Online Tire Ply Thickness Fabric Cord Balance Measurements Using Terahertz

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Presentation Agenda

1) Reasons for Online Measurements

Online Real Time Higher Density Measurements are used to

- Increase Product Quality
- Reduce Material Cost
- Measurement of Fabric Cord Products

2) Measurement Method - Terahertz (THz)

- Time-of-Flight (ToF) Measurements of Layer Interface Reflections
- Auto Calibration (STDZ) to Account for Possible Material Property Variations

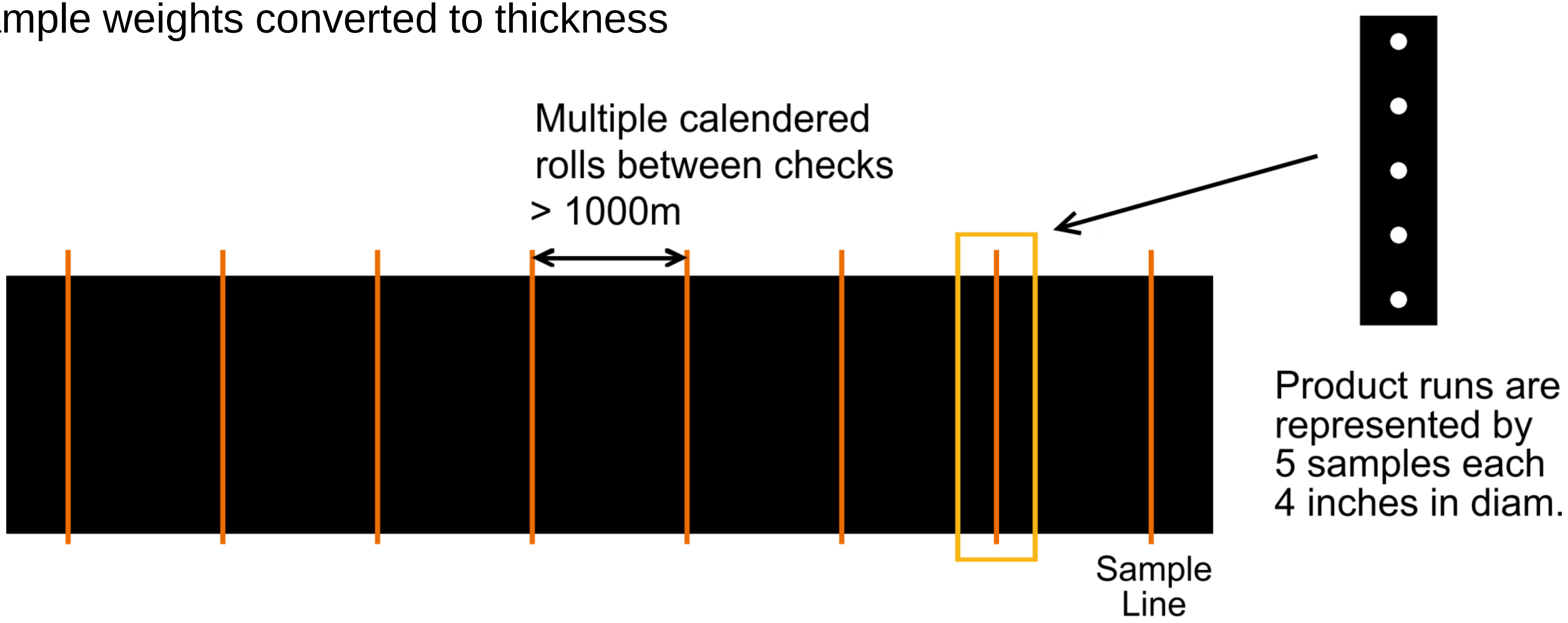
3) Results

- Correlation to Plant Measurements
- Average Sheet Gauge and Profile

Reasons for Online Measurements

Increase Product Quality By Increasing Sampling Frequency

- Typical product checks are:
  - Unit mass samples taken manually at intervals greater than 1000m
  - 5 “punched” samples (100mm dia.) across the calender sheet
  - Sample weights converted to thickness

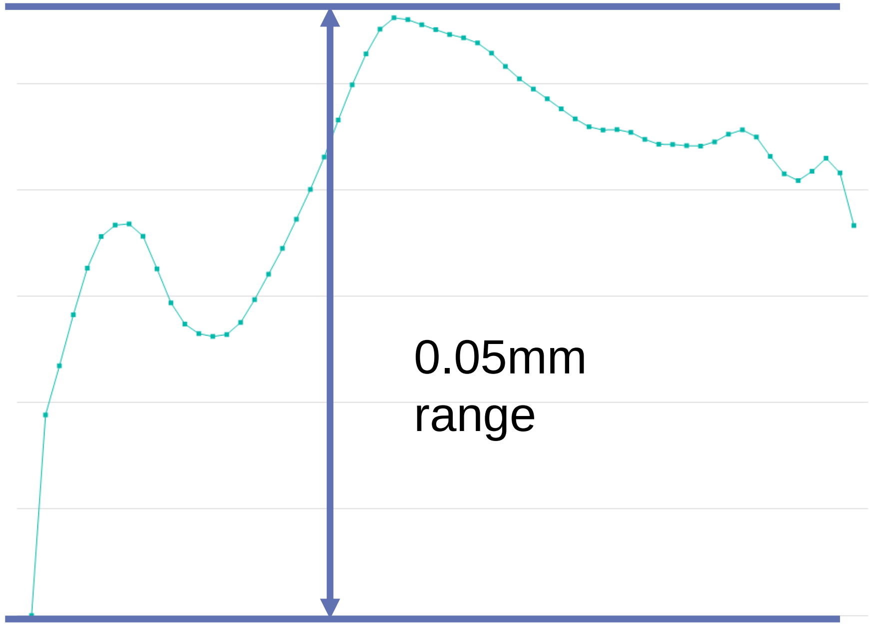


Reasons for Measurement

Reduced Material Cost

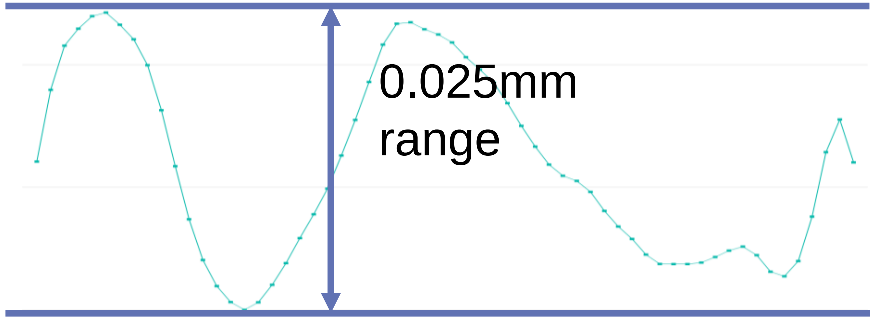
- Reducing gage by 0.01 mm can reduce material cost more than $500k/year
- Reducing variation in sheet gage will allow for target shifting → operating target slightly less than previously specified target

