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Field-portable THz Spectrometer for Characterization of Explosives and Chemicals

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Outline

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- Current Spectrometer
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- Summary

Motivation

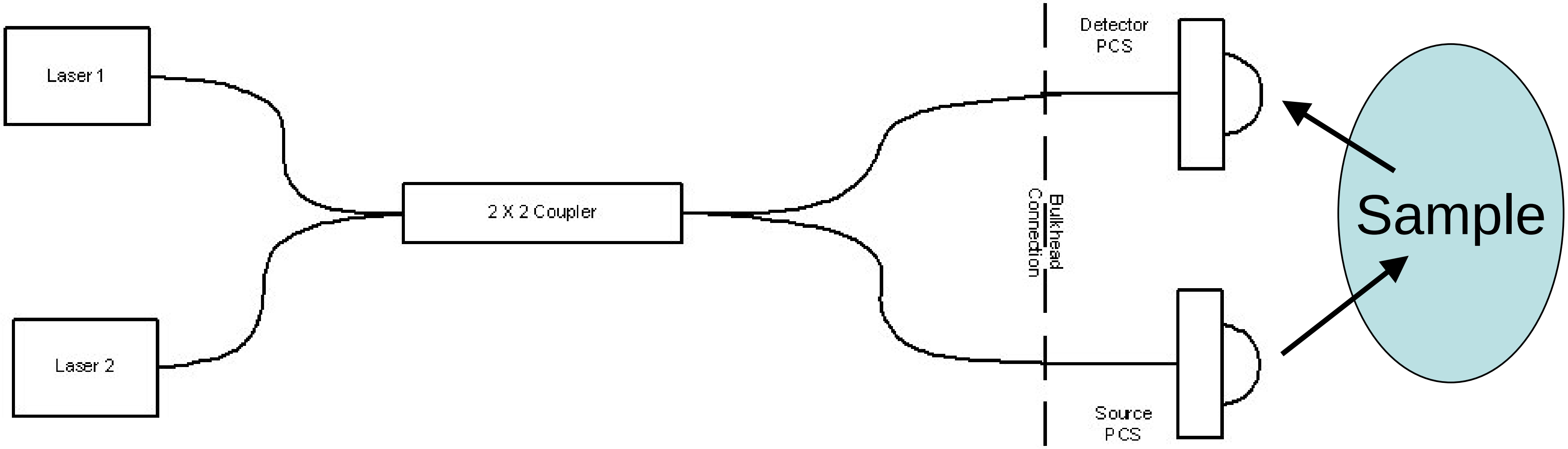
- **Develop and demonstrate a portable low-cost frequency-domain THz spectrometer**
  - Characterization of materials in the field
  - Transmission-mode or Reflection-mode
  - Rechargeable battery, low-power electronics design
  - Utilize telecom photonic packaging for low-cost and high reliability
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

- **Investigate optical control of terahertz phase**
  - Mitigate the effect of interference fringes in data sets by removing the requirement to resolve individual fringes
  - Potential to enable the 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

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 and other components (couplers, connectors)

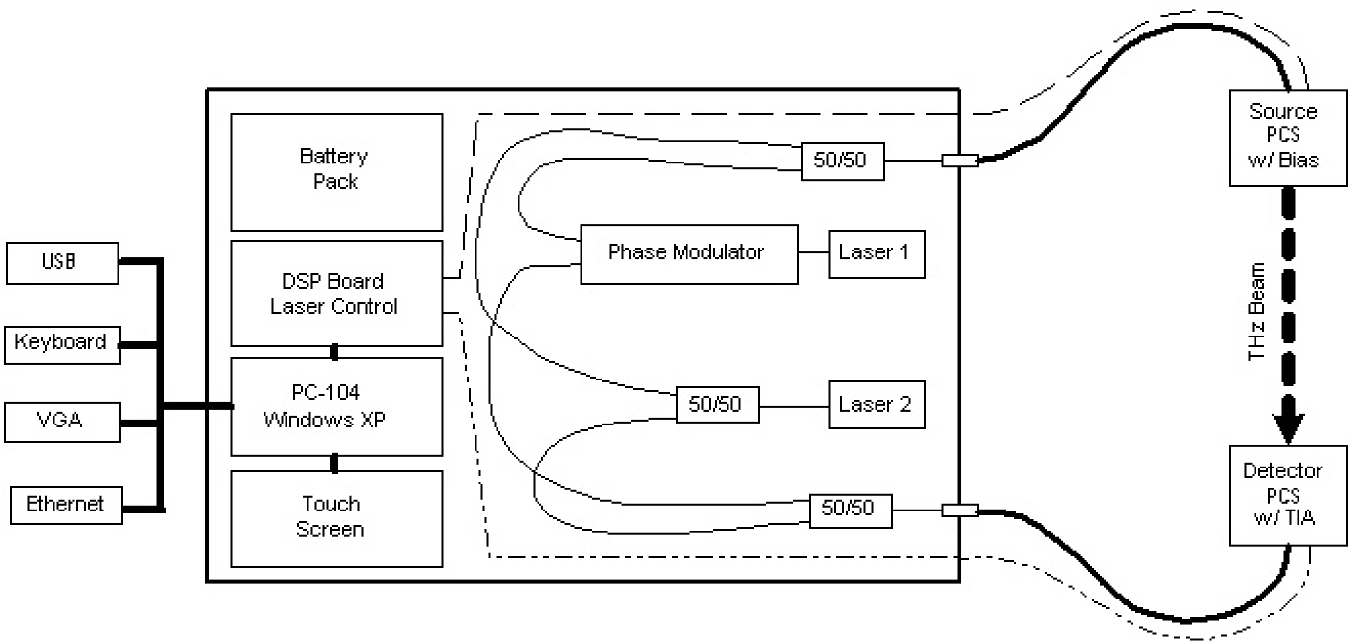


Compact spectrometer

- **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
- **Laser / Processor unit**
  - Houses lasers and tuning/data collection electronics
  - Single-board low-power PC running Windows
    - Touch-screen operation
    - Ethernet, 3 USBs, monitor output
  - Custom low-power DSP board

Detailed block diagram

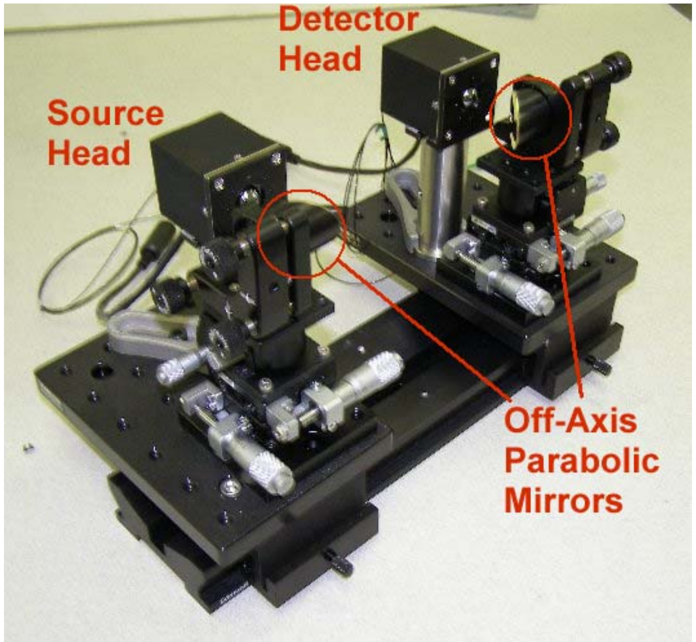
- **Dedicated DSP board**
  - Precise laser tuning control (better than 100 MHz resolution)
  - Calibration performed in factory, uses other spectral markers for field calibration
- **DSP board provides chopping and synchronous detection functions for high S/N**
- **Simple spliced-fiber assembly using commercial equipment**
- **Single-board PC running graphical user interface program**
  - Windows file system for data storage and USB/Ethernet/Monitor/Touchscreen support
  - User can run other Windows-based software for post-collection analysis



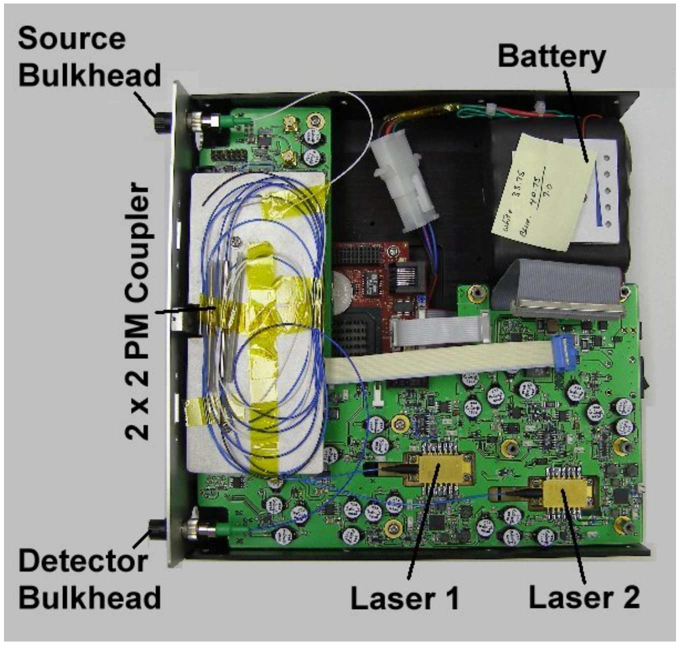
Keep powers from LD 1 and LD2 to maximize modulation depth

