Photomixing THz Spectrometer Review

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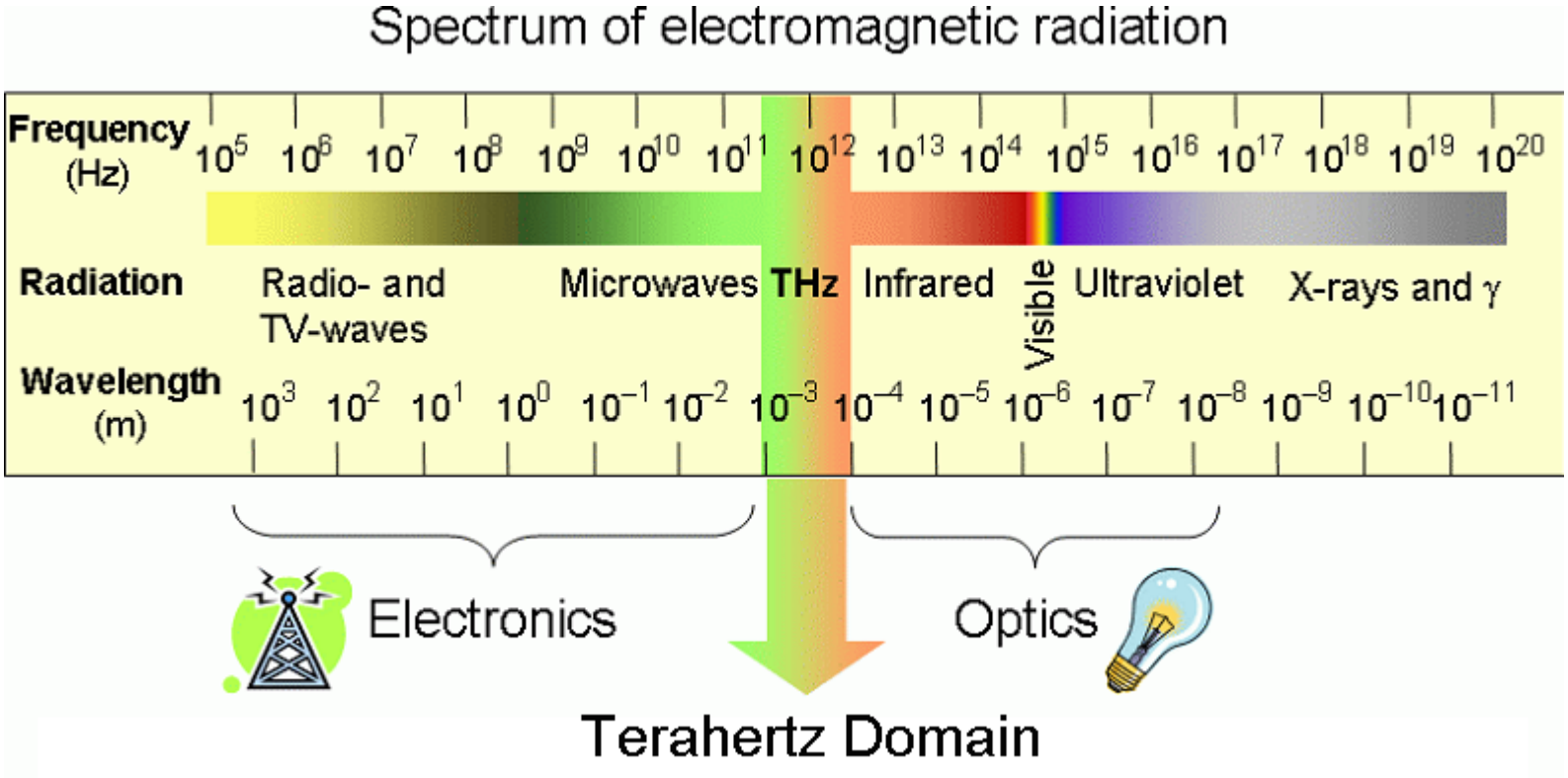
Leveraging Telecom Manufacturing Techniques to Improve THz Technology

Terahertz Spectrum



- THz radiation was difficult to produce and detect
  - Large, power hungry sources
  - Liquid Helium cooled bolometers for detection
- New materials and techniques have made it easier