2 Week Average Sheet Profile of Product A



Reduced variation and opportunity for target shift

Optimized Sheet Profile of Product A

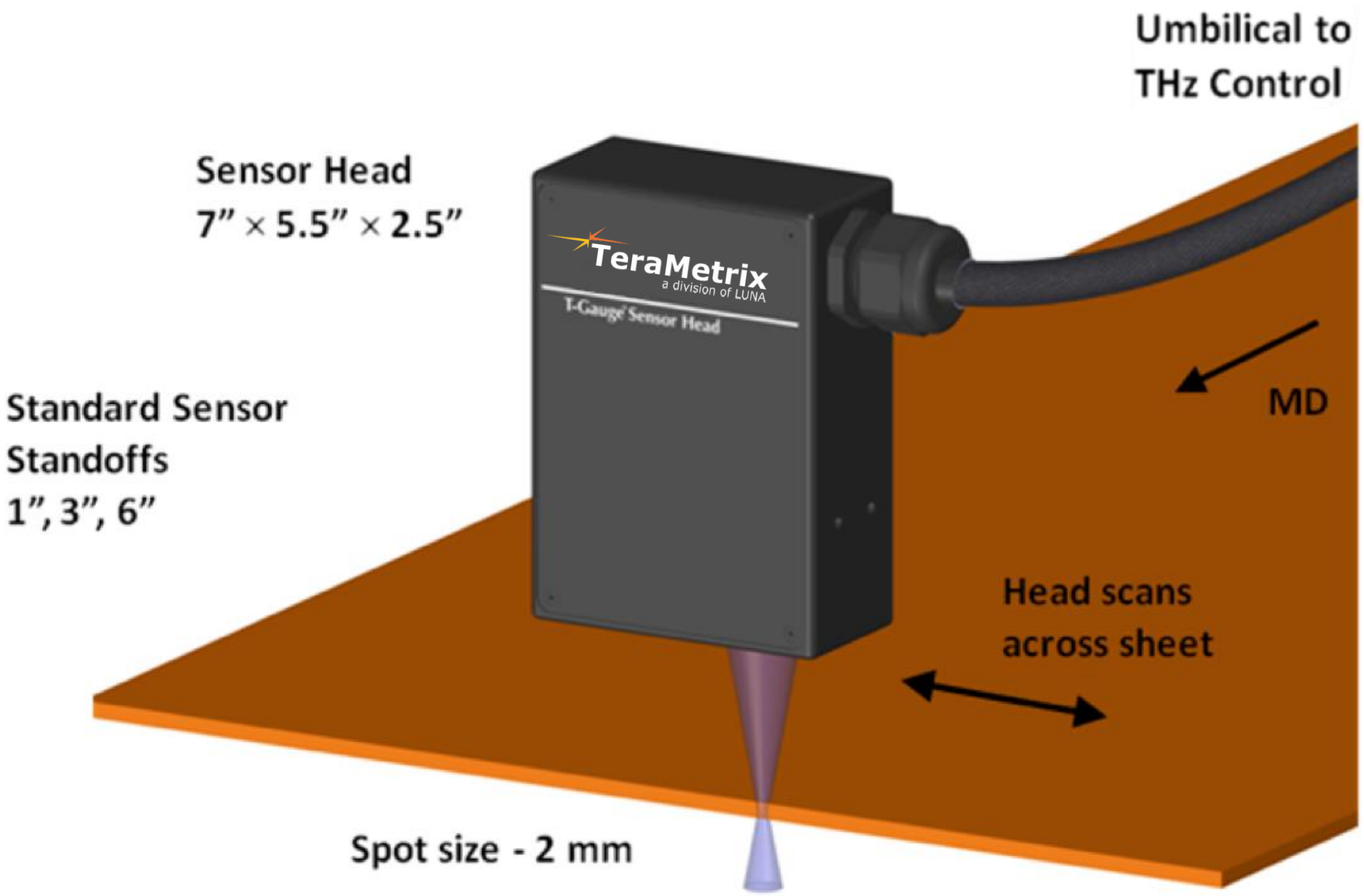


Measurement Requirements

- High accuracy measurement, especially for Total thickness
- Direct thickness measurement
- Measurement with all cord types, all fabric cords and steel cords
- Simultaneously measure multiple layers
  (i.e., find Top and Bottom Skim layer thickness values to obtain Balance)
- Maintain accurate measurements
- No safety concerns (i.e., NO nuclear or ionizing radiation)
- Ideally:
  - Single sensor measurement
  - Operate with a large standoff from sheet
  - Intuitive and easy for operators and engineers to setup and use

Terahertz Scanning Sensor

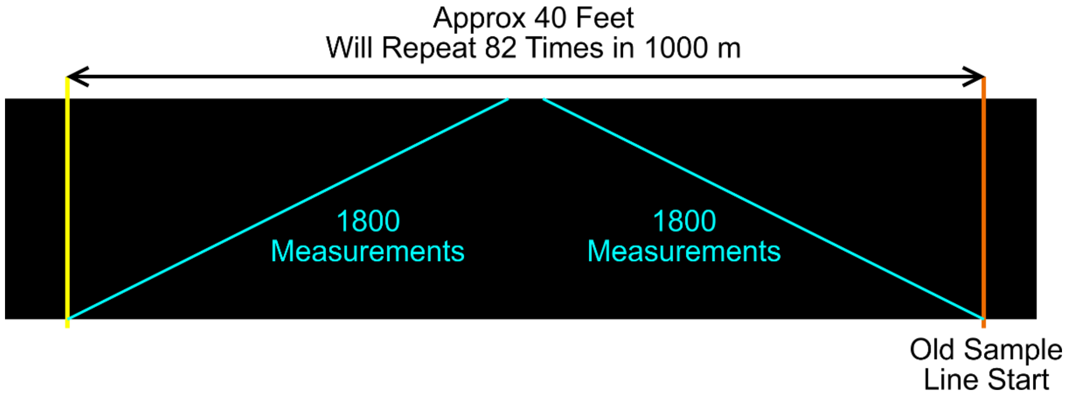
- Industrial Sensor is ruggedized to withstand harsh operating environments
- Sensor typically scans across sheet at 4 inches / sec
- Focus spot size is approx 2 mm in diam.
- The lens in the sensor can easily be switched offering choices for the sensor standoff

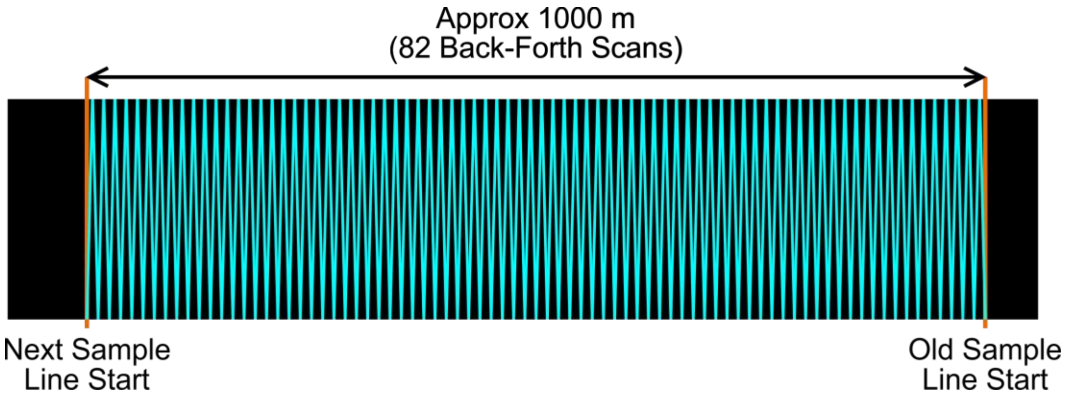


Reasons for Online Measurements

Increase Product Quality By Increasing Sampling Frequency

- THz systems make 100 measurements per second
- Sheet CD Scan time – 18 secs   Turn Around Time – 2 secs   Total Scan Time – 20 secs
- Expect approx. 3600 measurements in back-forth scan over 40 feet of product travel
- Nearly 300,000 THz measurements over 1000 m between current sample testing points



