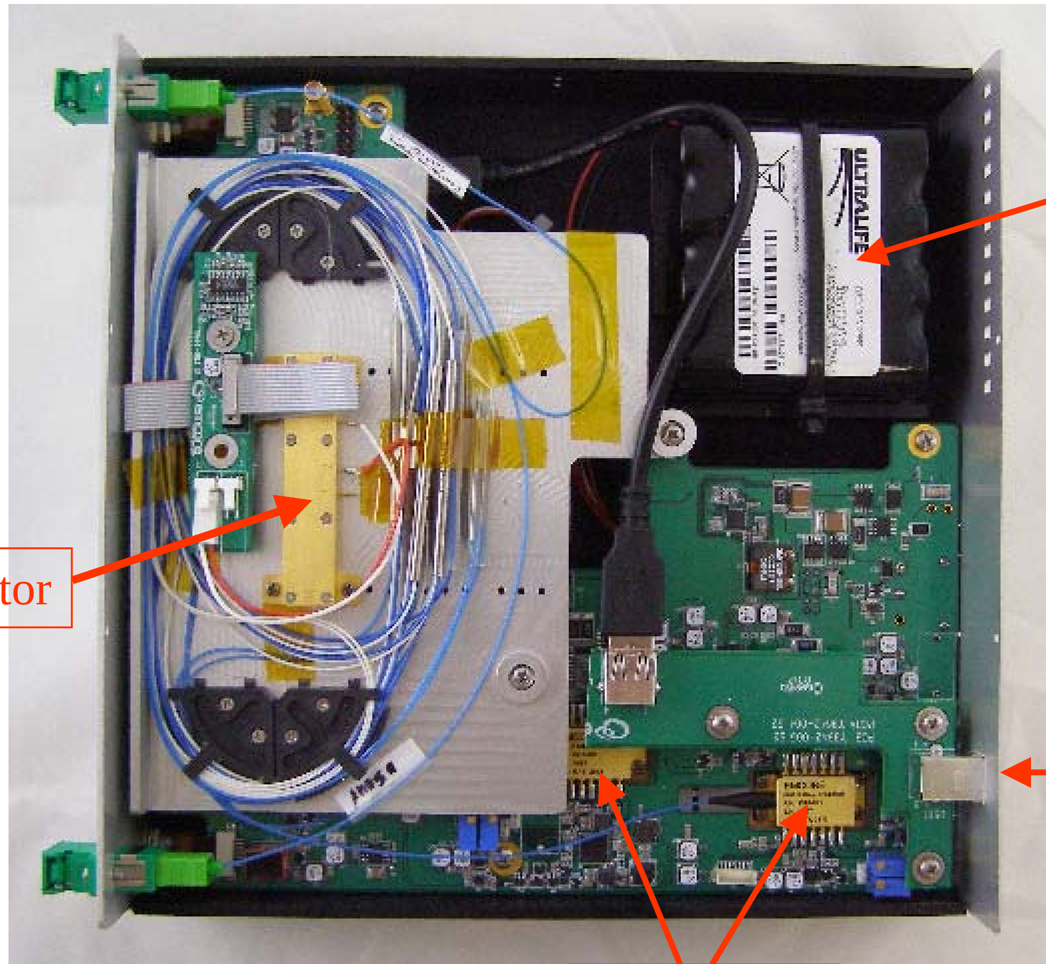


Detailed block diagram

- **Dedicated DSP board**
  - Precise laser tuning control (~100 MHz accuracy)
  - Calibration performed in factory, uses other spectral markers for field calibration
  - Reference oscillator, phase-control hardware, extra DAC hooks, on-board flash memory
  - Includes synchronous detection functions for high S/N
- **Simple spliced-fiber assembly using commercial equipment**
- **Controlled via external laptop computer**
  - Currently via Windows XP or 7
  - Planned platform independent