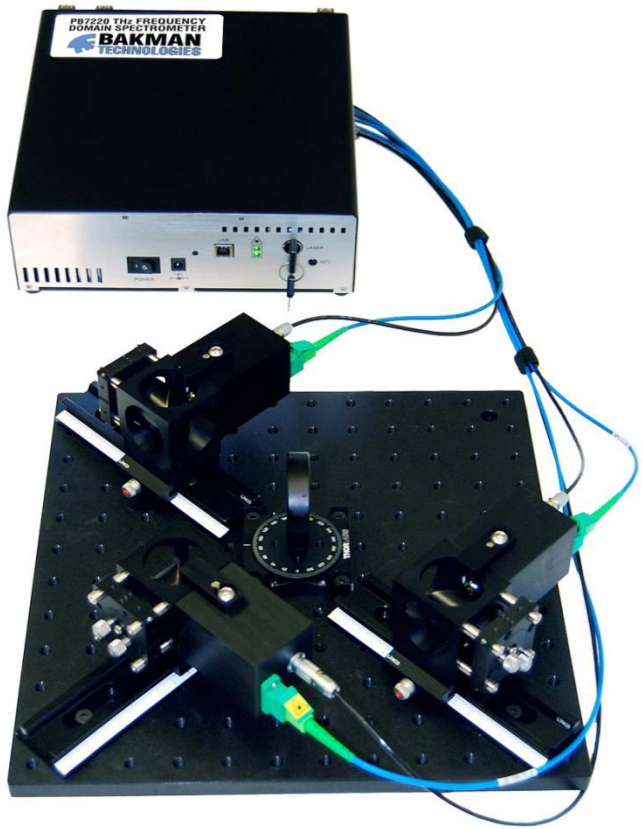
Terahertz Applications

- Interest in the THz frequency domain:
  - Eye safe and not a health hazard
  - Penetrates dielectrics
  - Capable of performing spectroscopic and dispersion analysis

- Several areas of potential use:
  - Screen individuals for weapons, explosives, drugs, etc.
  - Cancer detection, medical inspection and imaging
  - Biochip analysis of DNA, proteins and biological materials
  - Non-contact detection of chemical and biological agents
  - Non-destructive evaluation of artwork, corrosion under painted surfaces etc.
  - Monitoring manufacturing processes
  - Semiconductor and materials characterization

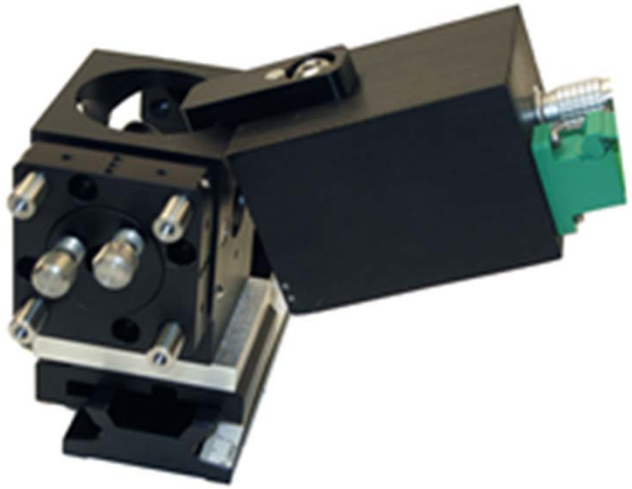
PB7220 Series of THz Spectrometers

- Continuous sweep: 100 GHz to over 2 THz
- Resolution better than 250 MHz
- Single frequency dwell possible
- Room temperature detection
- Transmission and/or reflection modality
- One and Two channel systems
- Integrated lock-in amplifier
- Portable with 12 hour battery
- Turn key operation with USB interface
- Extremely versatile and easily adaptable to any optical wavelength DFB laser



Adaptable THz Source and Detector Heads

- Snap together construction, no tools required
- Configurable for different THz beam path lengths
- Custom electronics in each head enables long tethering (> 5 meters)
- The Low Temperature Grown GaAs photomixers are easily replaced
- Telecom packaging techniques
- Welded photomixer construction enables reliable operation to 4.5 K
- Circular or linear polarization