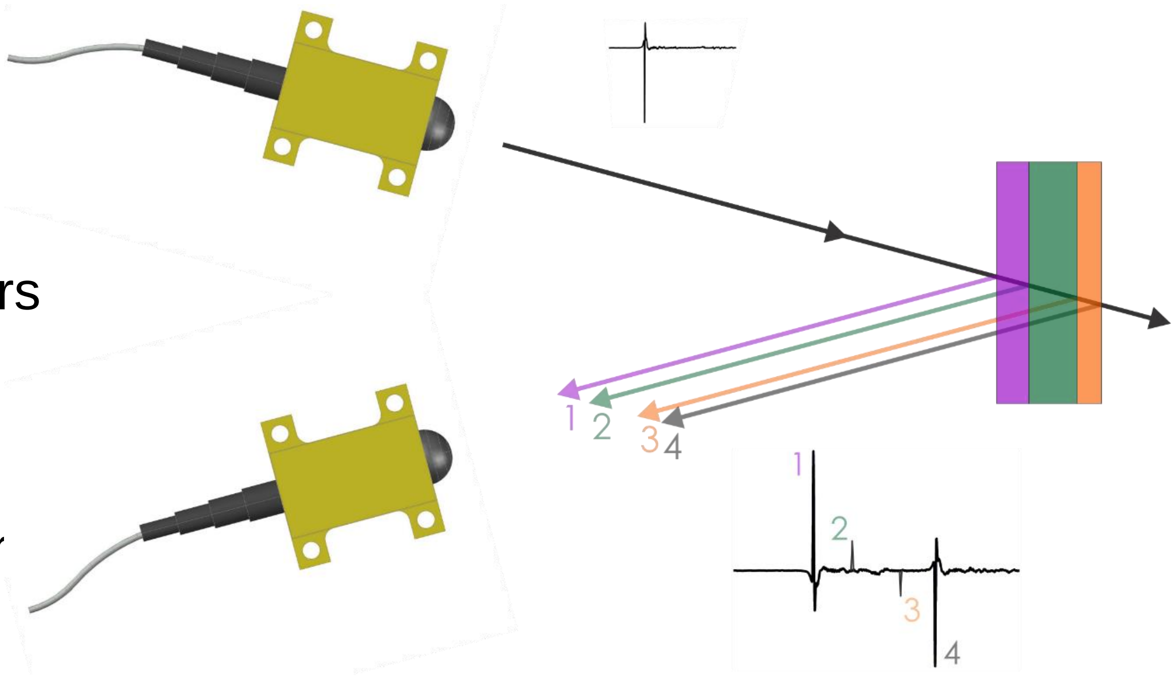


Measurement Method - THz

Terahertz (THz) systems are a relatively new method to make multiple product measurements

- Simultaneous multilayer thickness
- Single sided sensor
- Defect Detection (e.g., Delamination, missing cord?)
- Ply Density

THz Multilayer Reflections



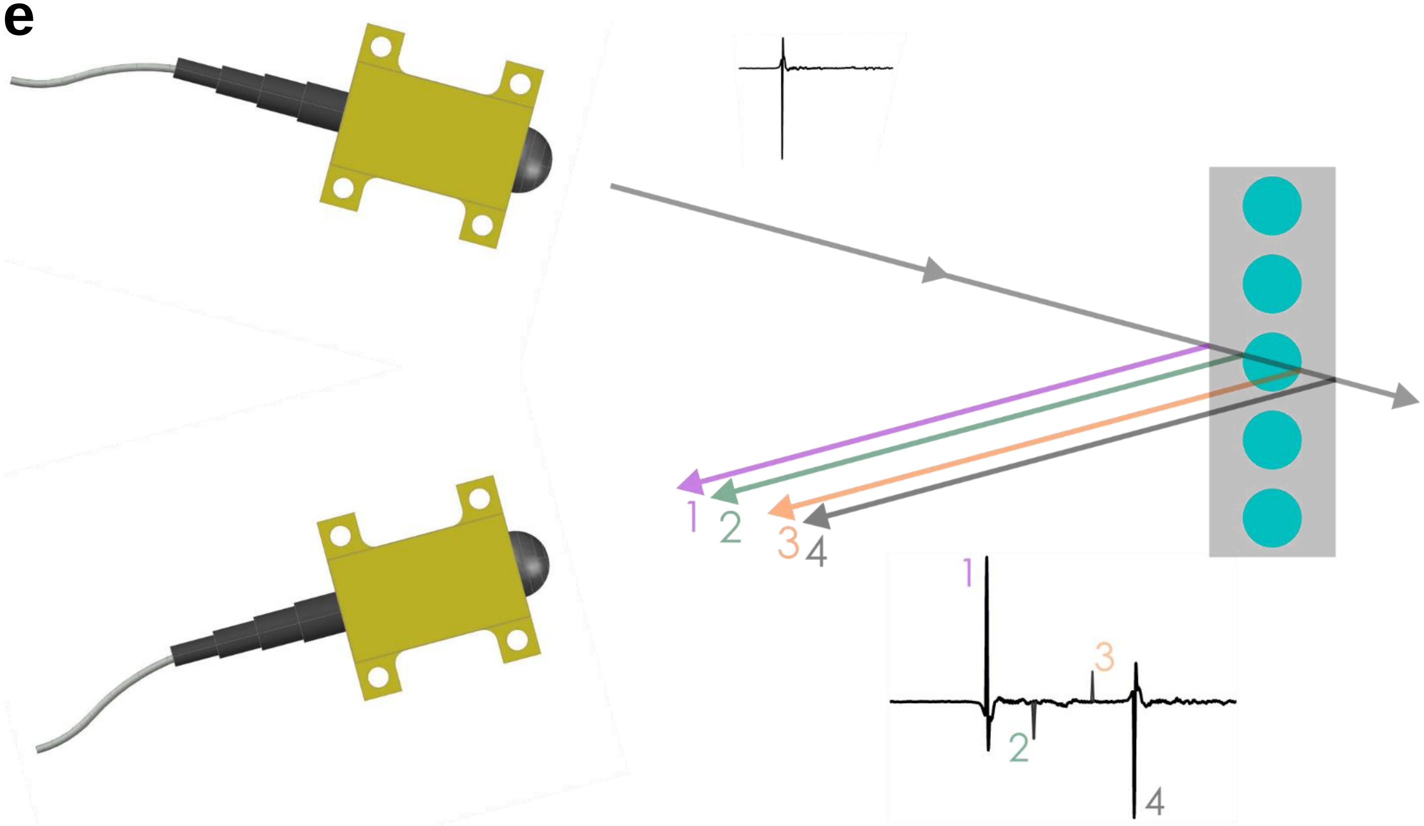
- Sensor emits a short, low power, safe pulse of energy
- Pulse travels through air and materials
- Reflections occur at any interface between layers
- These reflections travel back to the sensor and are recorded (i.e., waveform data)
- The TIME between reflections (Time-of-Flight or ToF) is used to calculate thickness

THz Measurement Method for Tire Ply Products

For tire ply products, it is possible to see the reflections from:

1) Top of the ply
2) Top of the fabric cord
3) Bottom of the fabric cord
4) Bottom of the ply