Two-piece flexible configuration

- **Source/detector heads on rail with parabolic mirrors for beam focusing**
  - Micrometer stages for precise positioning to achieve path balance
- **Fiber-optic source/detector heads can support other configurations**



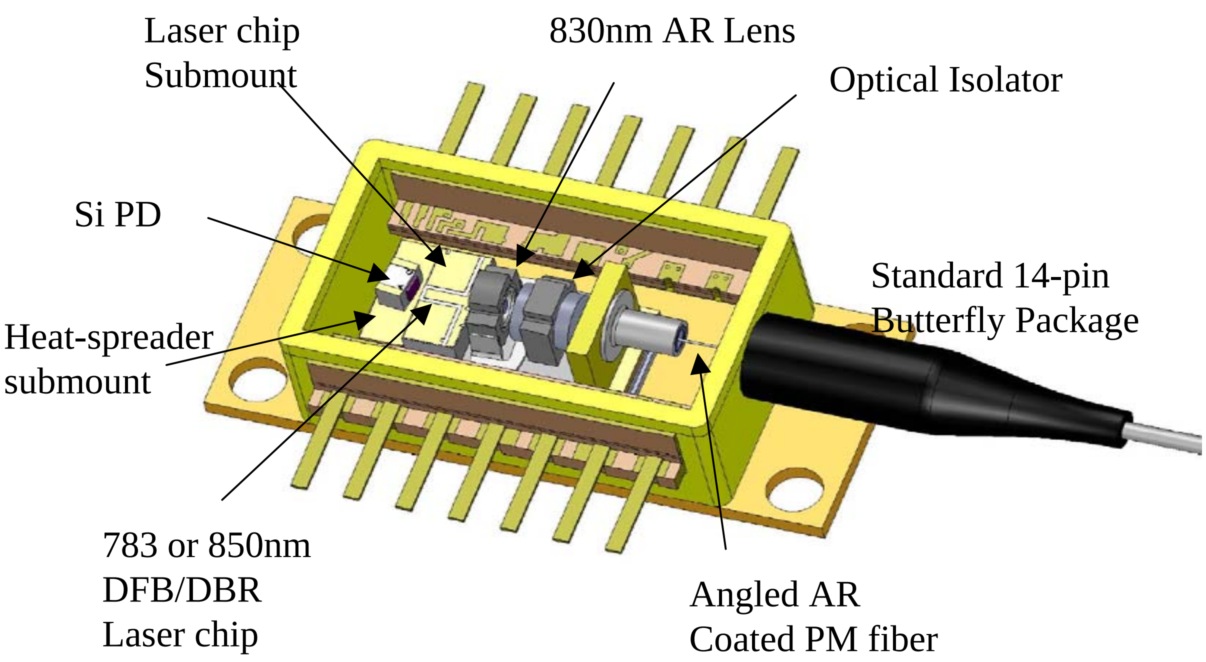
~8 inches

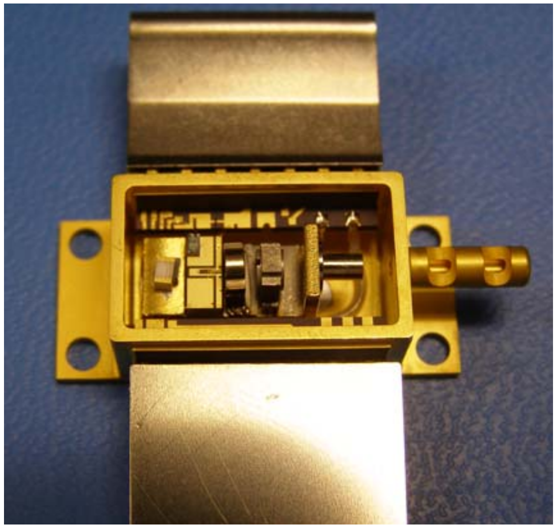


8 inches

Telecom 14-pin Butterfly Laser Package

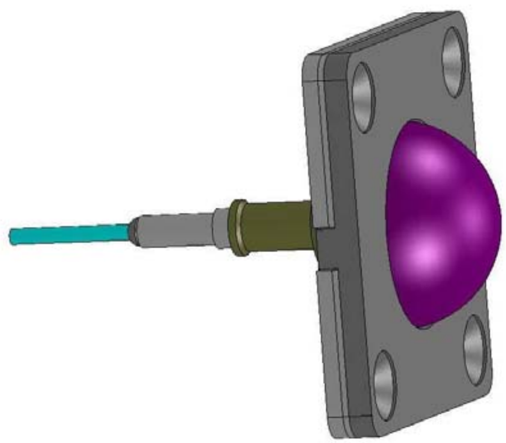
- **Low-cost optics is key to mass production and cost reduction**
  - Leverage huge prior investment in telecom laser packaging design and production equipment and techniques
  - ~100,000 butterfly units produced per year at EMCORE
  - Leverage volume buying for package, TE-coolers, chassis parts
  - Use automated production equipment (multi-million $ prior investment)
  - ~15 min assembly time per part