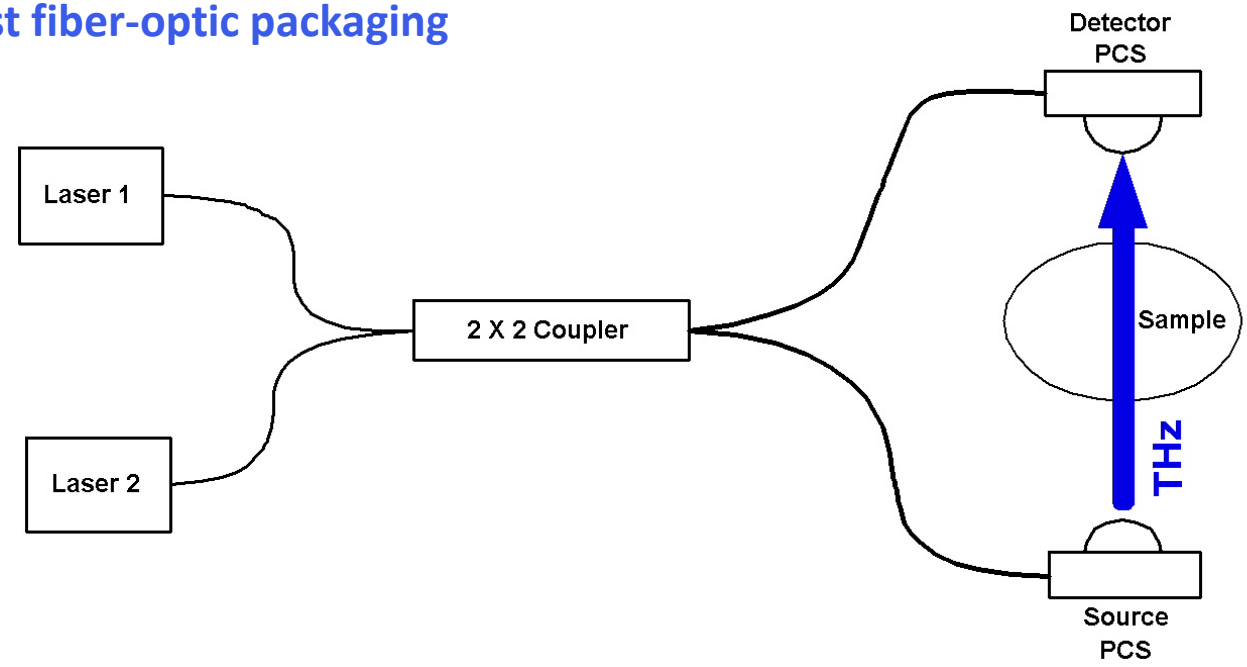
Typical Specifications

Performance Highlights

Parameter	Min	Typical	Max	Units
System Bandwidth	1700	1850	2100	GHz
Spectral Purity	0.010	0.015	0.025	GHz
Frequency Resolution	100	1000	5000	MHz
Dynamic Range @ 100 GHz	65	70	75	dB Hz
Dynamic Range @ 1000 GHz	40	55	60	dB Hz
Dynamic Range @ 2000 GHz	30	40	45	dB Hz
THz Beam Diameter @ 500 GHz		6		mm (FWHM)
THz path length	10	25		cm
Tuning speed		10		GHz/sec
Electronic Chopping Frequency		6000		Hz