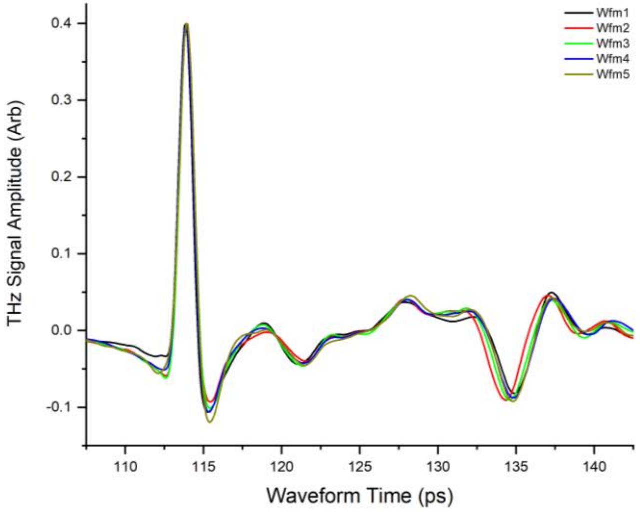
Top Skim layer, Bottom Skim layer and ply Total Thickness are all measured simultaneously



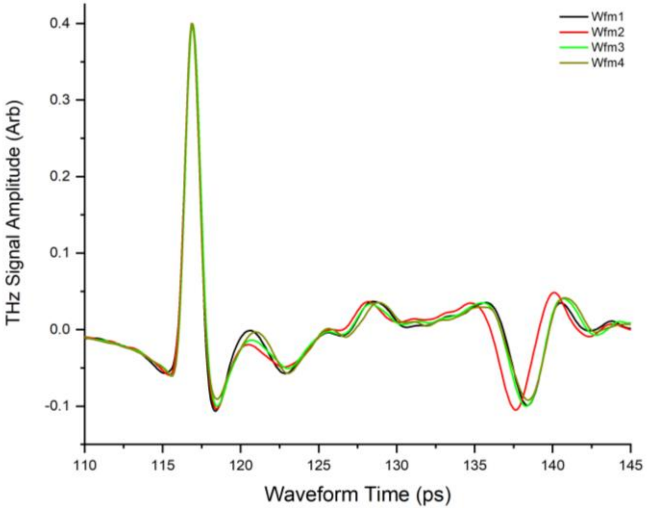
Example THz Waveforms

Multiple waveforms for individual Products show both overall consistency and normal expected variation within a Product

Product A

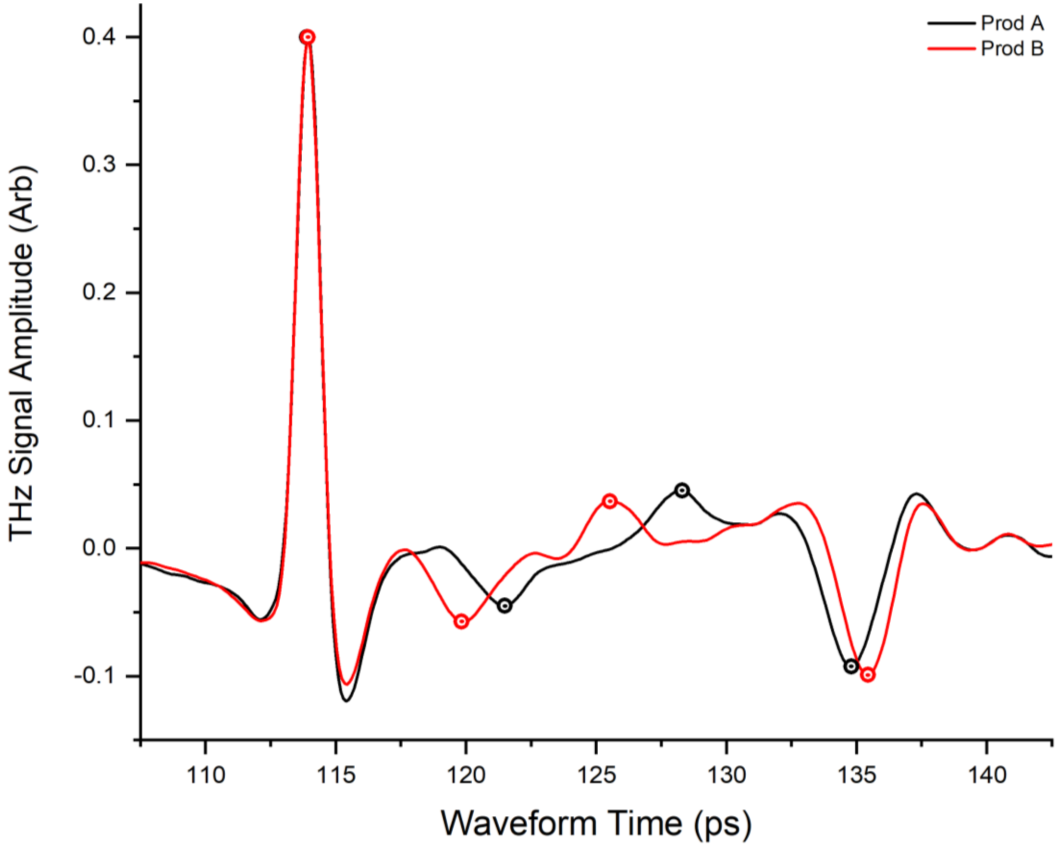


Product B



Comparing Products A and B

Clear differences are seen between Products



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Importance of Refractive Index (RI) Value

The equation to calculate the thickness of a layer is:

Thickness = (Time-of-Flight) / 2 * c / RI

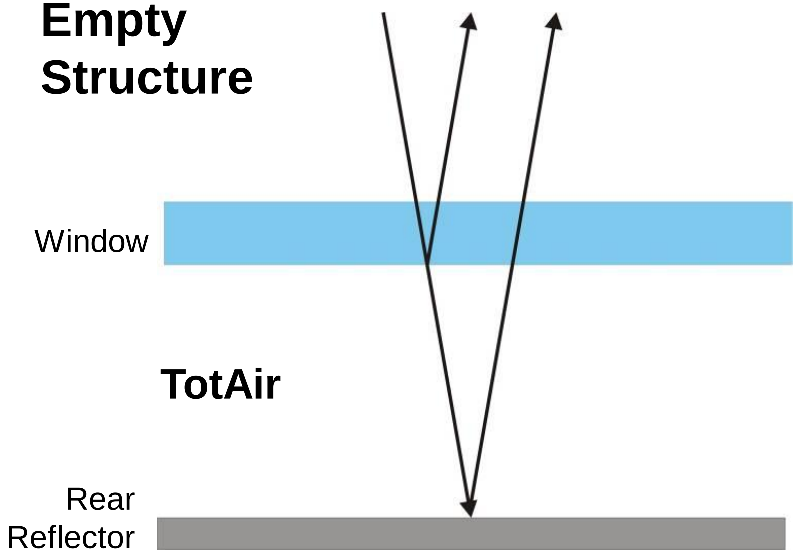
- RI stands for Refractive Index
  - This value is divided into the speed-of-light to find the velocity of the THz pulse through the sample material
- C is the speed of light
- Refractive Index values are typically stable
  - RI values are typically only measured once
  - However, a widely varying material stream may vary in RI
- Changes in RI will lead to accuracy errors

Refractive Index Calibration
External Reference Structure (ERS) Measurements

Using external components, it is easy to measure a material's instantaneous RI value

- Measure Empty Structure first and record Total Air Thickness $\Rightarrow$ "TotAir"
- Move structure on sheet and measure TopAir and BotAir
- Sample Thickness = TotAir – TopAir – BotAir
- RI is calculated from THz uncalibrated thickness divided by actual Sample Thickness