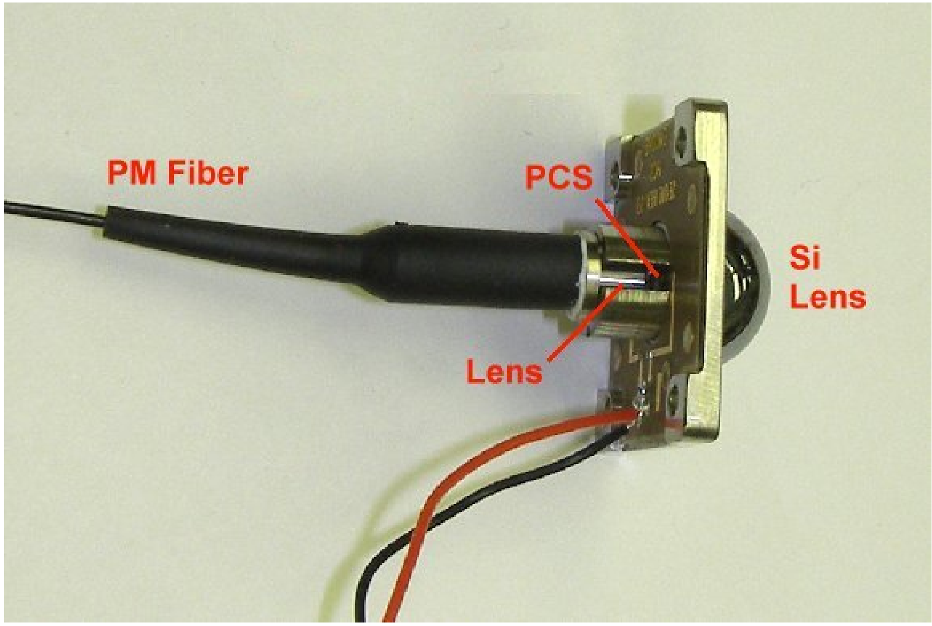




Fiber coupled photomixer design

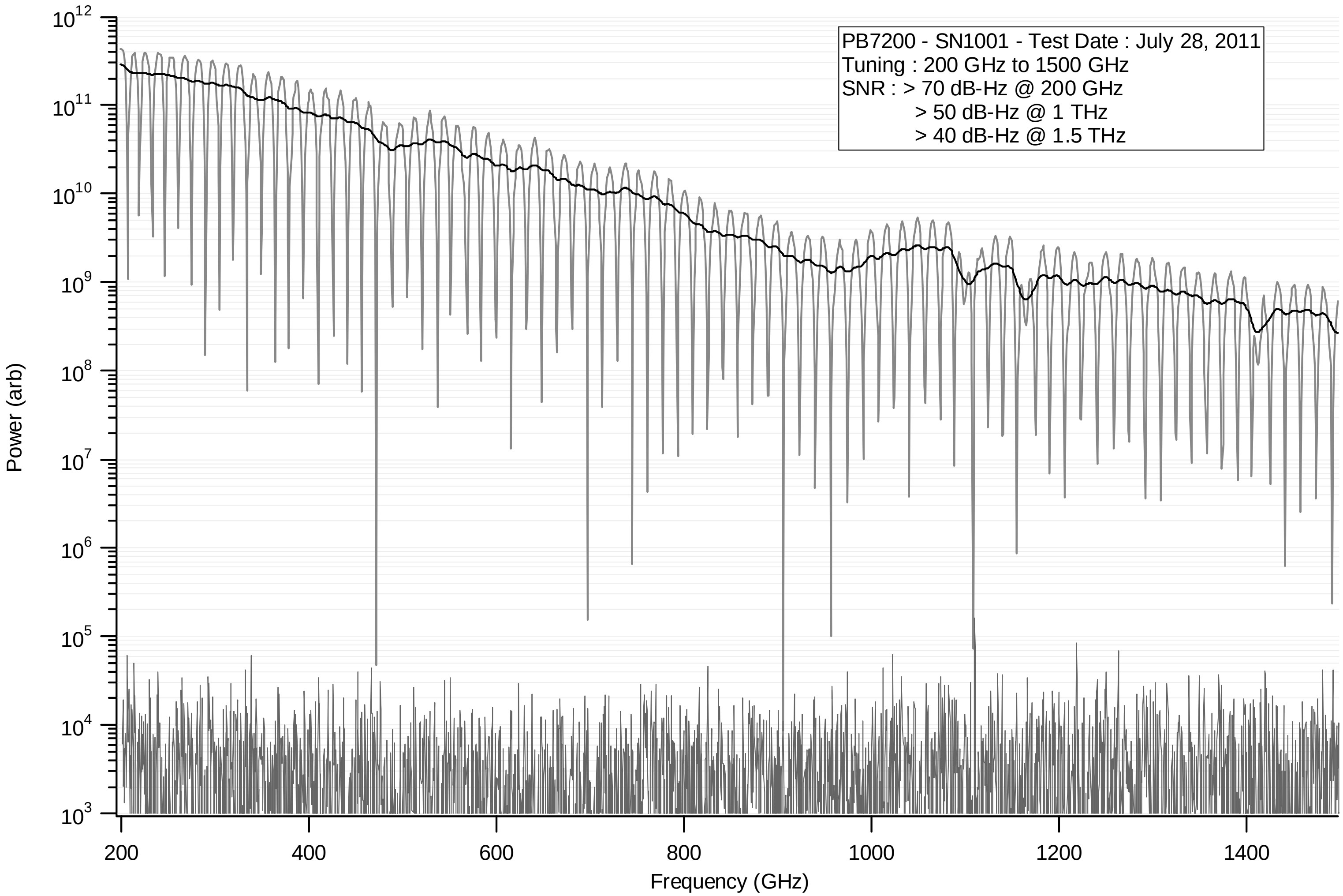
- Leverages low-cost un-cooled “TO-can” style telecom packaging
- Production processes in ISO9001 factory. ~15 min assembly time per part
- Laser welded lens and fiber with in semi-automated process
- Again, employ current production equipment (multi-million $ prior investment)
- Hermetic package possible but not currently implemented