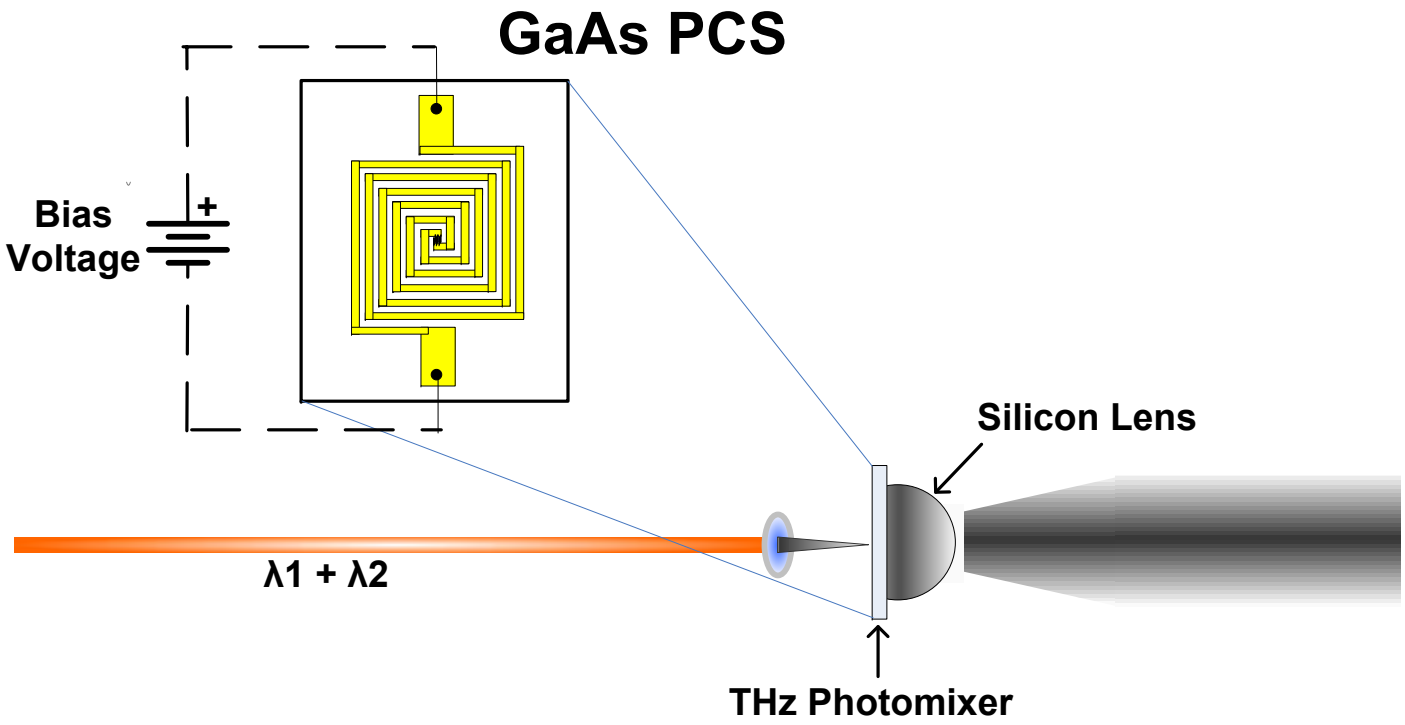
THz Generation and Detection Technique

- Multiple methods for THz generation and detection exist, but we employ photomixing
  - **Heterodyned semiconductor DFB or DBR 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 using a similar photomixer**
  - **Photomixers are Low Temperature Grown GaAs**
  - **Low-cost fiber-optic packaging**



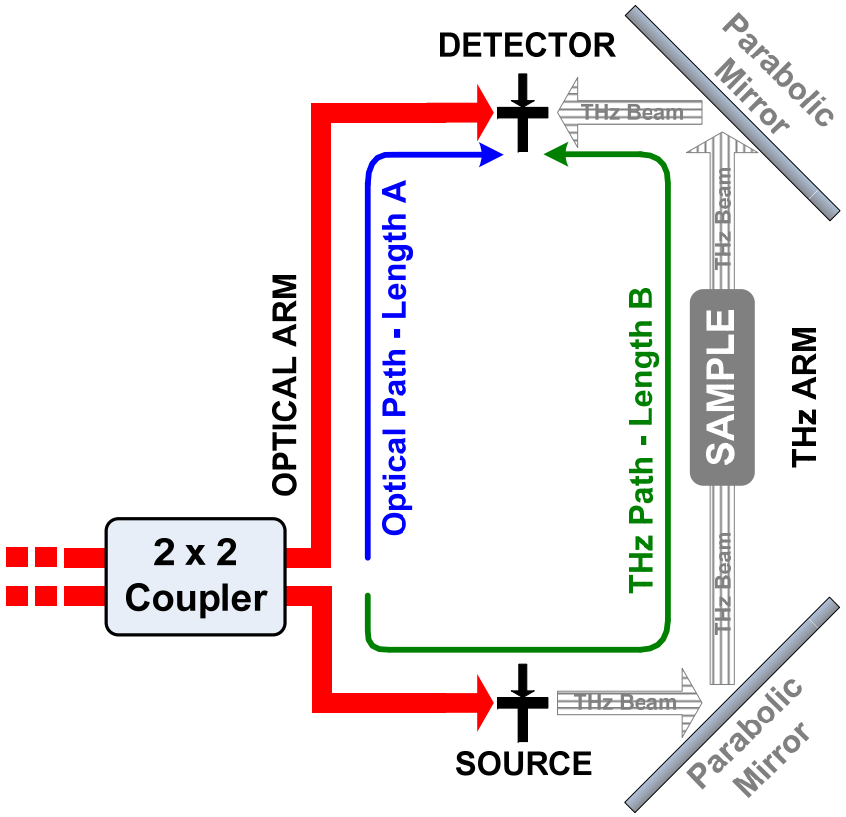
Photomixing

- Generation: optical radiation focused onto the center of an antenna biased with an electrically chopped voltage.
- Detection: optical radiation focused onto the center of an antenna attached to a lock-in amplifier
- Silicon lens for index matching, collimation and coupling to free space



Photomixing System is an Interferometer

- Interferometer is formed between output of heterodyne optical coupler and detector photomixer
- Fixed difference but changing wavelength (frequency)