PB7200 picture



850nm lithium-niobate phase modulator

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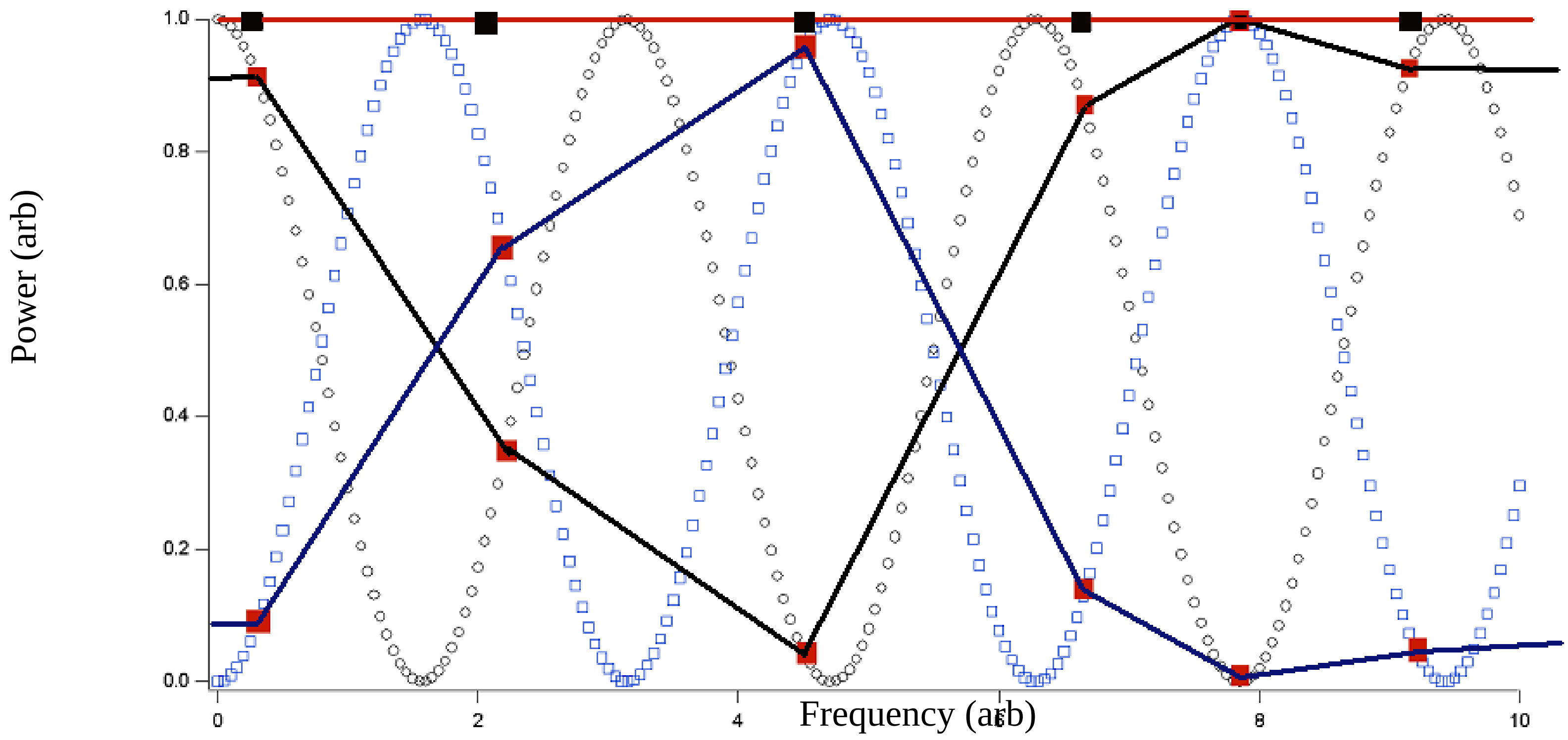
- Annealed proton-exchange waveguide process for high polarization extinction
- V = 1.8 V causes optical phase shift of 90 degrees
- Optical phase shift translates one-to-one to THz phase shift
- Precise shift of interference fringe pattern
- Practically instantaneous (i.e. phase modulator has 18 GHz bandwidth)