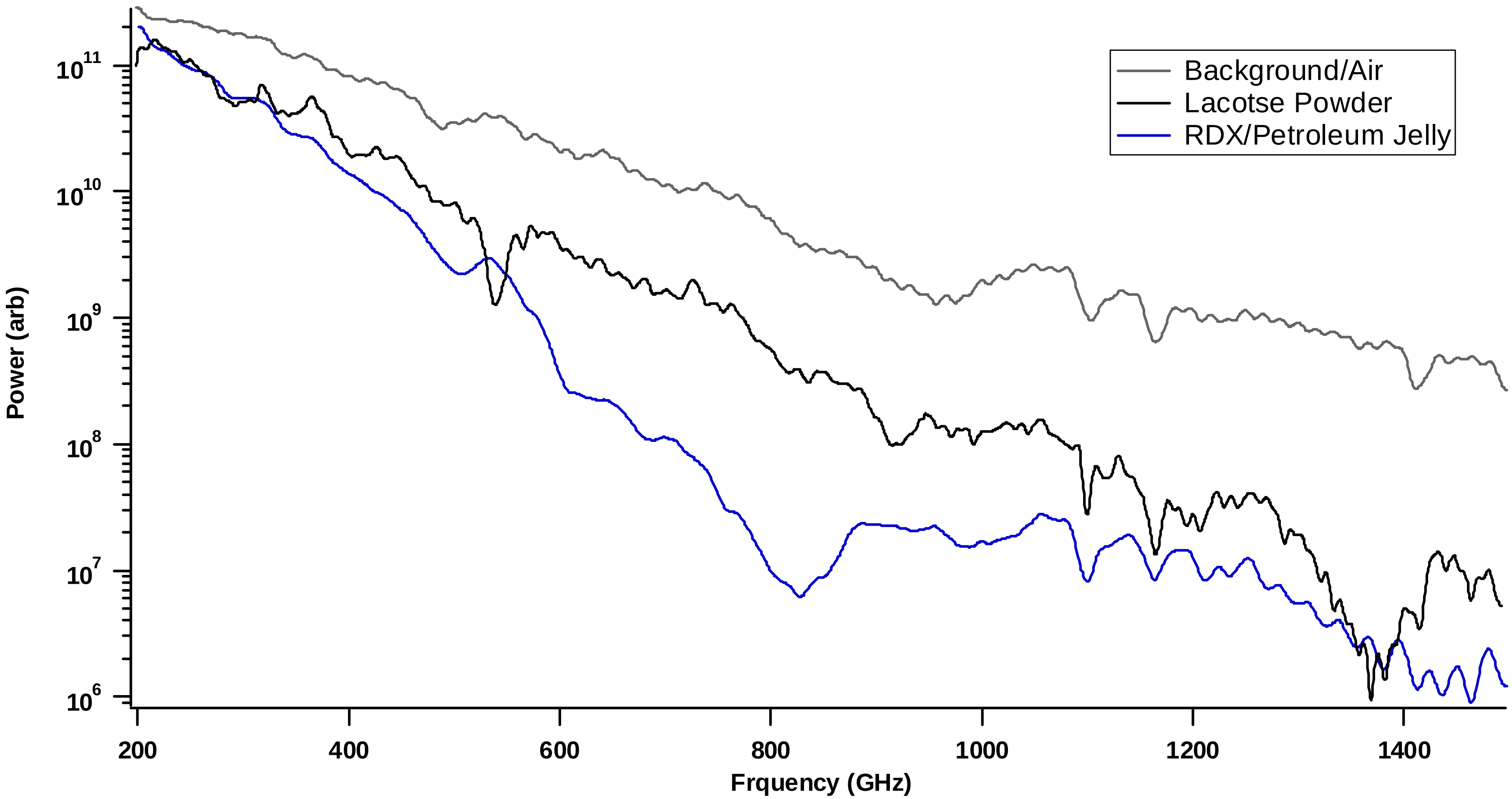
Spectrometer scan of lab air

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



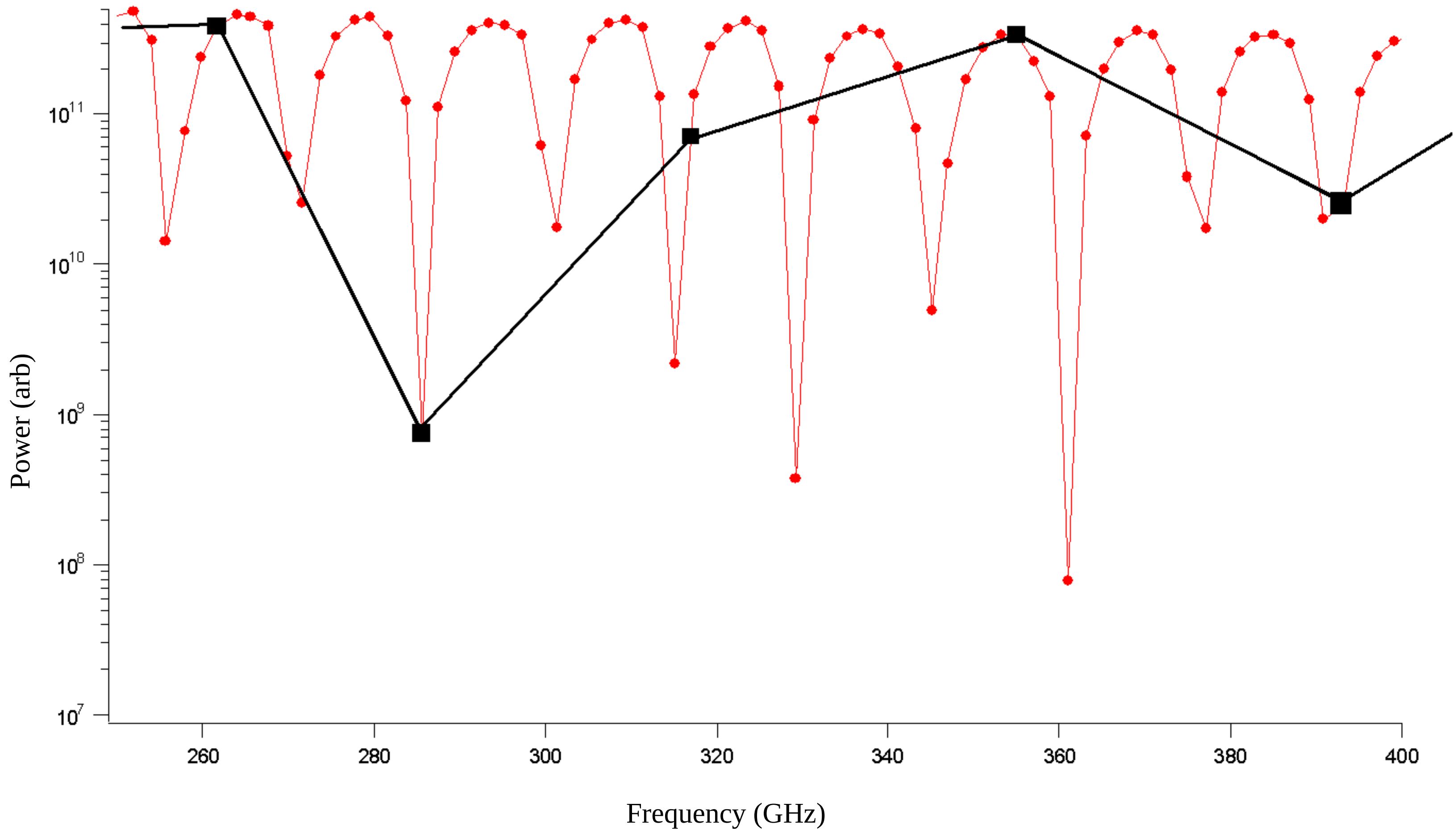
Spectrum of RDX and Lactose

- **For large features smoothing is acceptable**
- **System may clearly be employed for solid state transitions.**



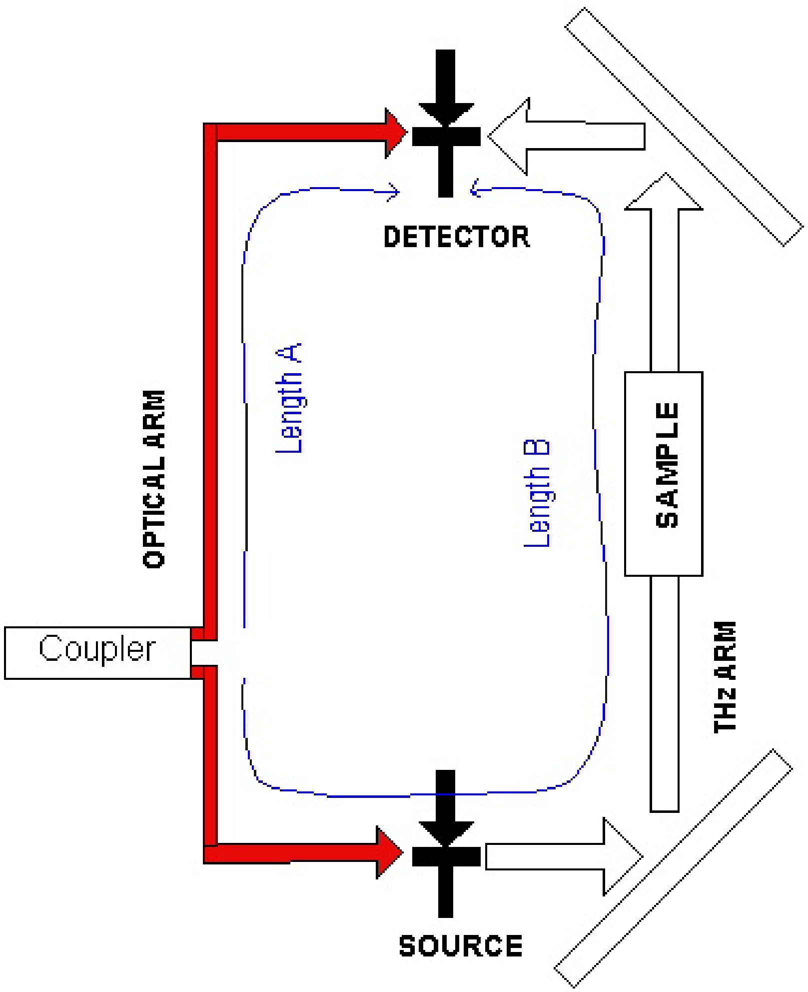
The Problem with coherent detection

- 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.



Where do the fringes come from?

- The spectrometer employs coherent detection
- Interferometer is formed between output of heterodyne optical coupler and detector photomixer



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

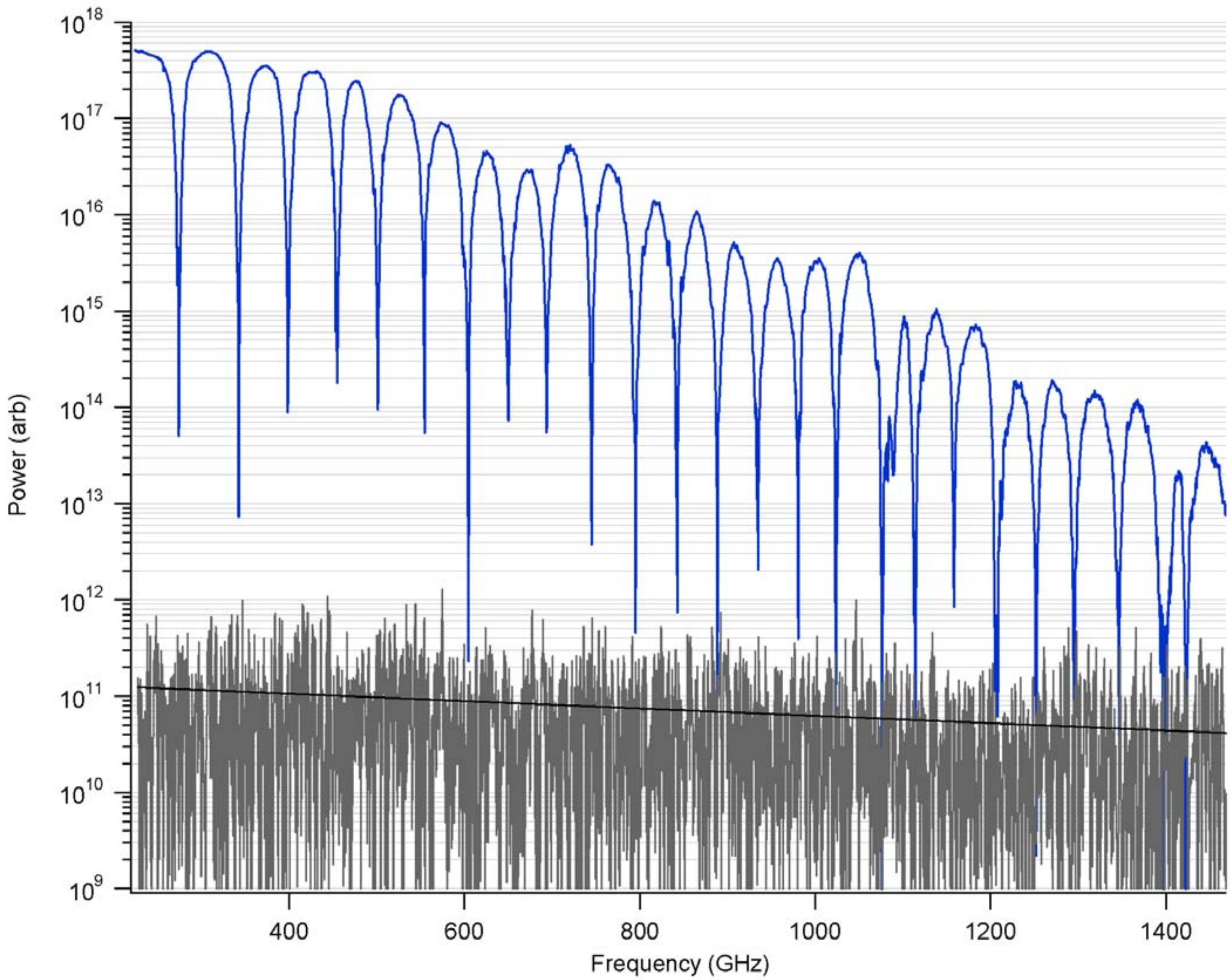
$$I_{out} \propto 1 + \cos(k \cdot \partial L)$$

