Analysis of THz Time-Domain Etalon Systems for Material Property Extraction

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Introduction and Objective

In THz time-domain spectroscopy (THz-TDS) any dielectric slab used as an optical element often contributes multiple reflections of THz pulses and therefore acts as an etalon. These can arise from standard optics such as non-linear crystals used for electro-optic sampling but also may carry meaningful information from samples themselves. Unfortunately to obtain high frequency resolution these reflections must be measured and thus contribute to the measured spectra. We investigate the use of a method to remove etalon oscillations from THz transmission complex spectra and its effect on isolating signals of interest in our samples and extraction of material parameters.

Optical Etalon

- Etalon acts as an optical resonator with resonant frequencies (**Figure 1**).
- Using THz-TDS the transmitted THz pulse is recorded as a function of time
- For large times, etalon reflections appear in the time trace.

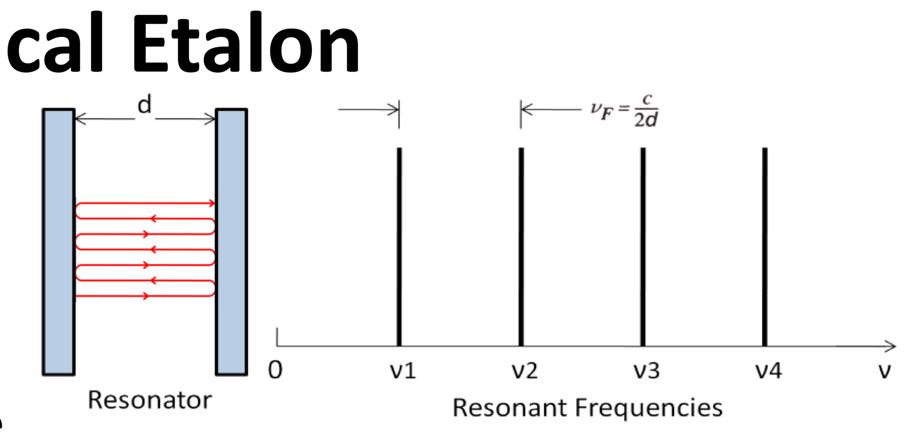
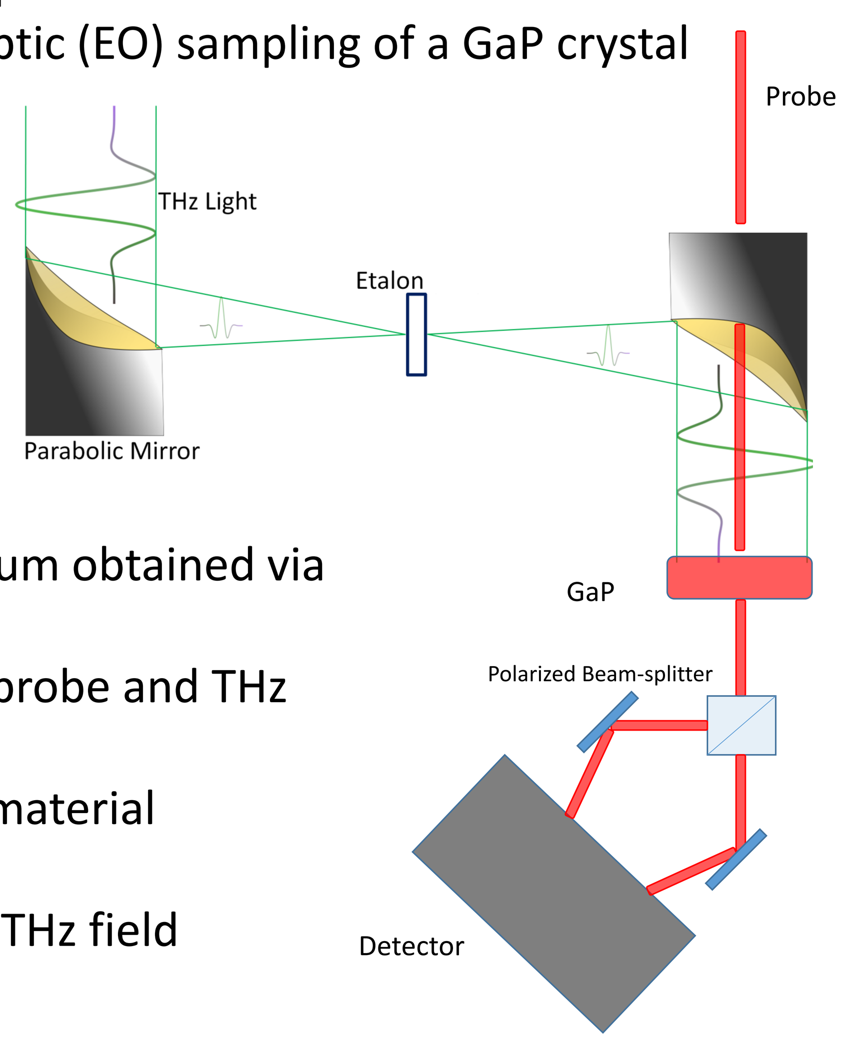