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

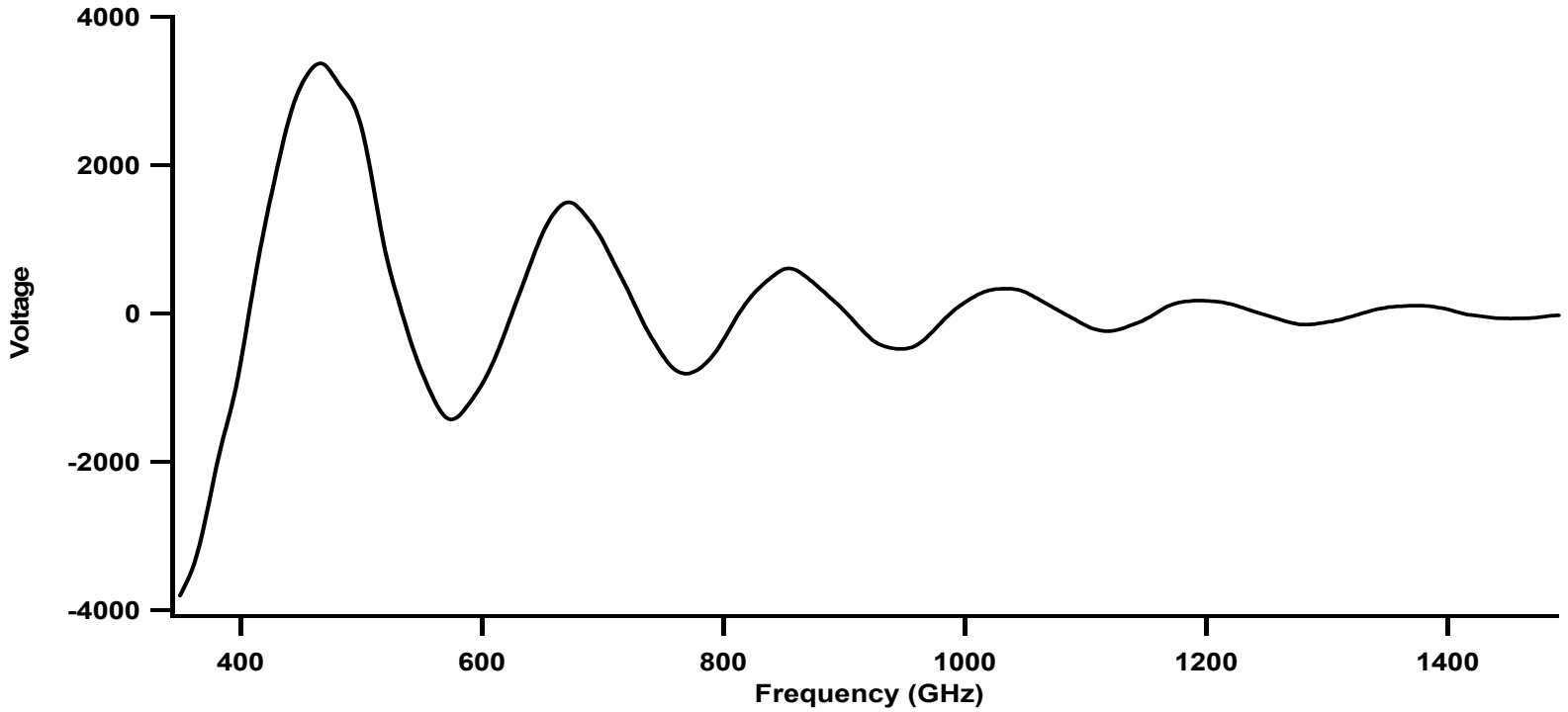
$$I_{out} \propto 1 + \cos(k \cdot \partial L)$$