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

Combined sample, photomixer, antenna and system path dispersion term

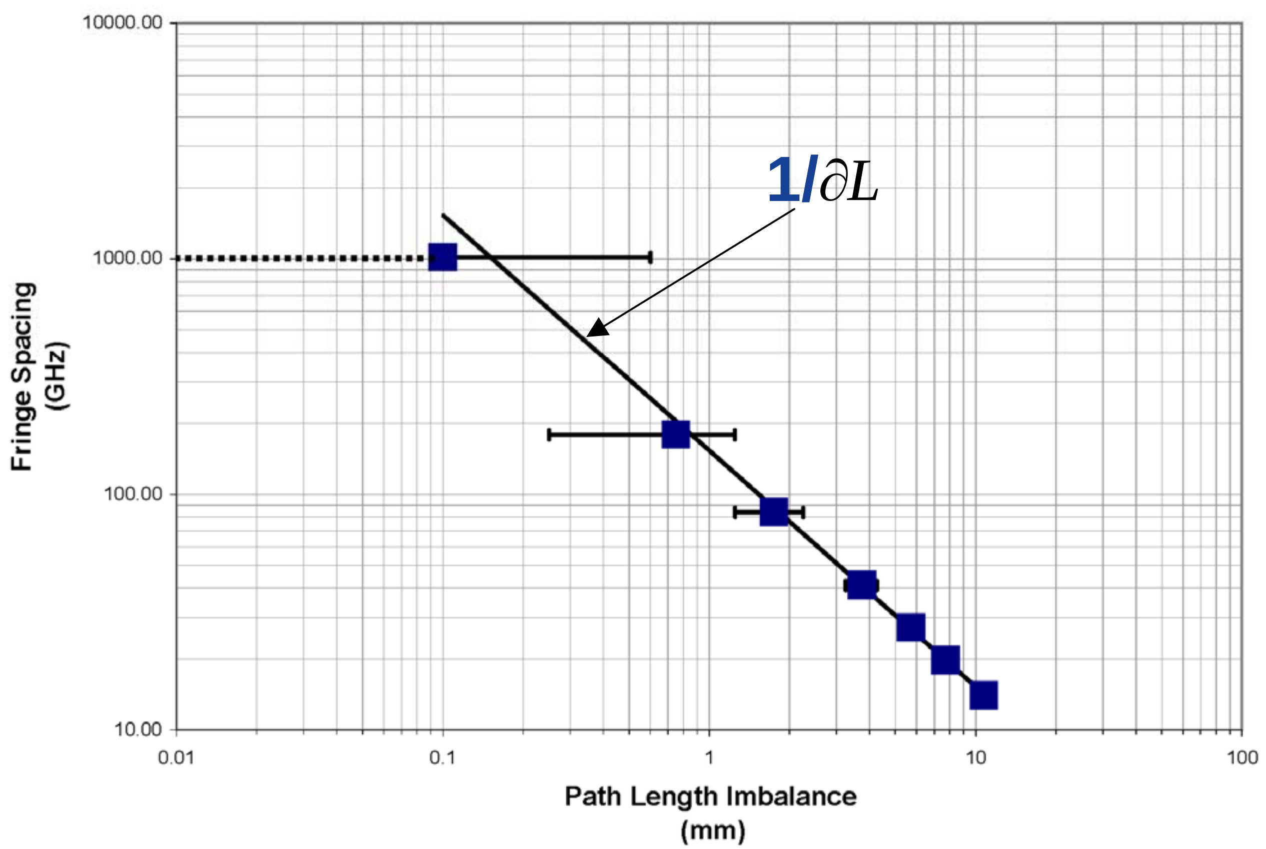
Improved matching of path lengths widens interference fringe spacing

- **Less susceptibility to laser frequency fluctuations**



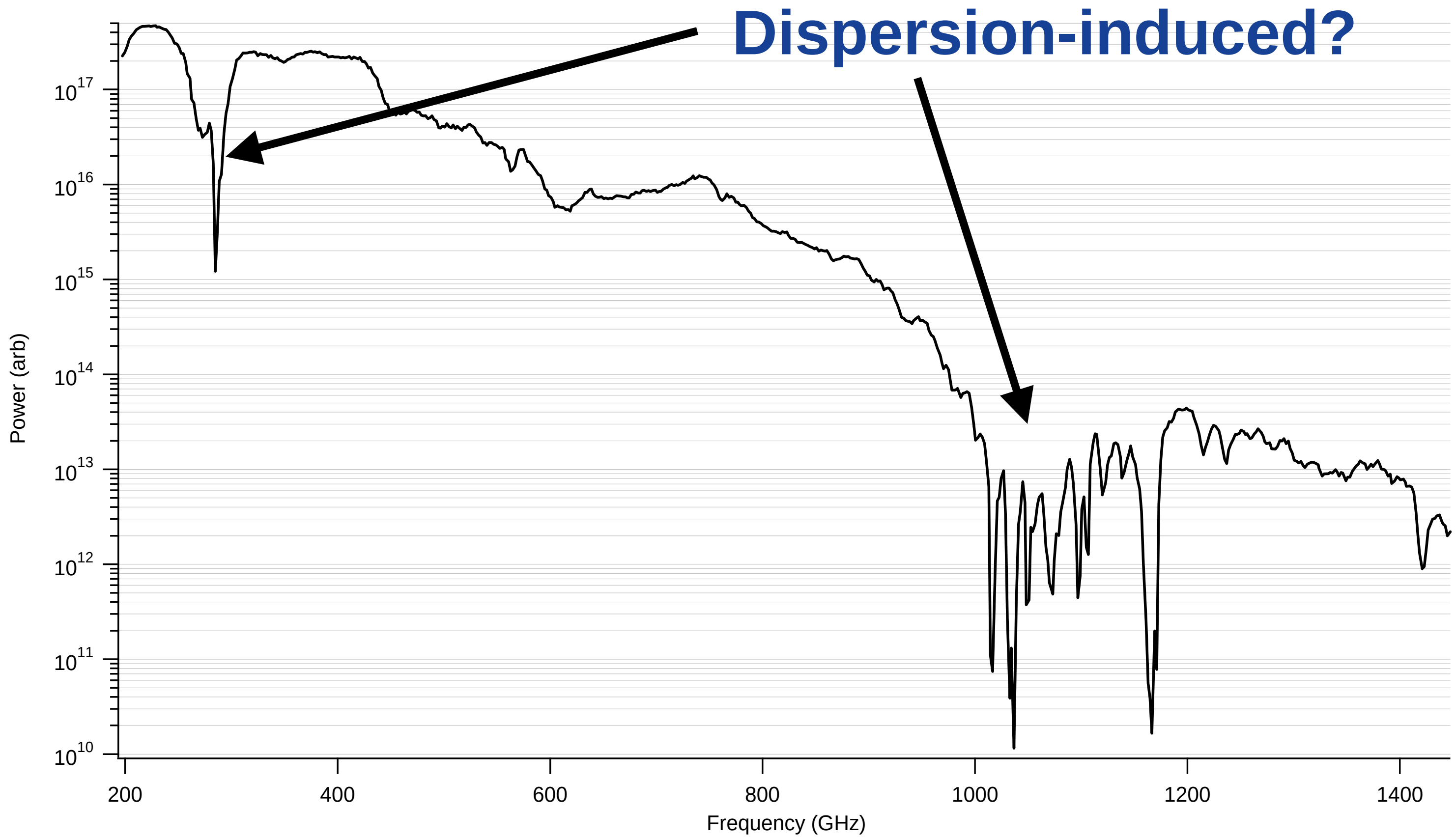
Dependence of path-length imbalance

- **Expect** $\partial \upsilon = \frac{c}{n_{eff}} \cdot \frac{1}{\partial L}$
- **Measured fringe spacing in lab air vs path-length imbalance =>** $n_{eff} \cong 2$