Phase Control Implications

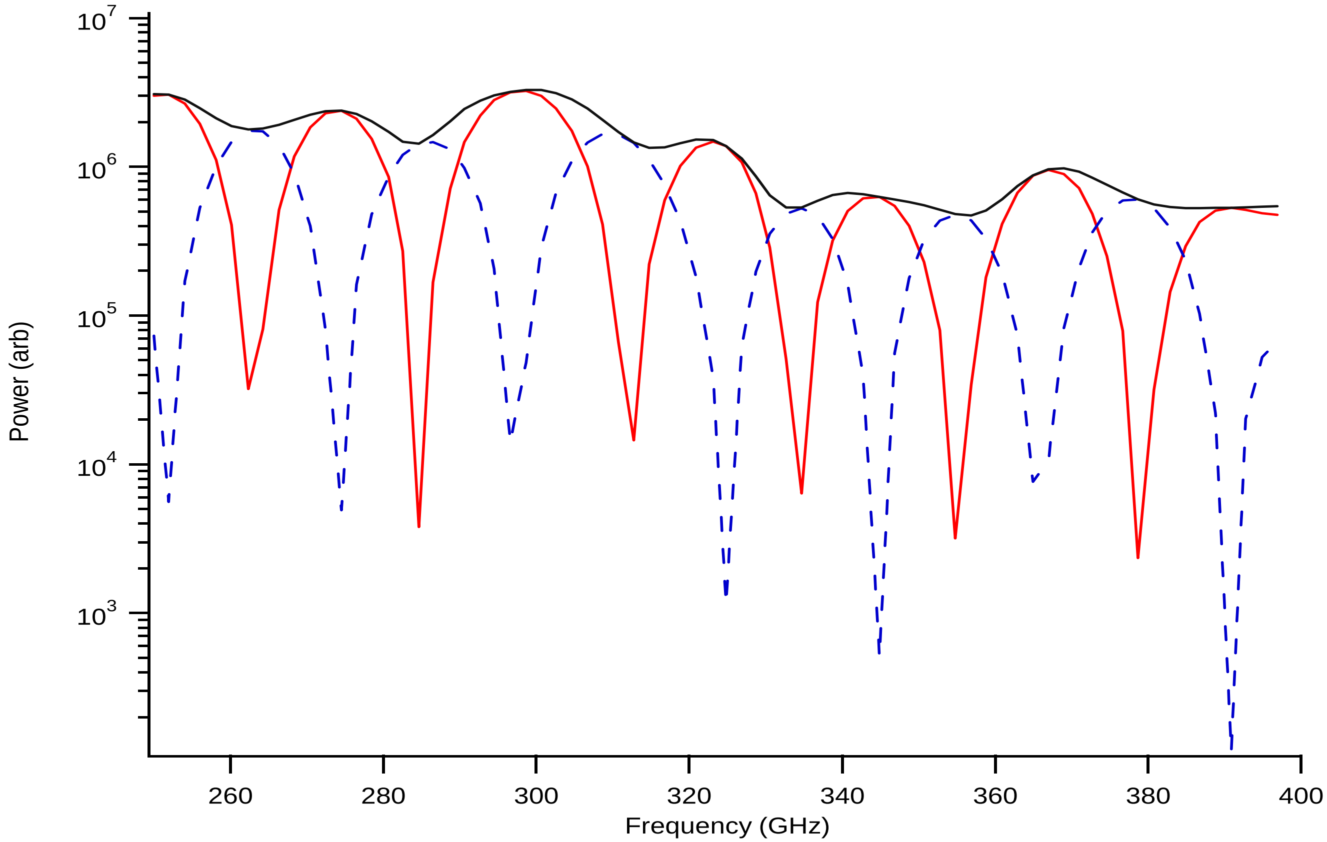
- **90 degree shift in relative laser phase produces 90 degree shift in THz signal**
- **Summation of the shifted and shifter power results in actual amplitude**
  - $Cos^2(\theta) + Cos^2(90^o - \theta) = Cos^2(\theta) + Sin^2(\theta) = 1$
- **Removes interference pattern regardless of frequency resolution**