Figure 1: Optical Etalon produces resonant frequencies with a characteristic spacing

THz Time-Domain Spectrometer

The THz radiation source is a free space time-domain THz spectrometer, capable of producing a broadband pulse between 0.1 and 2 .5 THz. The waveform is obtained via electro-optic (EO) sampling of a GaP crystal

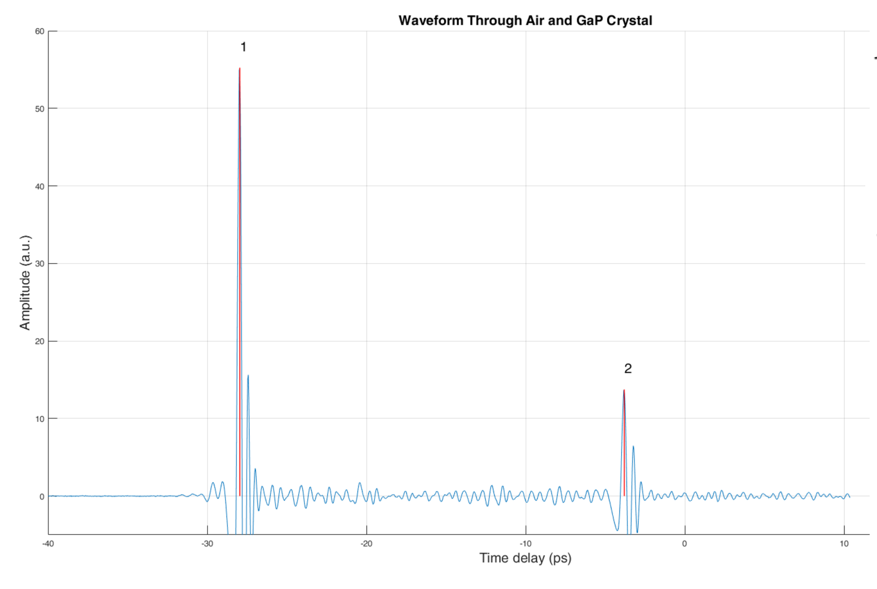
Figure 2: THz Transmission Spectroscopy. The THz pulse is focused through a sample and sent to a GaP crystal for EO-sampling



- High-resolution THz field spectrum obtained via "pump-probe" technique
- Control relative delay between probe and THz beam in GaP crystal
- Polarization change induced in material (Pockel's effect)
- Change directly proportional to THz field amplitude

Method

- Model obtained time signal as the main waveform $A_0(t)$ and a series of deltas with heights a_i [1]
- Use convolution theorem to separate the contribution of the main signal and the etalon contribution in the Fourier (frequency) space
- Etalon part can be separated, divided out, and normalized (*N*) to isolate the main waveform spectrum $E_0(f)$.
- Apply the same correction to the phase of the complex spectrum



$$A(t) = A_0(t) \text{ x } \sum_{i=0}^{\infty} a_i \delta(t_i)$$

Equation 1: TD-THz signal and convolution

$$E_0(f) = E(f) \text{ x } \frac{N}{\mathcal{F}(\sum_{i=0}^{\infty} a_i \delta(t_i))}$$

Equation 2: Isolating main peak contribution in frequency space

Figure 3: The algorithm identifies the main pulse and subsequent reflection peaks