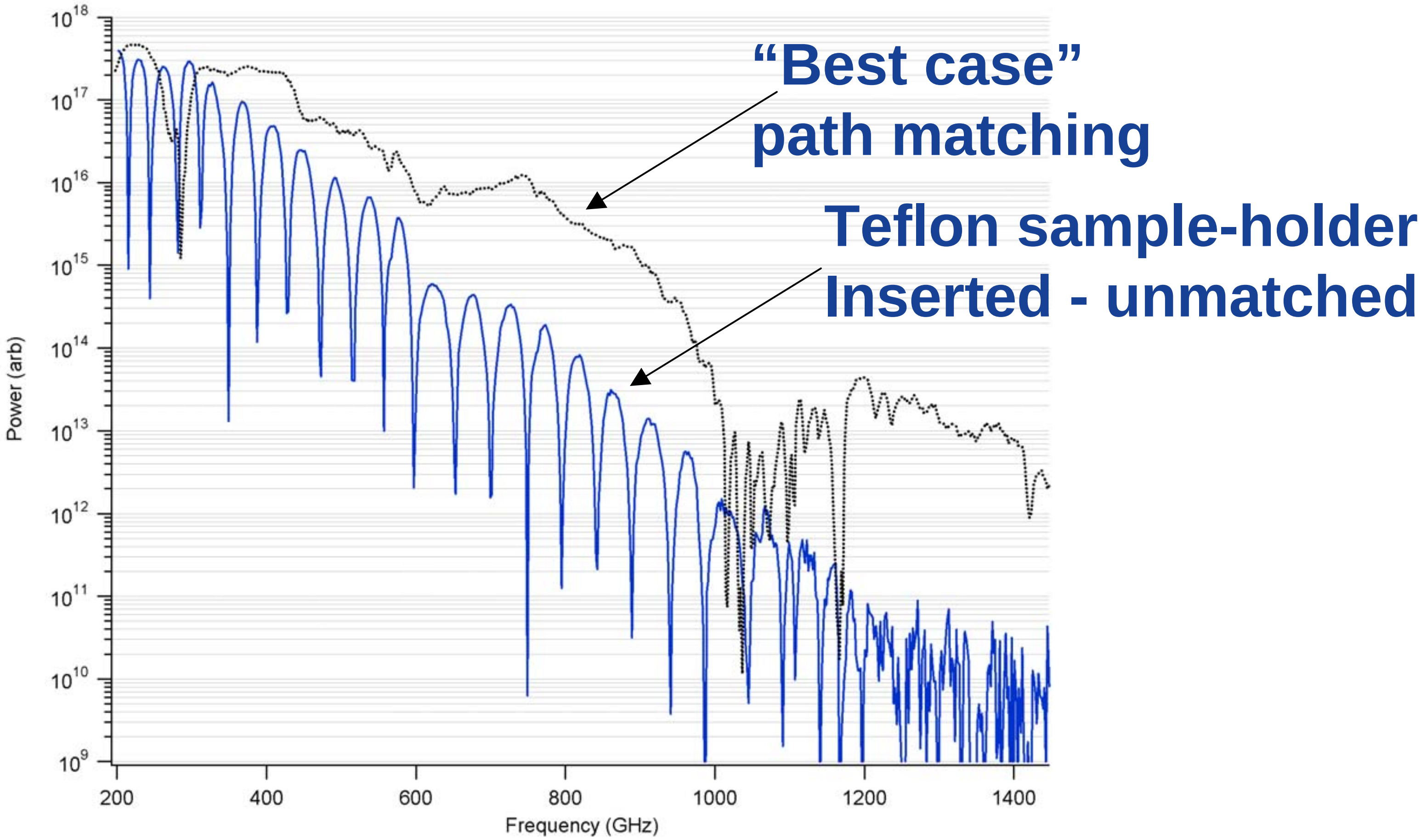
Exact path length matching condition

- **Exact path matching should result in no interference fringes, but not achievable in practice**
- **Limited by dispersion?**
  - photomixers (antenna and material) and path (air)



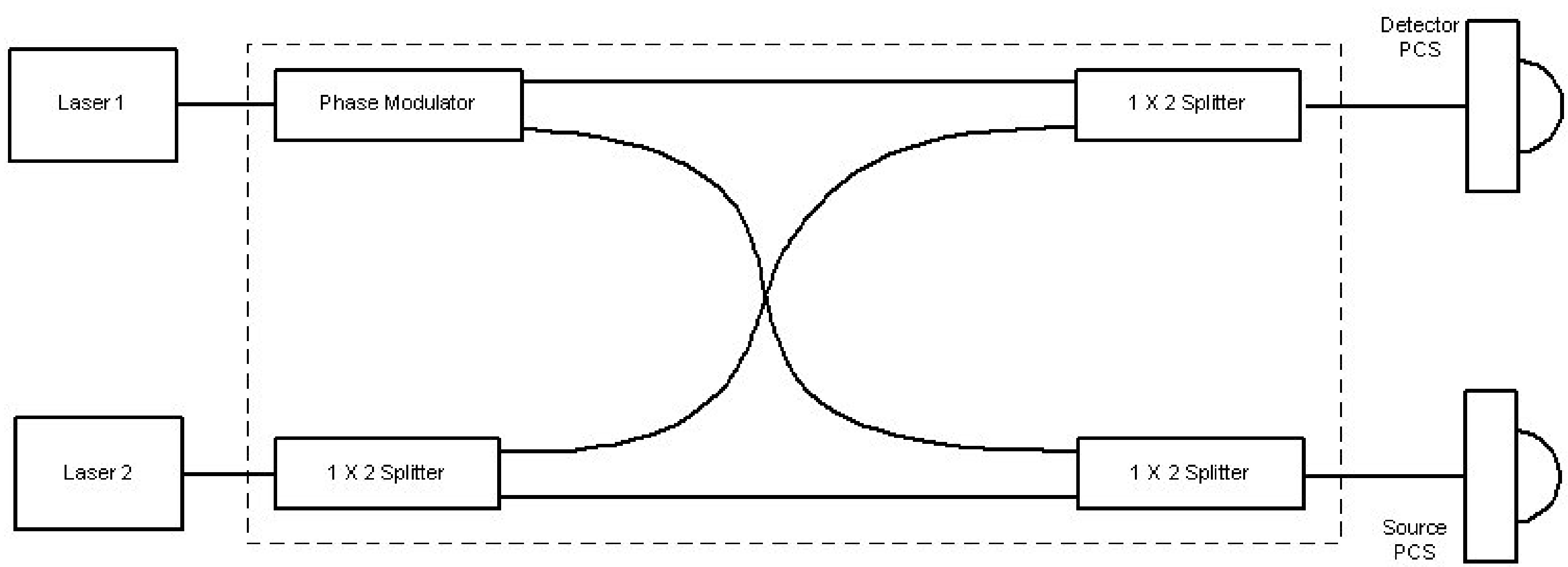
Sample induces path-length changes

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



Optical terahertz phase control

- Use lithium-niobate optical phase modulator to control phase of one laser only, prior to heterodyne combination
- Fully integrated hermetic package with PM fiber input and output
- Bias voltages less than 5 Volts
- Laser phase shift causes terahertz phase shift
- Wideband operation with no moving parts or high-power components

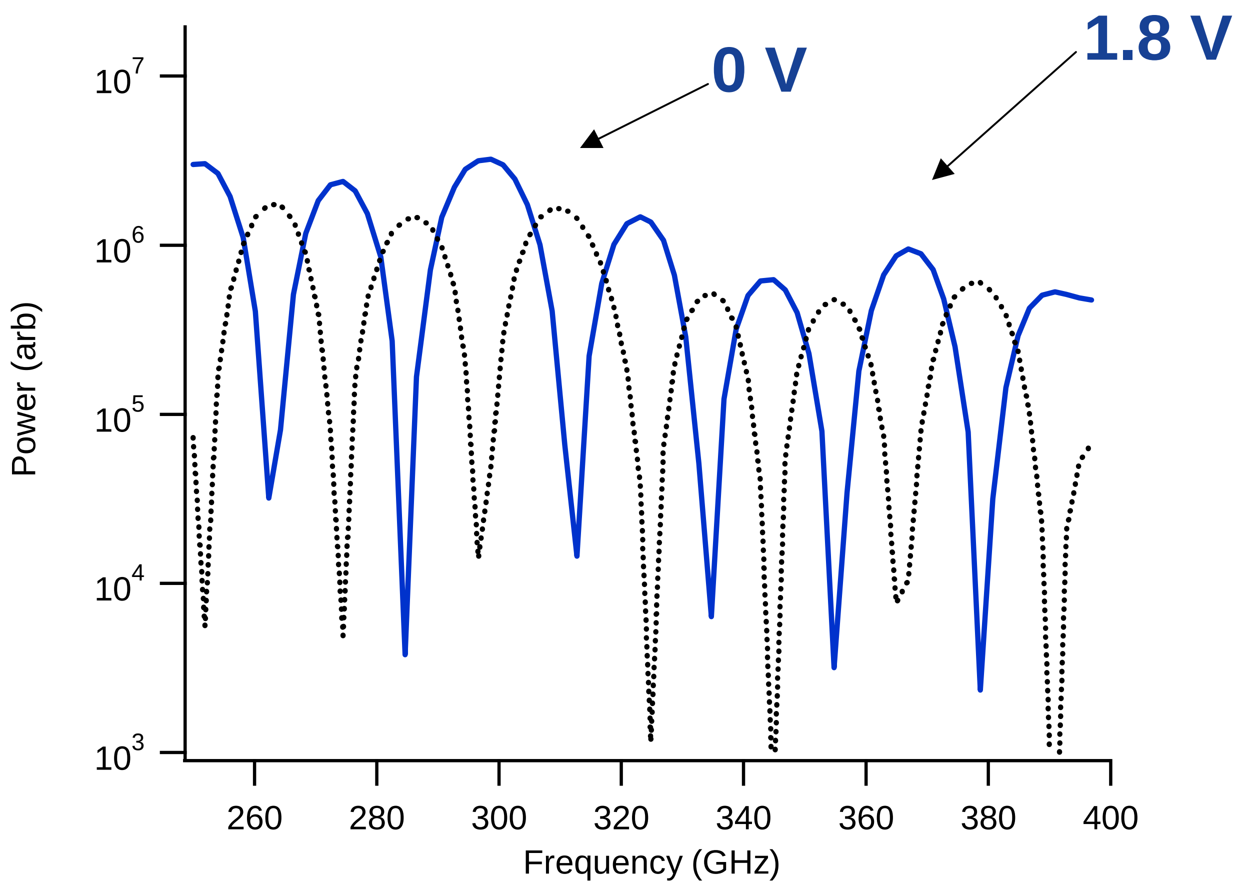


850nm lithium-niobate phase modulator

- 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)