Linear plot, not log

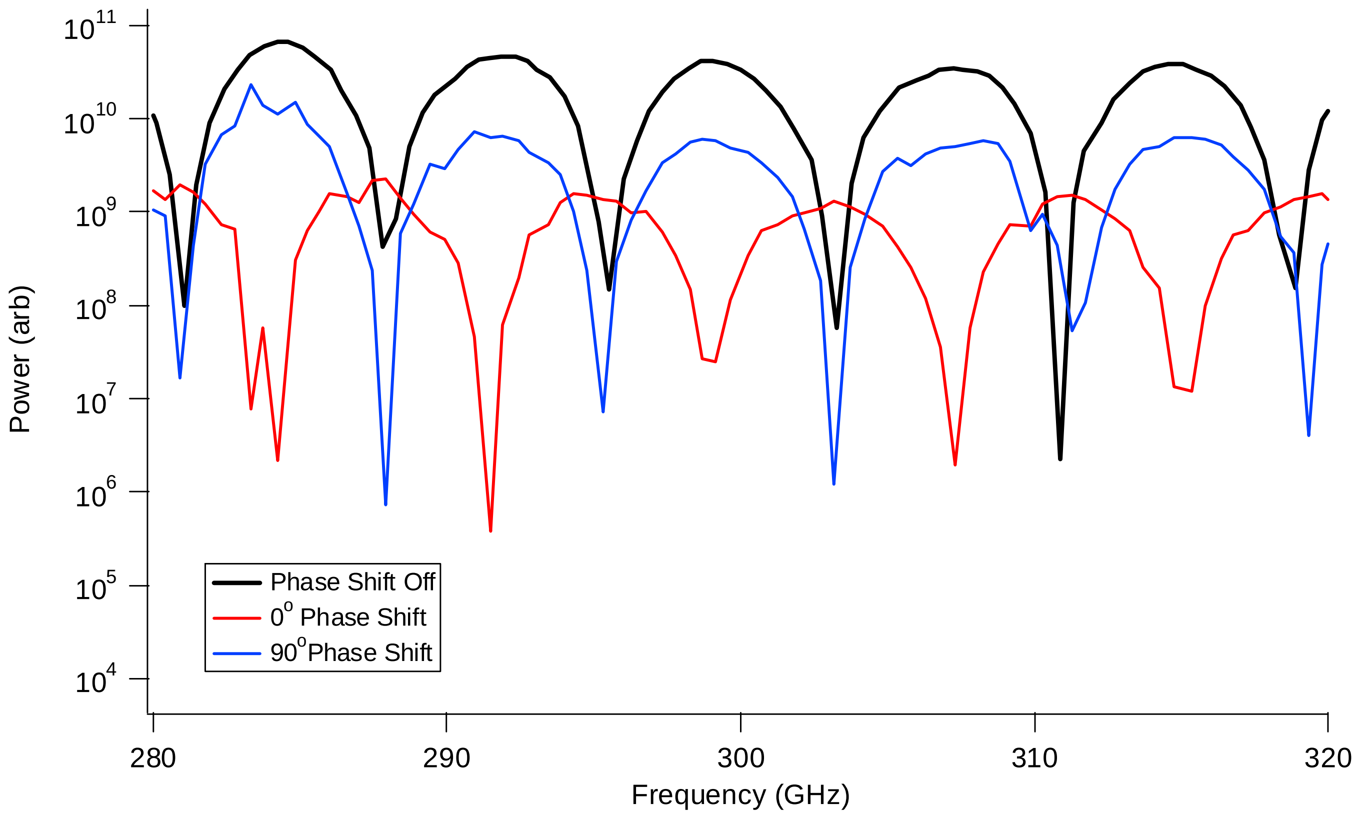
Previous demonstration of phase shift

- Labview program external power supply
- Previously demonstrated data from 90 degree shift summed with 0 degree
- Variation in 0 phase and 90 phase amplitude results in ripple
- Scanning range limited by insertion loss of modulator (i.e. low optical power output)