Results

GaP Crystal

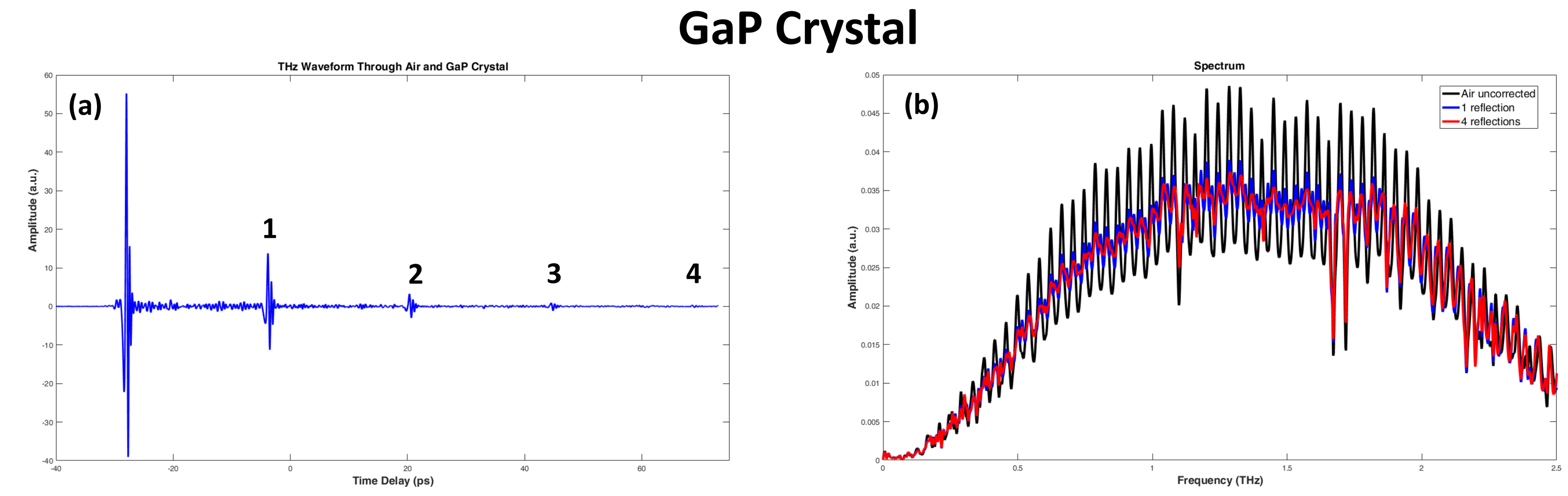