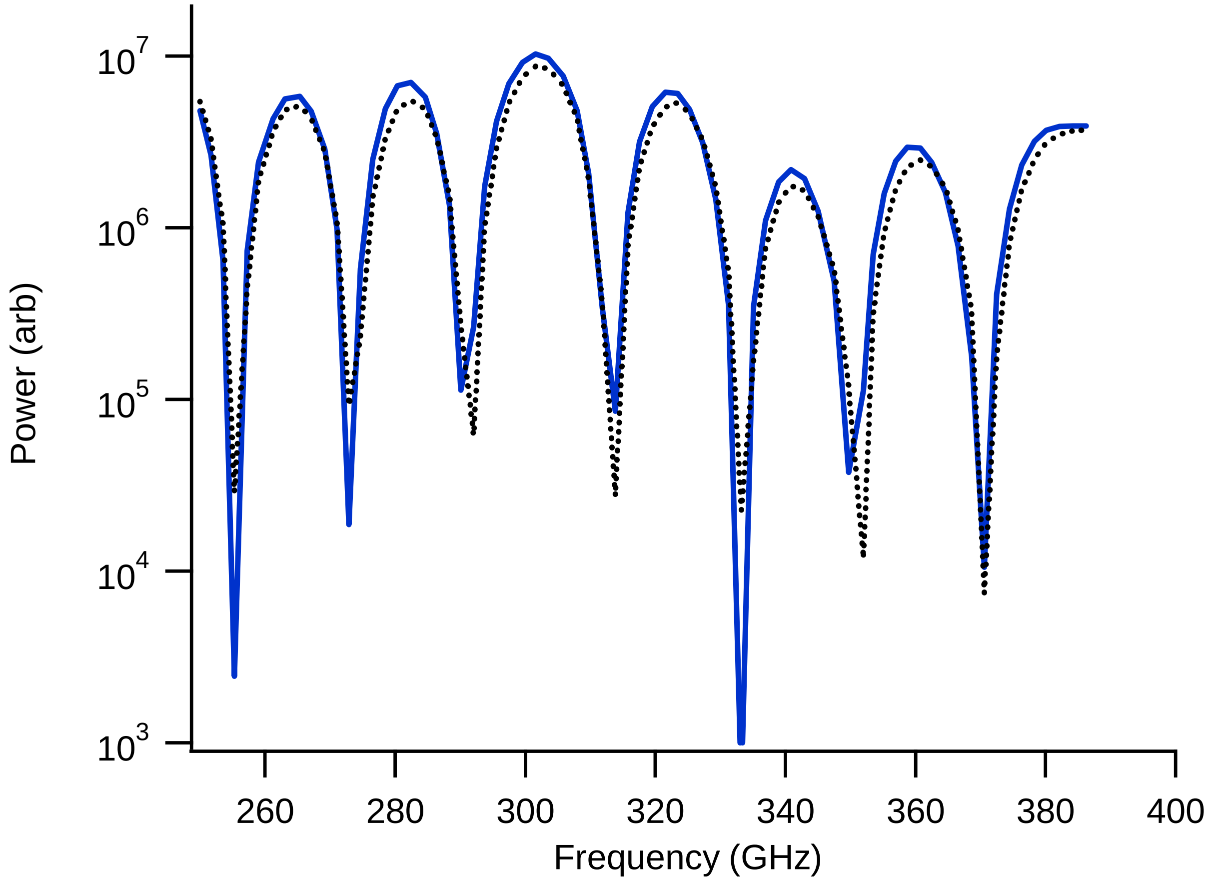
90-degree phase shift (1.8V)

- Peaks of interference fringes shift to overlap nulls
- Enables full coverage of terahertz spectrum without gaps
- Actual data reveals 1.8 V is slightly off



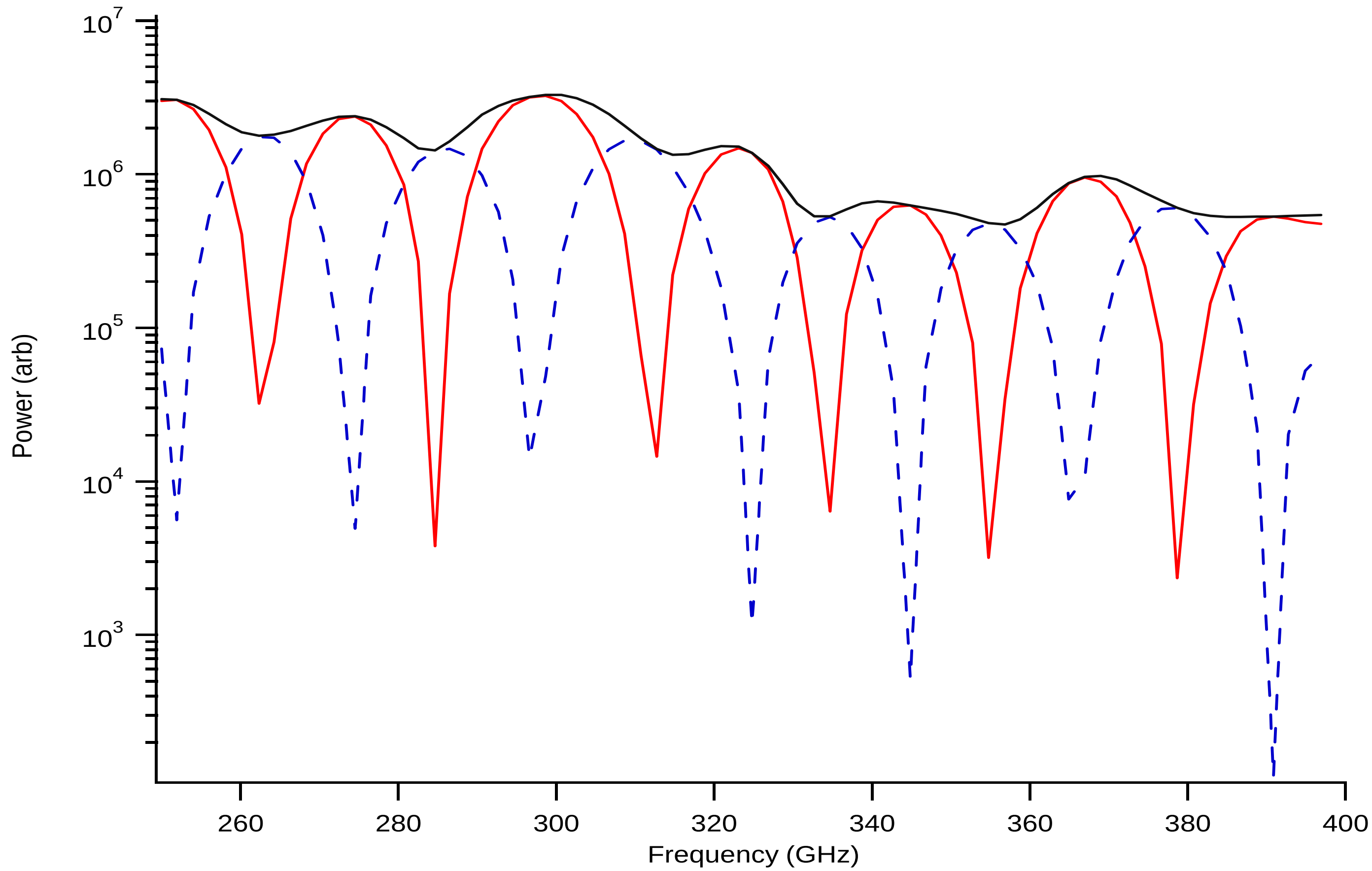
180-degree phase shift (3.6V)