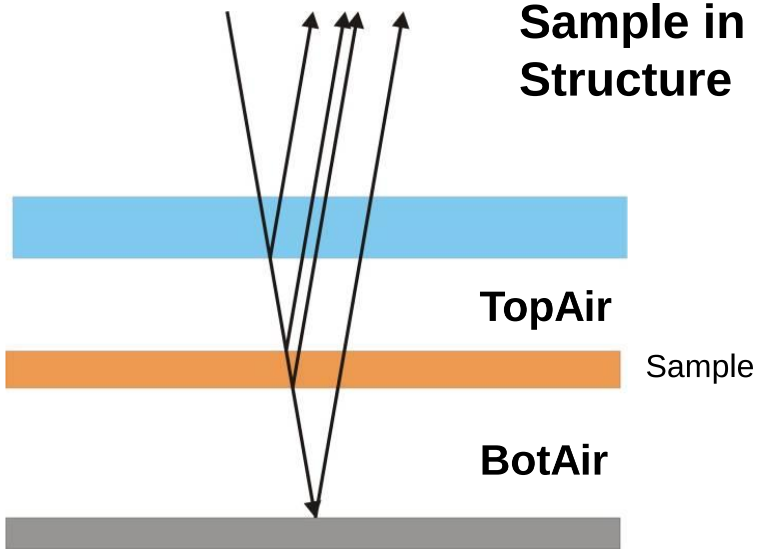
Empty Structure



Thk = TotAir – TopAir – BotAir

RI = Sample ToF Thk / Actual Thk

Sample in Structure



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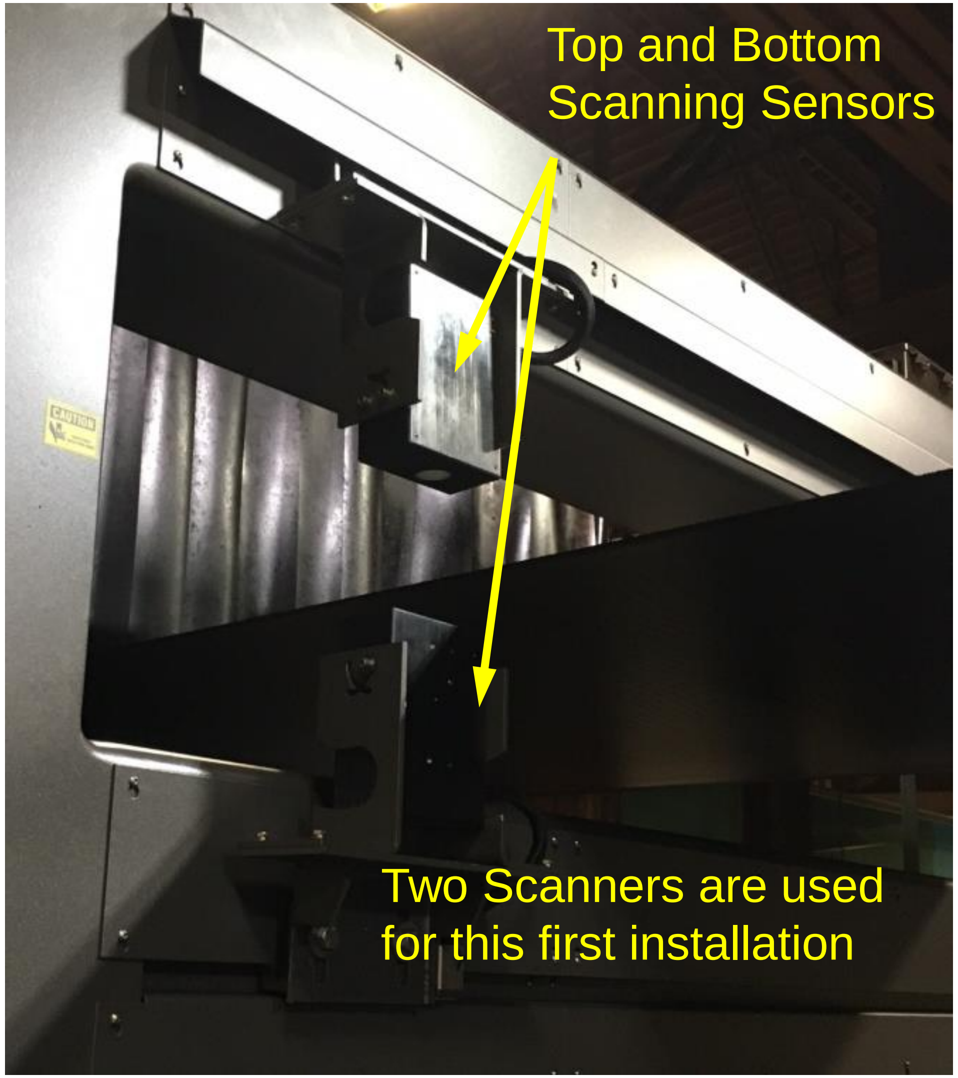
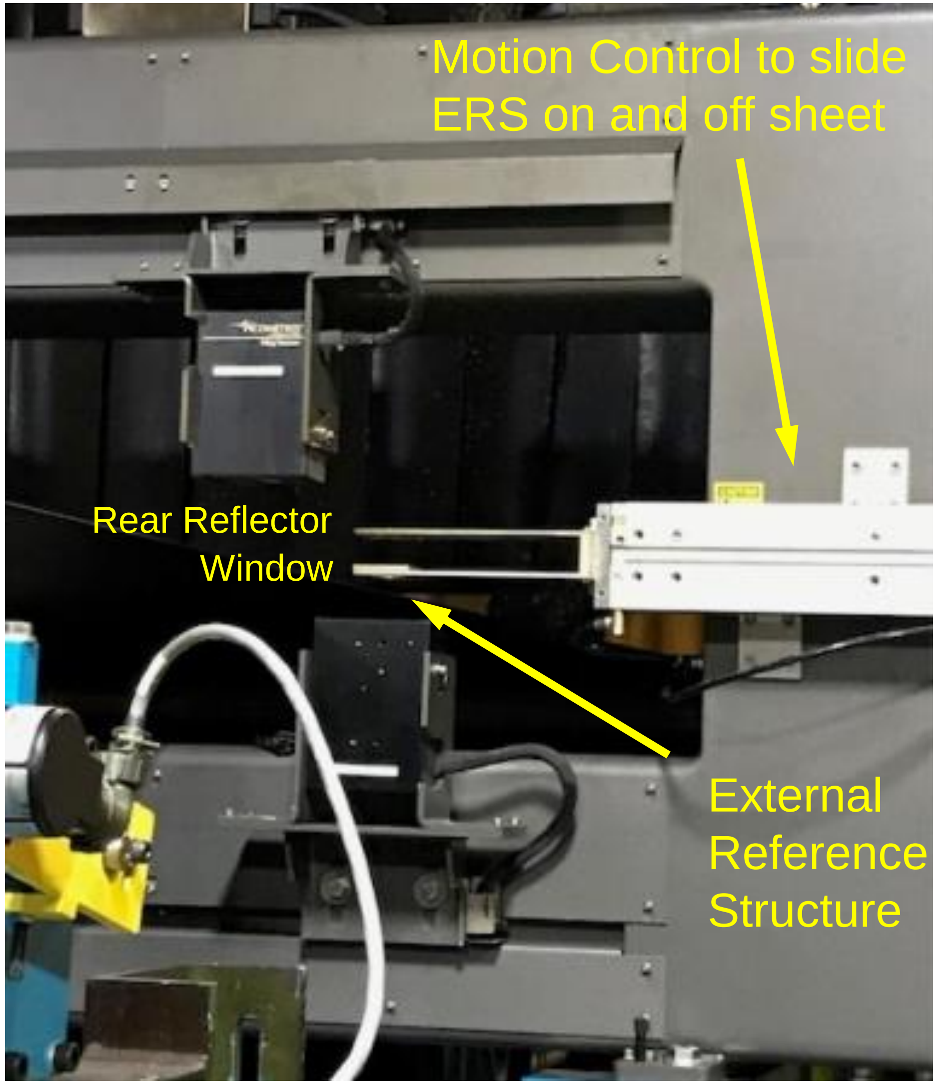
Installed Hardware