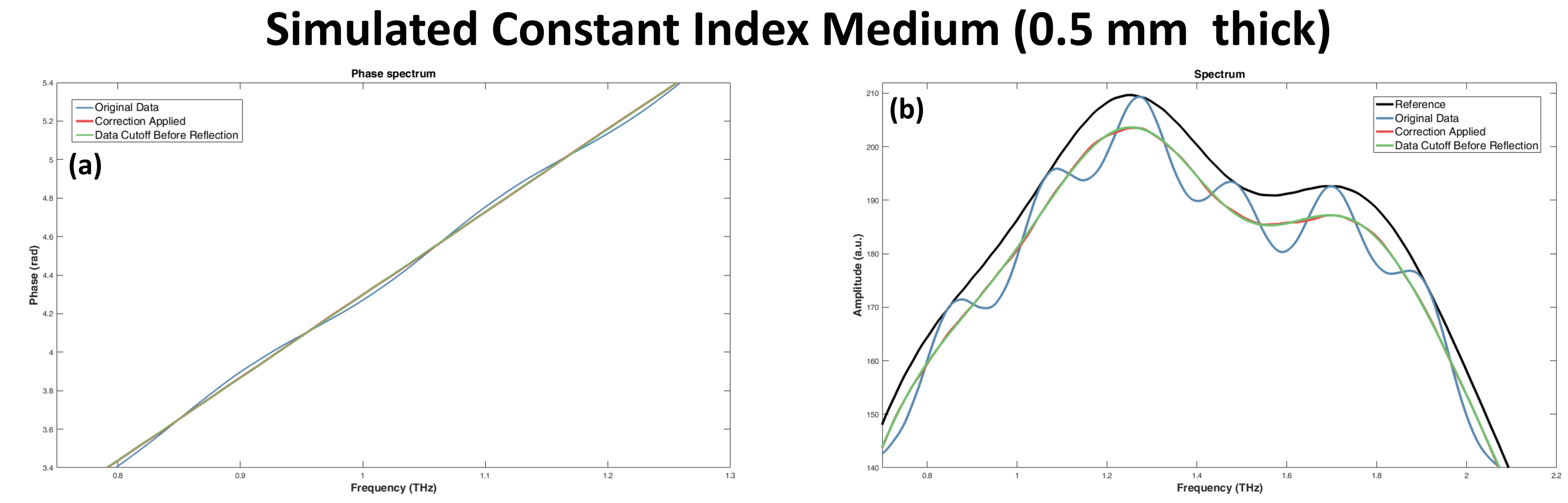
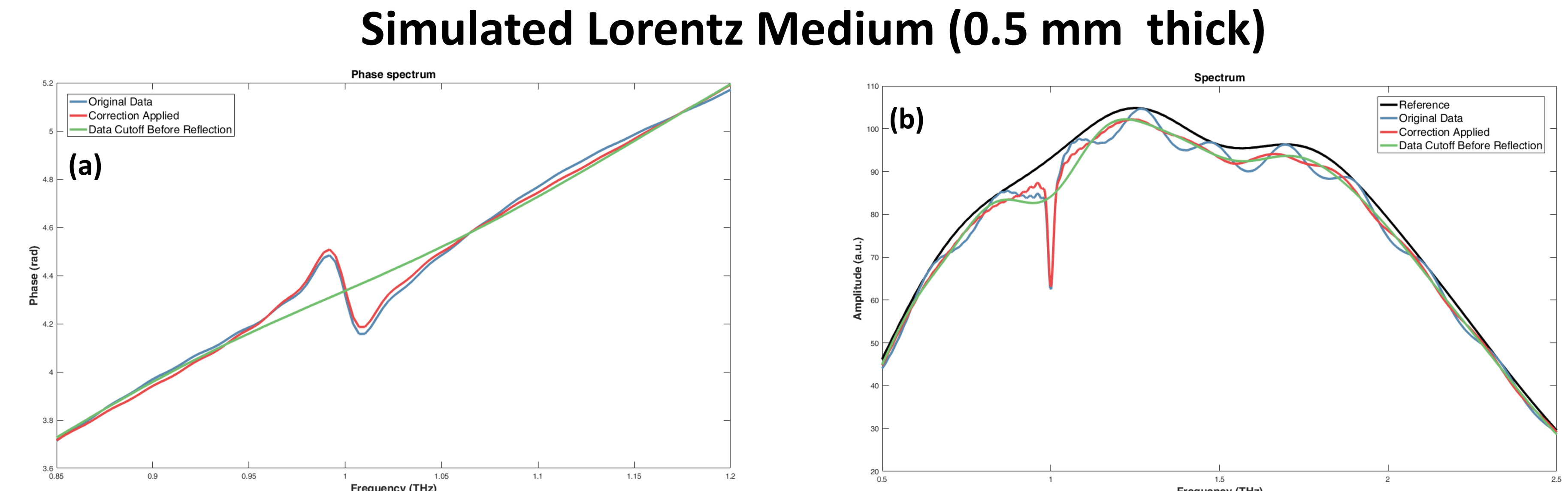