- **As expected, at 180 degrees, the two squared curves overlap**

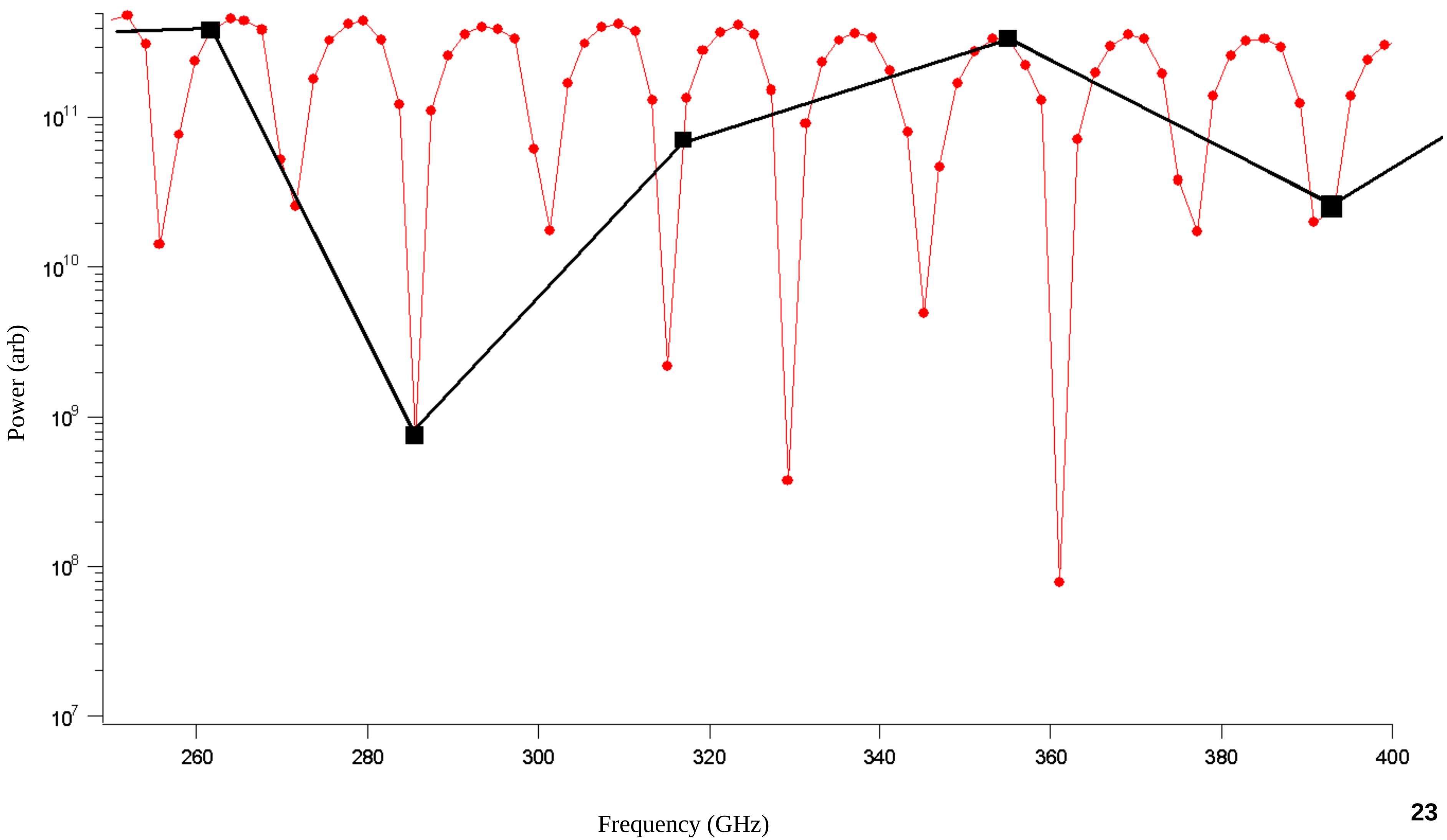


Sum of 0 and 90 degree

- Data from previous 90 degree shift summed with 0 degree
- Bias voltage slightly off results in slight variation of combined signal
- Scanning range limited by insertion loss of modulator (i.e. low optical power output)

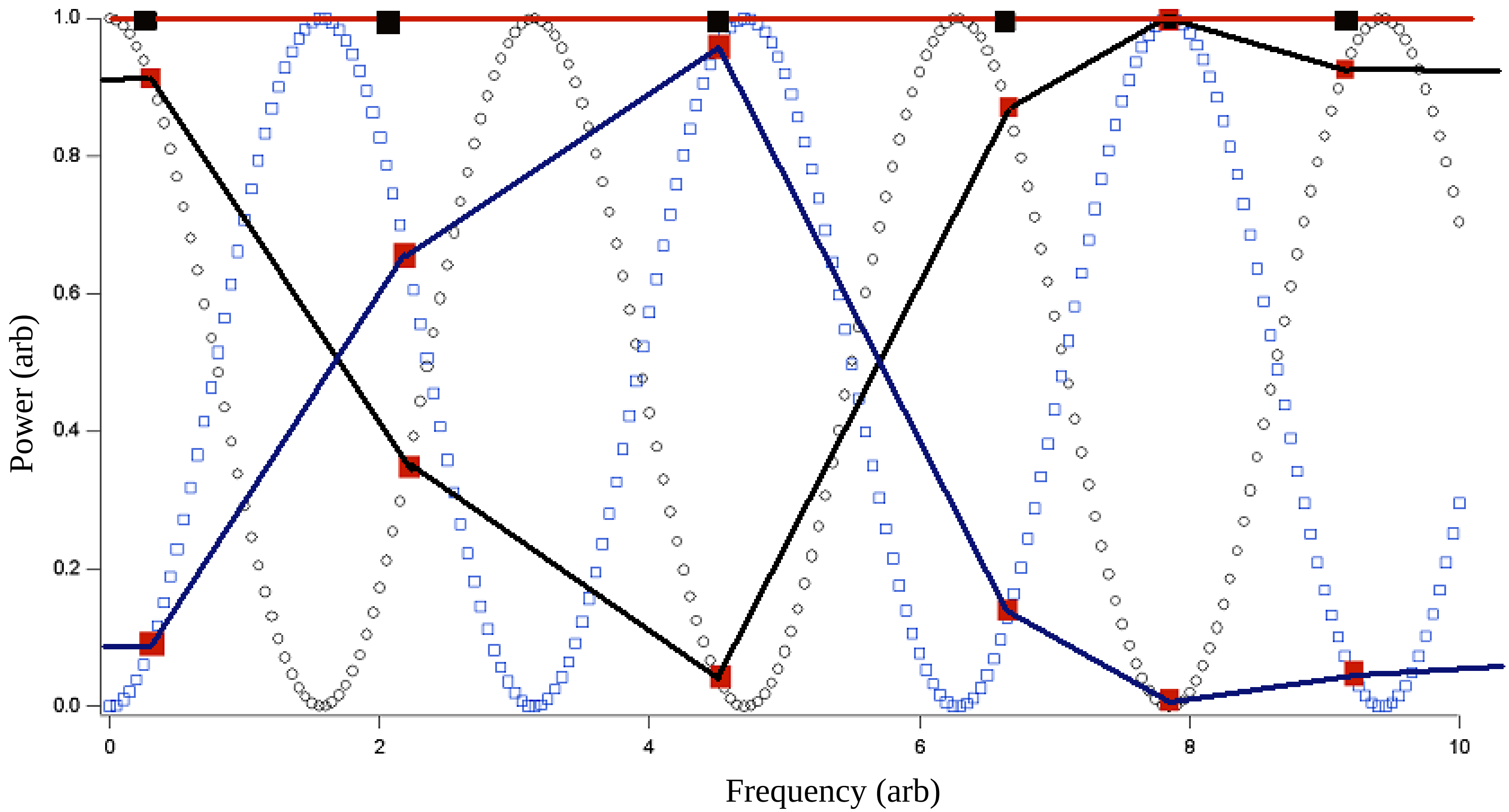


Large resolution – small fringe spacing



Phase Control Implications

- **Why is the ability to instantaneously switch phase so important?**
- **It removes the interference pattern regardless of frequency resolution!**



Linear plot, not log

Phase modulator status

- EMCORE has lithium niobate foundry for 1310 nm FOG modulators
- Current phase modulator is first article at 852 nm
- Insertion loss of 7 dB precludes full scanning over system capability of 2 THz
- Theoretical insertion loss of 2.5 dB should be obtainable
- Currently manufacturing another wafer of 852 nm phase modulators with different optical tapers
- PB7200 can operate with up to a 3 dB insertion loss due to the phase modulator without seriously affecting performance.
- Custom software will calibrate the V_{π} before each scan

Summary

- Portable, low-power CW swept-frequency THz spectrometer was developed and demonstrated
- Low cost design leverages telecom fiber-optic packaging
- Flexible two-piece, fiber-coupled system adaptable to wide range of applications
- Precision terahertz phase control demonstrated

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  - M. Flach, H. Ngo, KK Wong, P-N Dong, D.Duong – EMCORE

- For more information, visit EMCORE booth:

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- www.emcore.com