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

Combined sample, photomixer, antenna and system path dispersion term

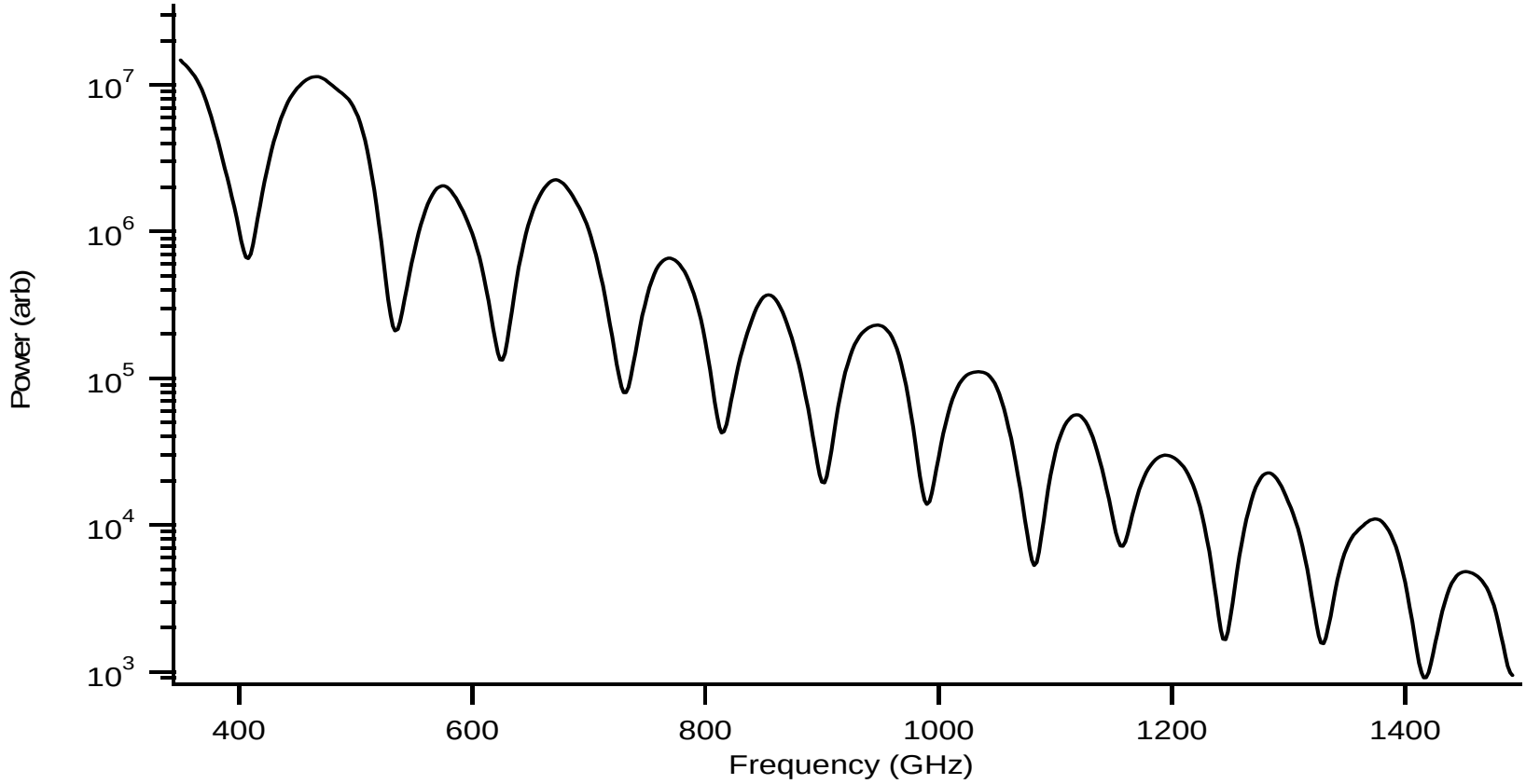
Voltage vrs. Frequency

- THz tuning is achieved by changing the differential wavelength of the two lasers
- At 780 nm wavelength (.075 nm/°C * 480 GHz/nm) = 36 GHz/°C
- Recorded lock-in voltage variation is due to coherent detection