Refractive Index Standardization – RIMod values

- All Products use the same Universal RI value for Total thickness calculation (2.33)
- Using the ERS, the instantaneous RI value is found (STDZ process)
- RIMod = New ERS RI value / Stored single RI value (e.g. 2.31 / 2.33 = 0.991)
- This RIMod is used to correct the Universal RI value
- Five selected RIMod measurement sets

Prod Code	Overall RIMod	PreDec RIMod	Dec RIMod	Jan RIMod
I	0.987 ± 0.008	0.985	--	0.987
A	0.990 ± 0.010	0.995	0.988	0.992
D	1.035 ± 0.009	1.033	1.034	1.037
J	1.077 ± 0.009	--	1.077	1.070
F	1.104 ± 0.008	1.102	1.101	1.106

Effect of RIMod Variation - Product A

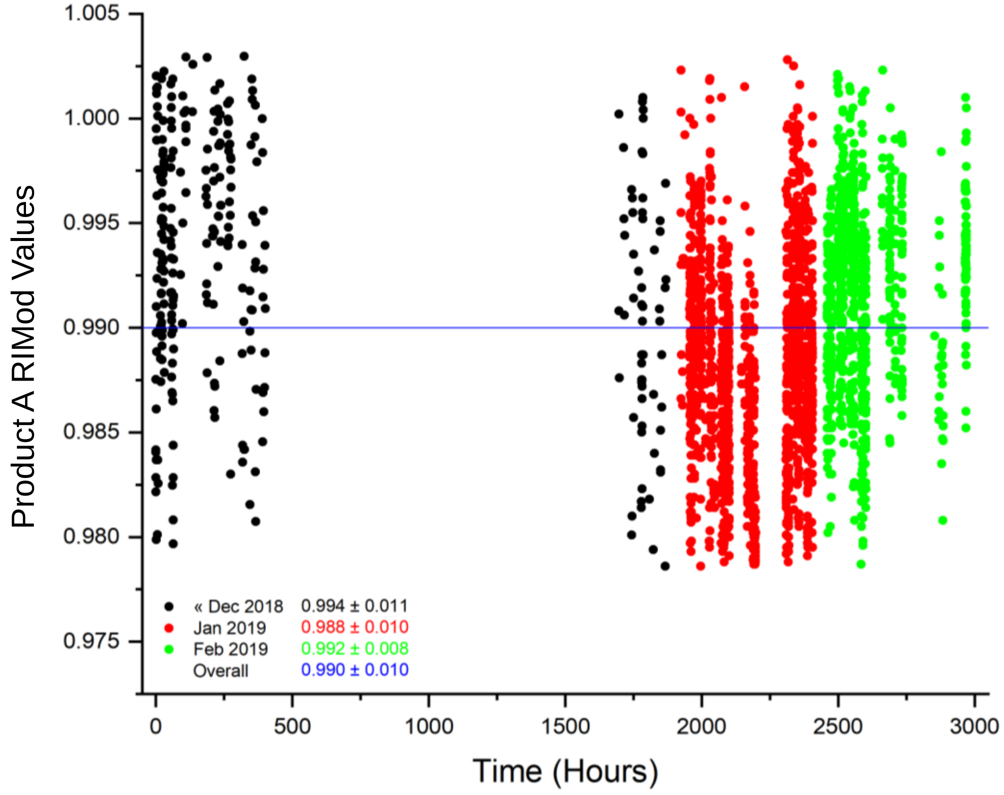
Refractive Index Modifier (RIMod) values over
4 months of operation: 0.990 ± 0.010 (±2σ)

<u>Universal Preset RI = 2.33</u>

- (RIMod Ave -2σ) = 0.98 ⇒ 2.33 * 0.98 = 2.283
- (RIMod Ave Nom) = 0.99 ⇒ 2.33 * 0.99 = 2.307
- (RIMod Ave -2σ) = 1.00 ⇒ 2.33 * 1.00 = 2.330

<u>Time-of-Flight (ToF) = 21.38 ps</u>

- Thk = (21.38 ps / 2 * 0.29979 / 2.283) = 1.404 mm
- Thk = (21.38 ps / 2 * 0.29979 / 2.307) = 1.389 mm
- Thk = (21.38 ps / 2 * 0.29979 / 2.330) = 1.374 mm



±15 microns difference without any control of RI

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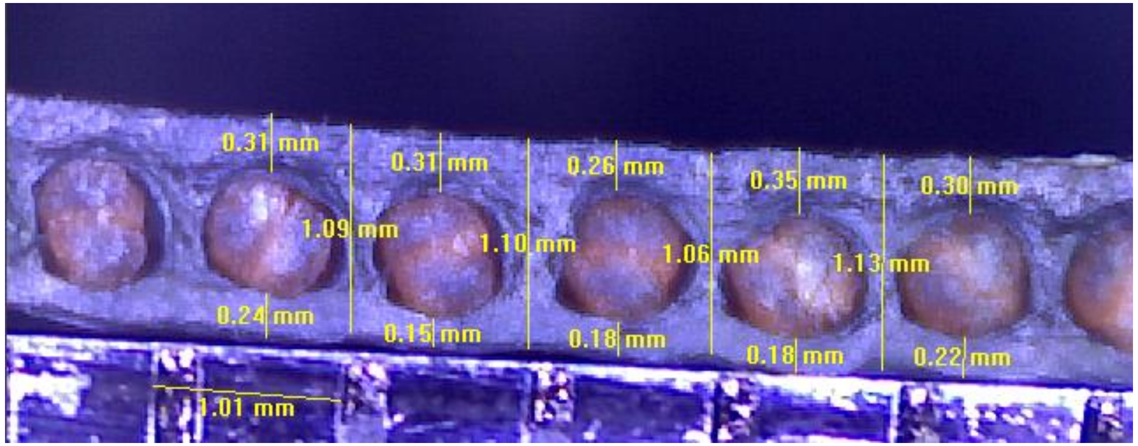
Correlation to Plant Measurements

Qualification Process:

- Focused on correlating production standard checks (snap gage) for operator buy-in
- Microscope measurements to further validate balance measurements and total gage