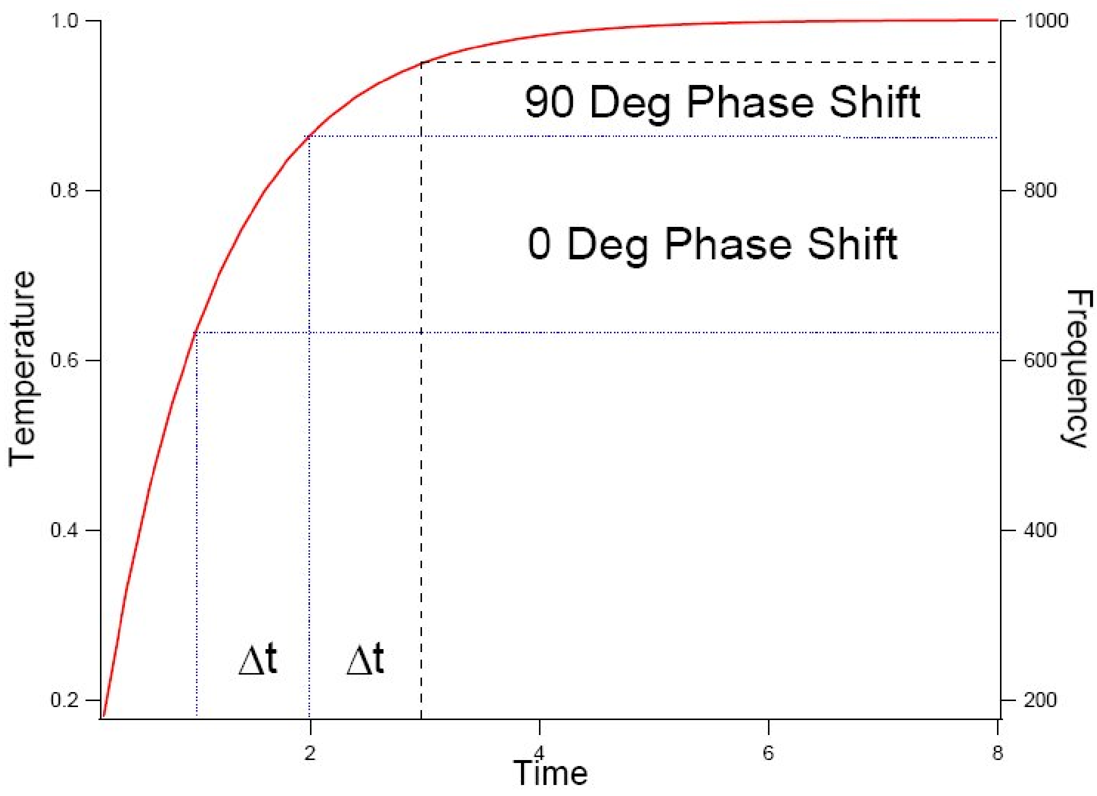


Current demonstration of phase control

- **New Visual Basic program with internal DSP controlled power supply**
- **Phase shifted power down ~ 15 dB, un-shifted power down ~10 dB**
- **Believe power decreases are not real, but related to software**
  - Sampling and normalization
  - Consistant time constant