Figure 4: a) Time trace of a 4 reflection THz pulse through N_2 purged air. **b)** Removal of GaP reflections in the spectrum. Water absorption lines at 1.1 and 1.7 THz are preserved.

Simulated Constant Index Medium (0.5 mm thick)



Simulated Lorentz Medium (0.5 mm thick)



Figures 5 & 6: The **a)** phase and **b)** spectrum of the original dataset, corrected set and a dataset with no etalon contribution for a medium of index n = 1.41 and a Lorentz Medium with a 1 THz resonance. Note the corrected set (red) closely matches the 0 reflection set (green) while preserving key absorption features

Extracted Material Properties

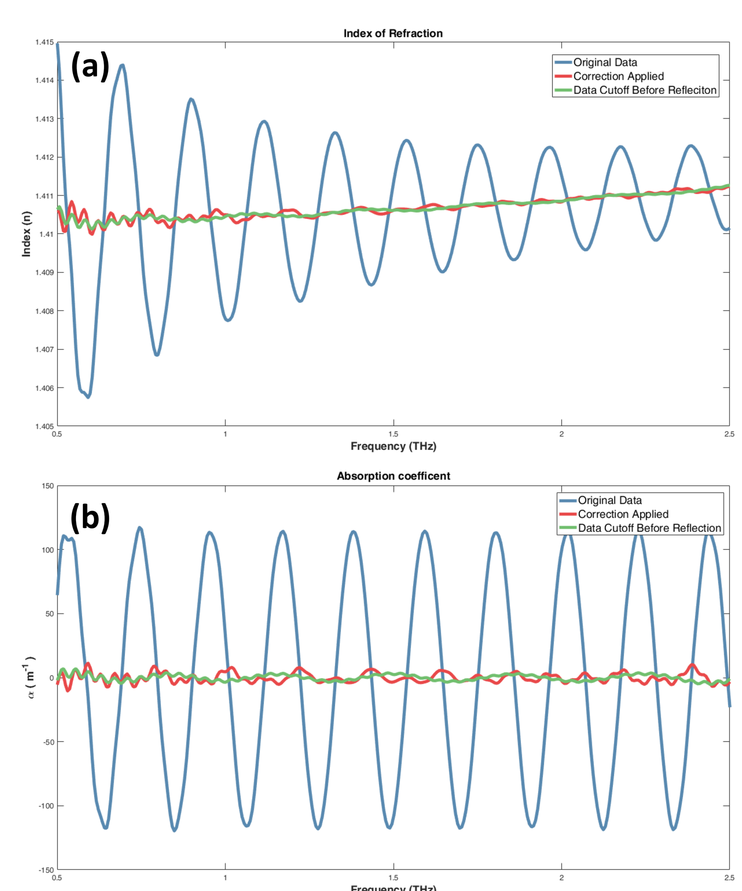


Figure 7 (Left): (a) Calculated index of refraction and **(b)** absorption coefficient for a constant index material

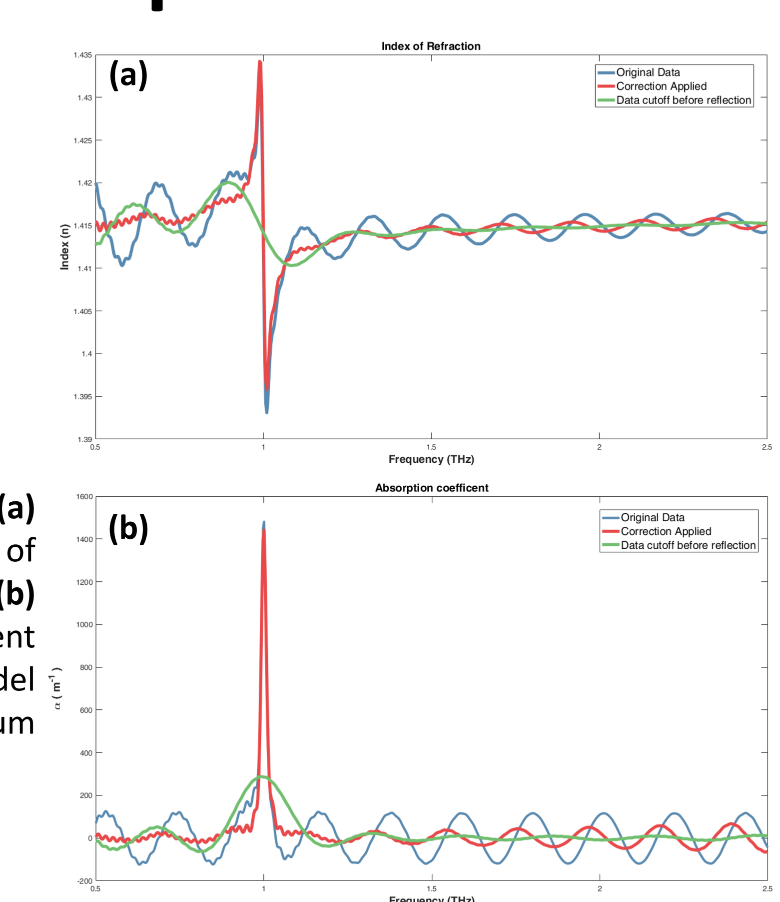


Figure 8 (Right): (a) Calculated index of refraction and **(b)** absorption coefficient for a Lorentz- model based medium

Conclusion

Utilizing a standard method [1], we reduced the etalon oscillation contribution present in measured time-domain THz traces in both reference, and simulated samples. This enables better identification of signals of interest that would otherwise be hidden in the etalon modes. Additionally, a reduction in oscillations while keeping a high frequency resolution allows for easier index of refraction calculations and model fitting. Using this better understanding of the effect of reflections on spectroscopic data and how to correct for it, future work will involve modelling the coupling of such optical etalon systems to the magnetic dynamics of materials of interest in the field of spintronics.

Acknowledgements

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Reference

[1] M. Naftaly and R.E. Miles, *Optics Communications*. 280, 291-295 (2007)

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