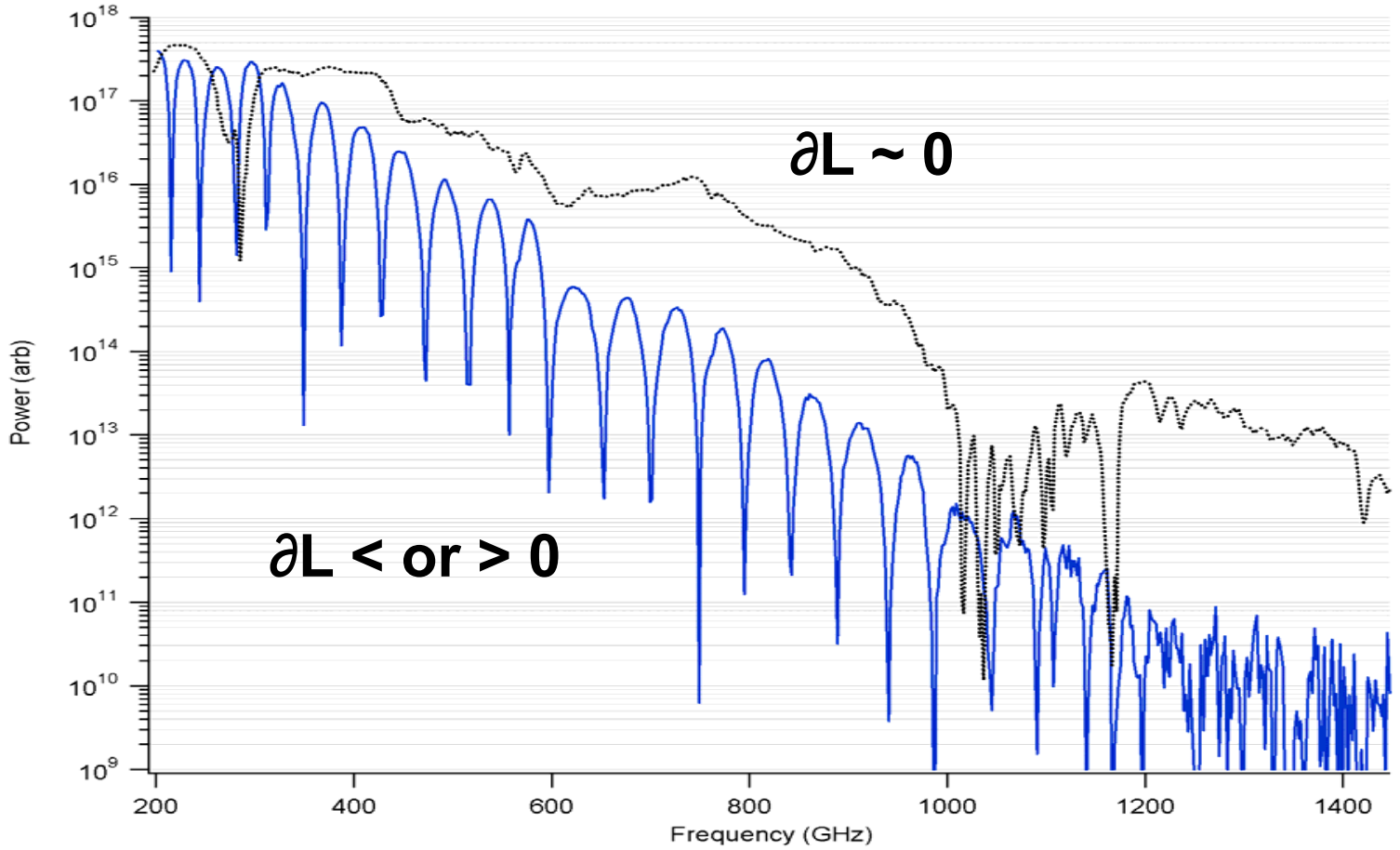
Power vrs. Frequency

- Square the voltage to graph the detected power
- Allows logarithmic plot
- Produces “fringe pattern” with ∂L dependent spacing



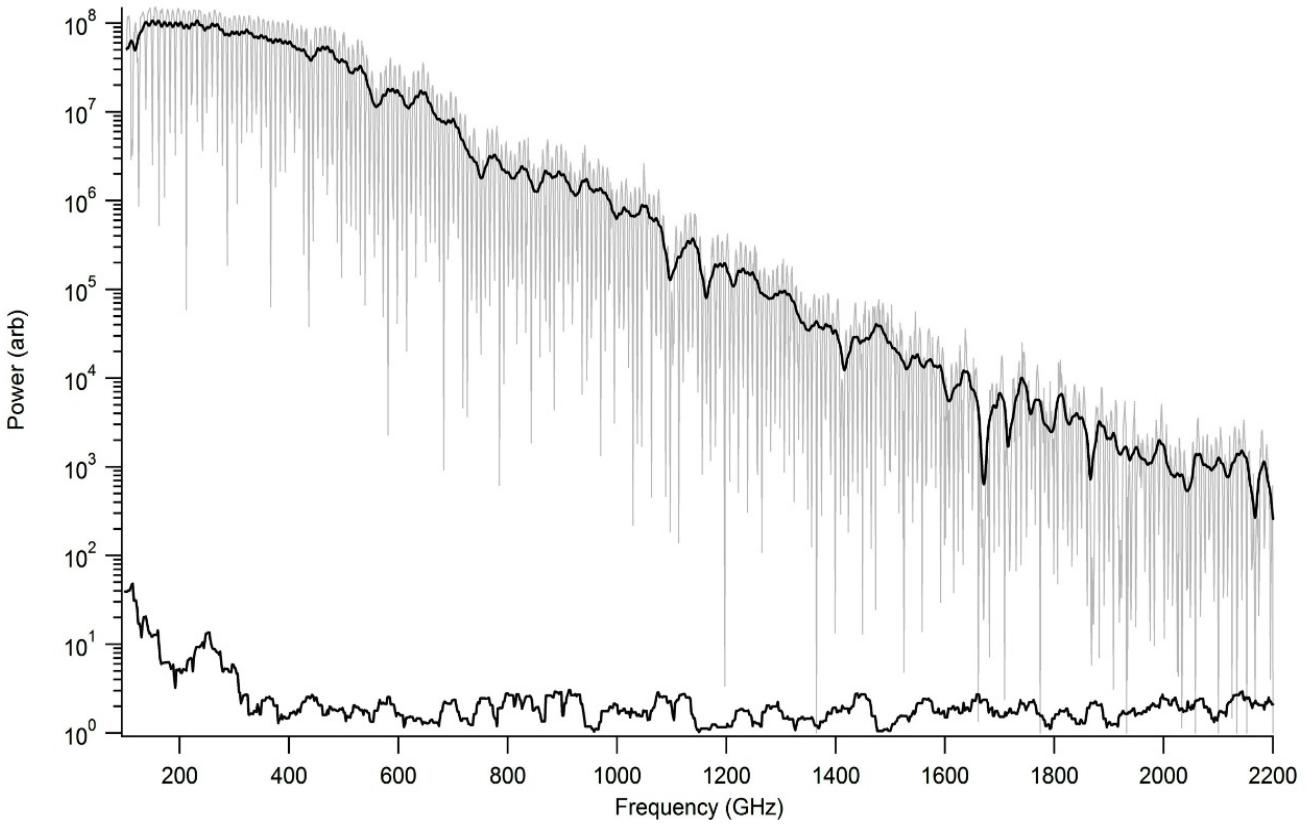
Two Regimes of Operation

- ∂L much greater or less than zero (lots of fringes)
- ∂L close to zero (few or zero fringes)