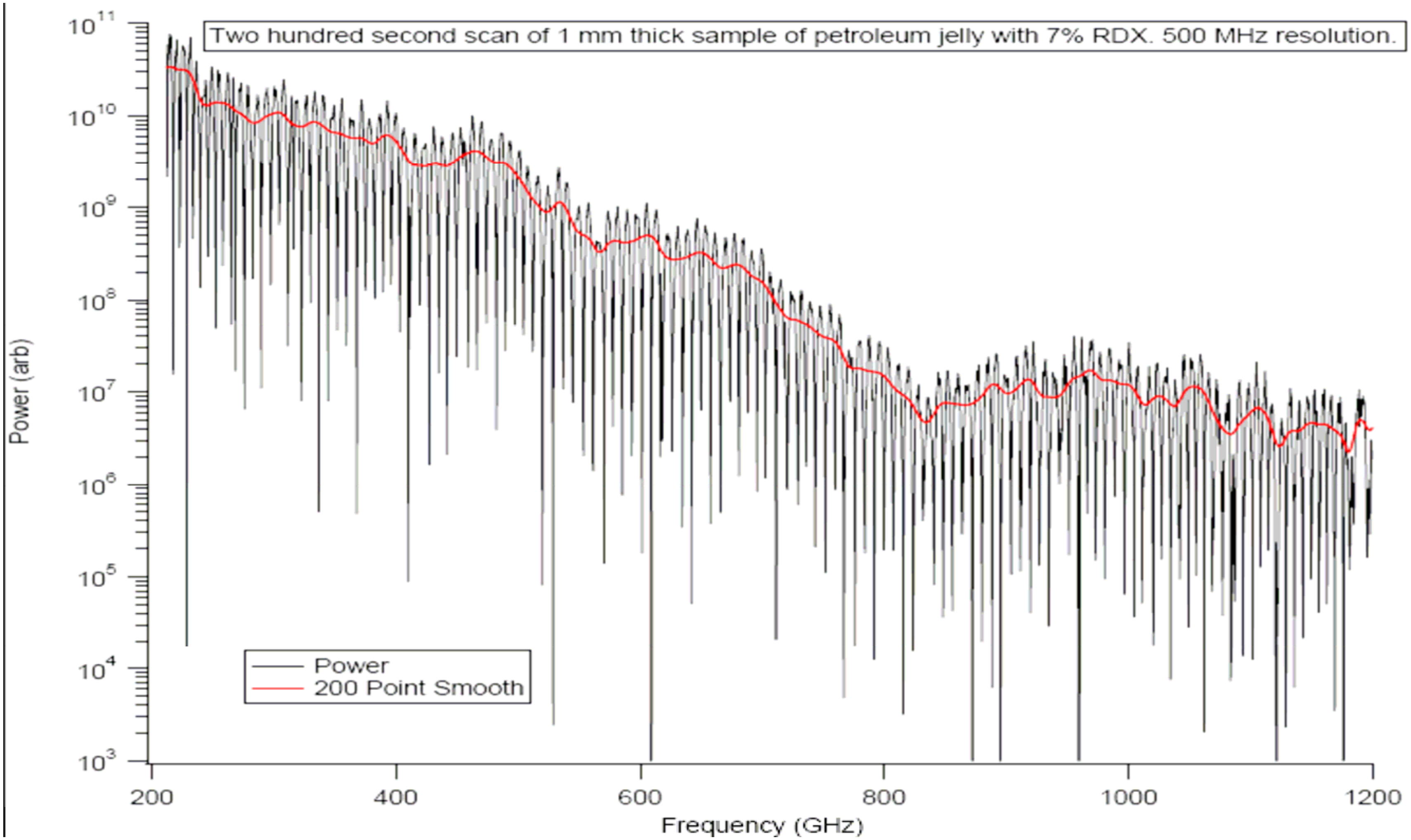


- **Decreased scan time by a factor of 5**
  - 5 GHz resolution compared to 500 MHz (two points taken for each 5 GHz step)
- **Issue of scanning rate and integrated fringes**