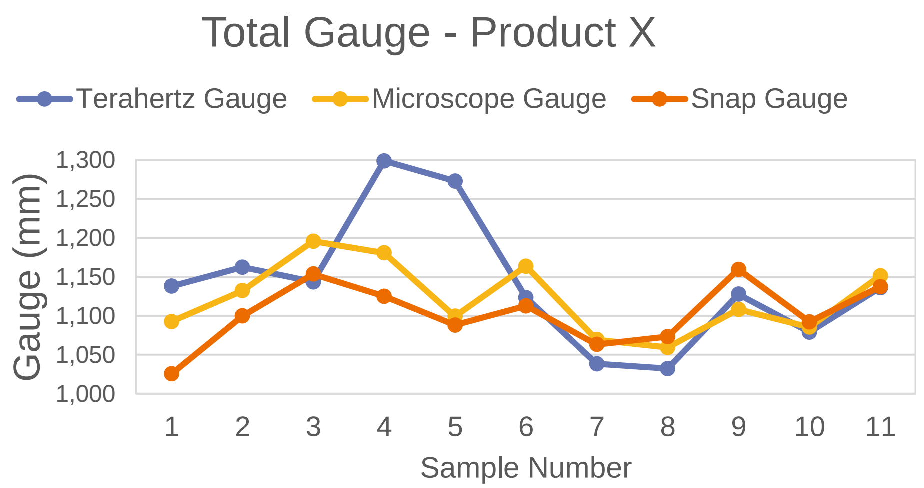


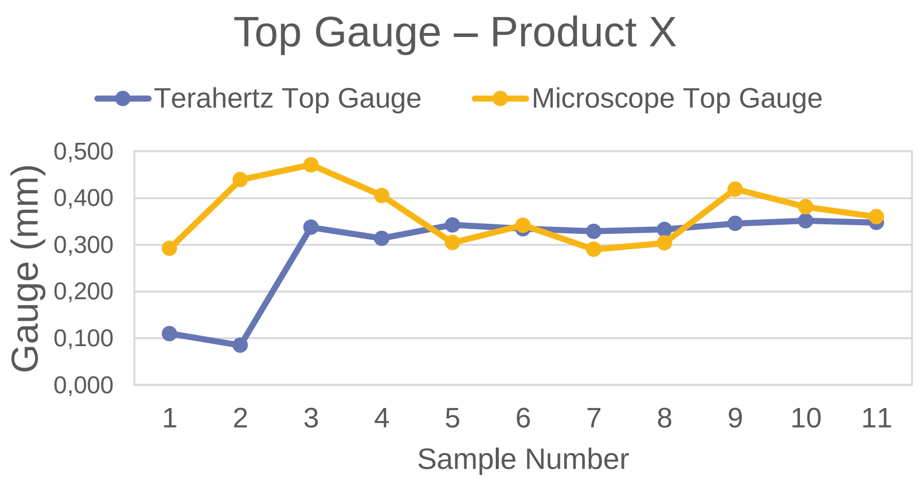
Correlation to Plant Measurements

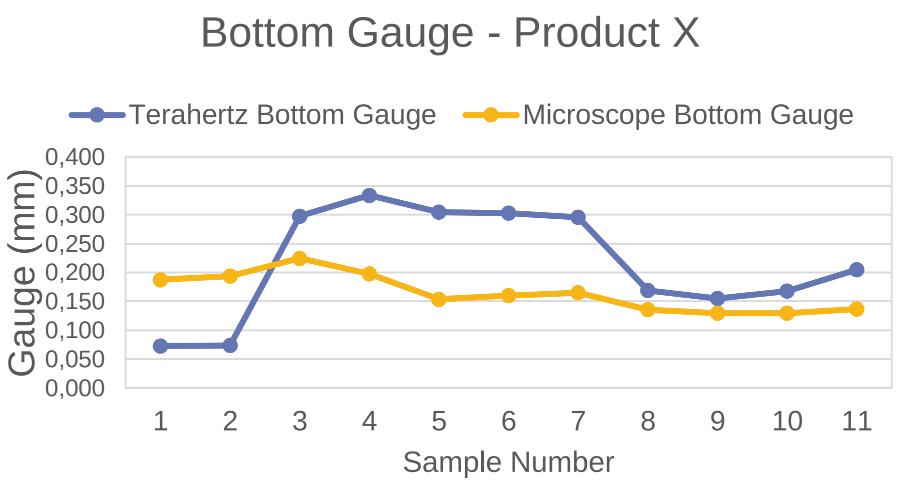
We were able to resolve gap between plant and THz measurements

Main issues:

- Debugging code
- Identifying correct window for peak measurement
- Adding actual refractive index feedback



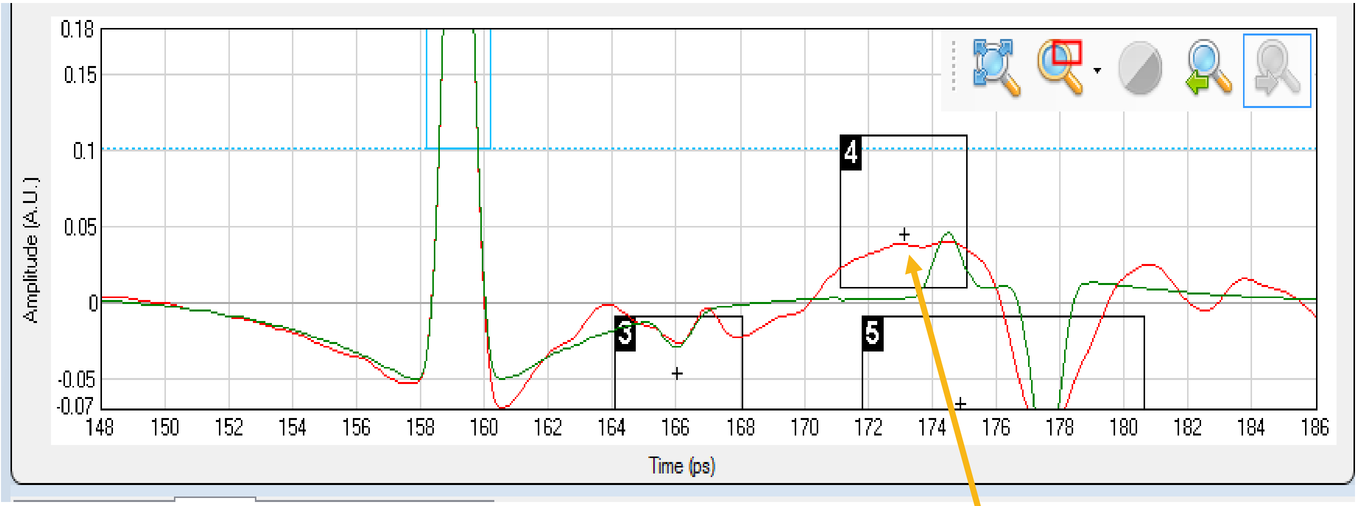




Correlation to Plant Measurements

Remaining Work on Correlation:

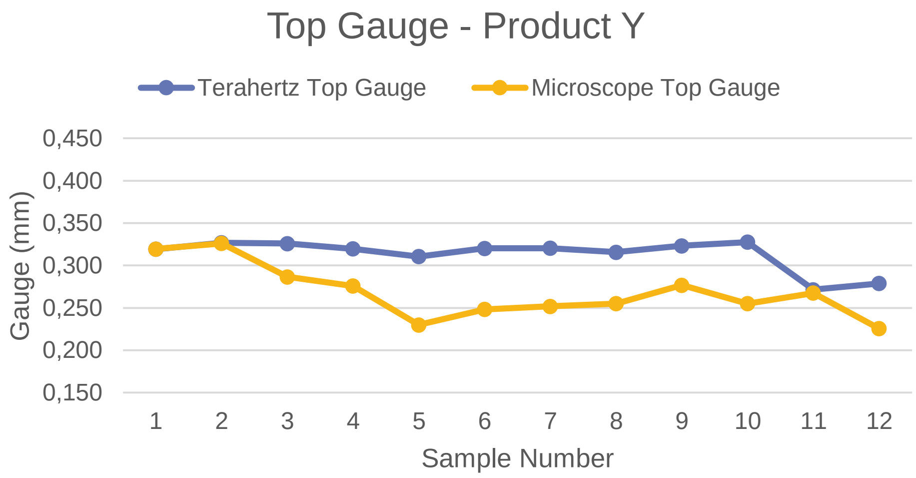
- Unresolved gap for skim gages on some products
- Primarily driven by overlapping or broad peaks