Unbalanced System

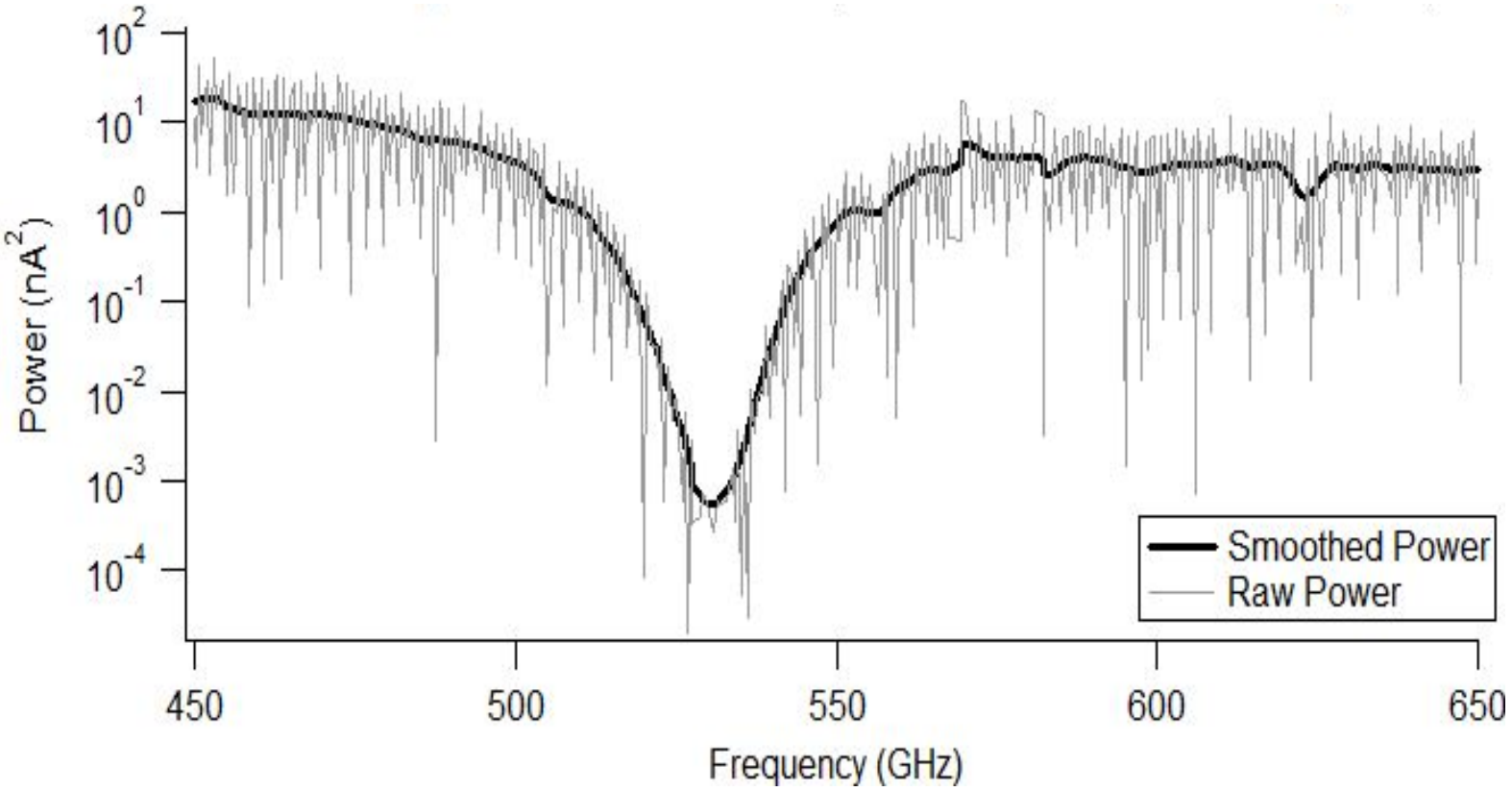
- ∂L much greater than zero and many fringes in region of interest



A single scan of laboratory air at 1 ATM with a PB7220-2000-T - THz Spectrometer (1 sec time constant, 1 GHz resolution) compared to the noise floor (blocked THz beam). A twenty point smoothing was applied to remove the fringe pattern for the black traces.

Lactose Spectrum

- Smoothing employed to remove fringe pattern from the lactose line at 531 GHz
- Can still resolve shoulders on the Lactose feature
- An unknown feature at 625 GHz, filler material?



Balanced System

- ∂L close to zero and no fringes in region of interest

Air at 1 ATM with water vapor transitions present. An average of 10 scans. No smoothing was performed because head spacing was adjusted to remove interference fringes from the region of interest.

Summary

- Portable, compact, CW swept-frequency THz spectrometer
  - 100 GHz to ~ 2 THz continuous sweep or specific frequency-hopping
  - Frequency resolution ~ 200 MHz
- Flexible two-piece, fiber-coupled system adaptable to wide range of applications
- Available with two detection channels and an extra detector for simultaneous measurements
- Fully integrated DSP control and Windows interface with port for external computer or software control
- Low cost design leverages telecom fiber-optic packaging

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