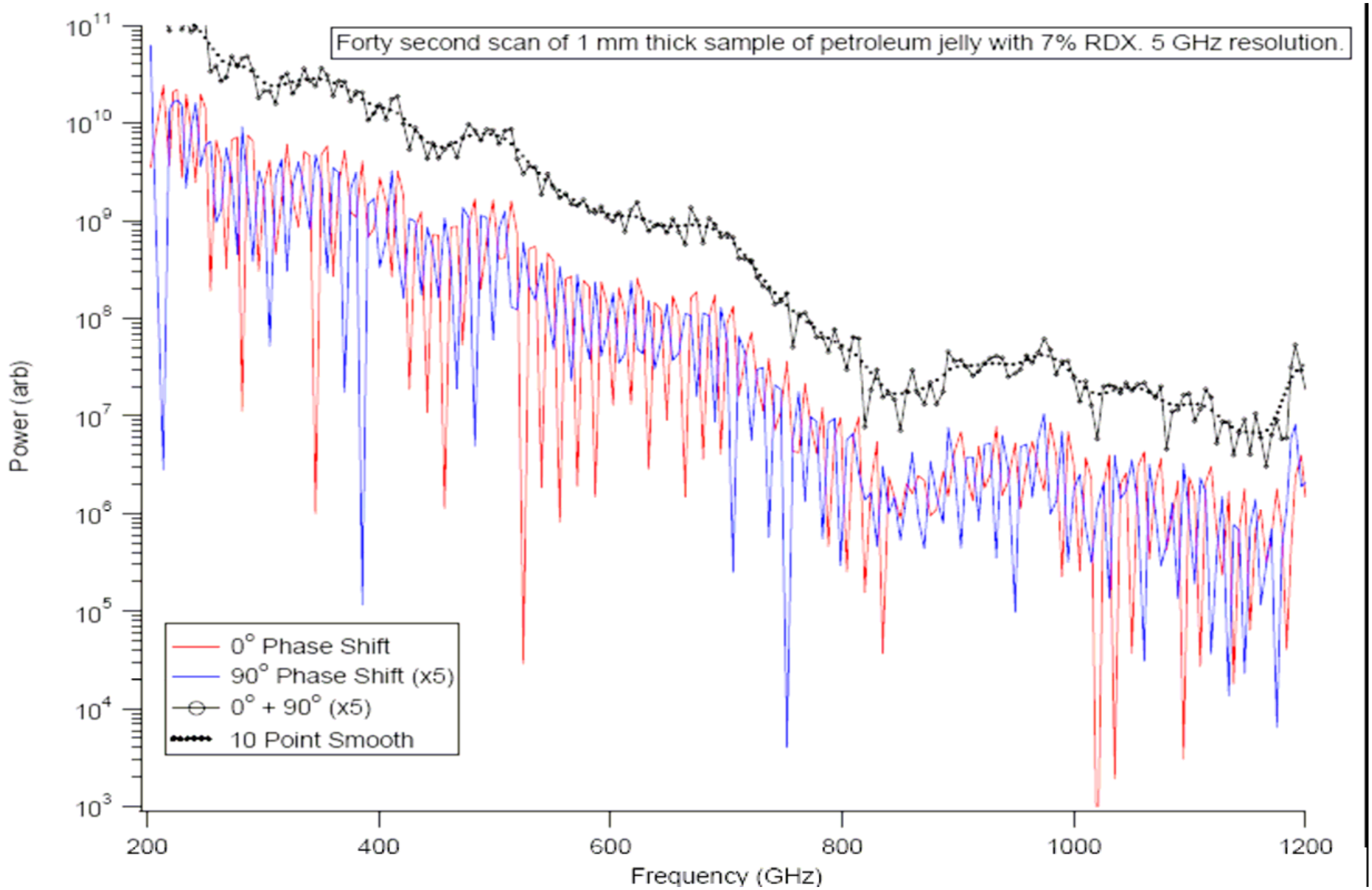
Spectrum of RDX without phase shifting

- **500 MHz resolution required to accurately sample interference fringes**



Spectrum of RDX with phase shifting

- Same exact settings as previous scan but with phase shift and 5 GHz step
- 5 GHz resolution with results similar to 500 MHz measurement



Future Work

- **Improve phase modulator insertion loss from 5 dB to less than 3 dB**
- **Resolve power discrepancies with phase and un-phase-shifted data**
- **Transfer software from the computer to the DSP making system faster and platform independent**
- **Enable averaging and fast scans (sub-10 seconds)**
  - Averaging currently works – need to run the software from DSP to improve speed
- **Integrate "Direct Phase Detection" as performed by Thorsten Gobel et. al.[1]**

"Direct phase detection in continuous-wave photomixing THz systems," Thorsten Gobel, Daniel Schoenherr, Cezary Sydlo, Michael Feiginov, Peter Meissner and HansLudwig Hartnagel, IEEE Lasers and Electro-Optics Society, 2008. LEOS 2008. 21st Annual Meeting of the

Summary

- Precision wideband terahertz phase control demonstrated
- Low cost design leverages telecom fiber-optic packaging
- Flexible two-piece, fiber-coupled system adaptable to wide range of applications

- Acknowledgements:
  - R T. Logan, Jr., B. Kasper, M. Flach, H. Ngo, KK Wong, P-N Dong, D.Duong

- For more information, visit EMCORE booth:

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- www.emcore.com