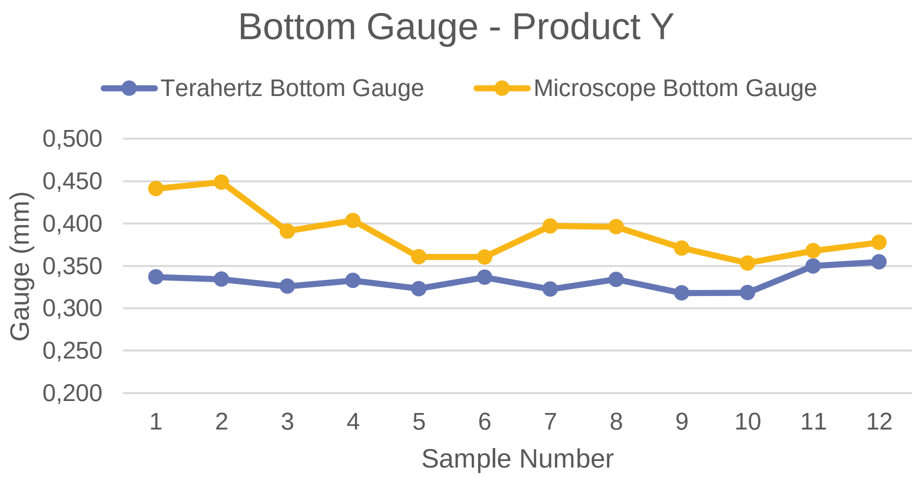


Interface between bottom of cord and rubber

Actual waveform in red

Interpolated wave in green

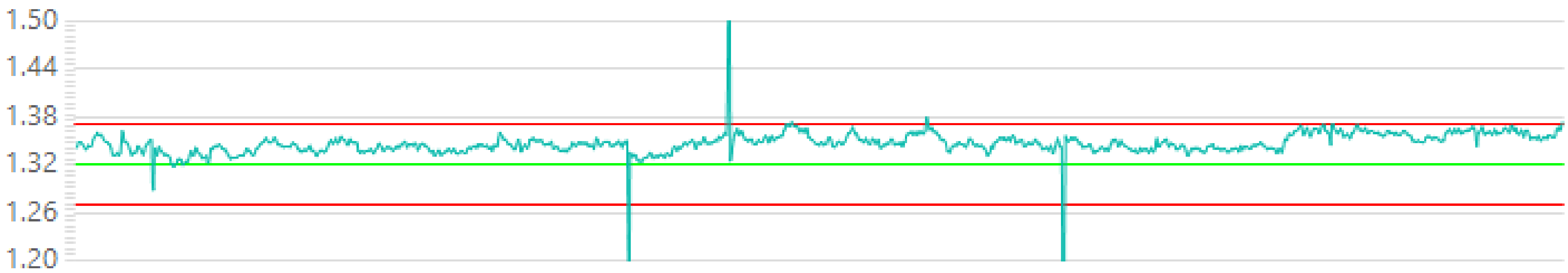




Results - Average Sheet Gage

Recorded average sheet gage for each scan

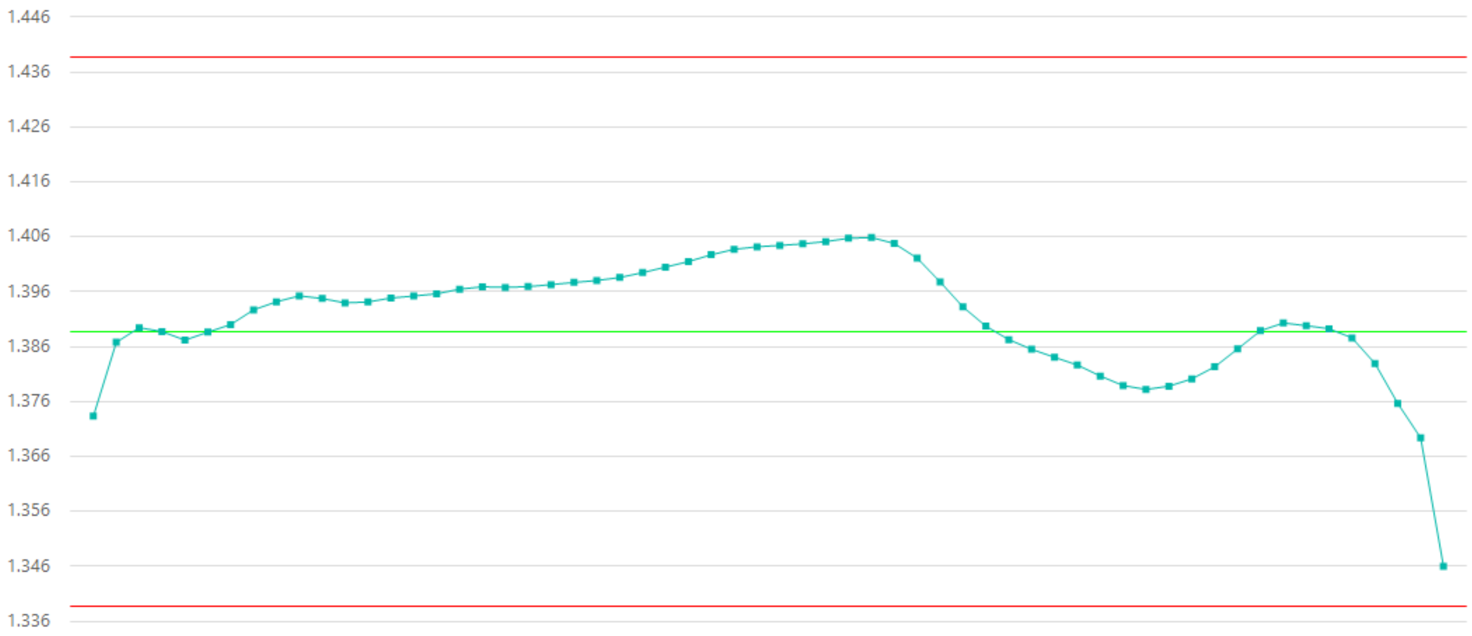
- Quick and accurate view of long term product trends for process engineering and quality departments
- Fast disposition of held material for questionable gage
  - No need to measure the entire roll by hand



Results - Product Profile

Multi Month Average Profile

- Averages out noise of individual measurements and gives process engineer high volume of data to make usual recipe adjustments
- Improved quality
- Target shifting opportunity



Summary

Online measurements of tire ply critical features (total ply thickness and cord balance) allow for better control and thus provide a clear advantage to tire manufacturers with higher quality and lower costs. For products with fabric cords, the ability to make online balance measurements has not been previously available. This presentation concentrated on the use of a single THz sensor to provide safe, fast, accurate thickness and simultaneous measure the balance of ply constructions, particularly on products with fabric cords. A THz sensor uses reflections of an emitted energy pulse to make layer thickness measurements. Results from multiple product configurations were presented.

Authors

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Biography: Steven is a senior process engineer for Bridgestone. He has been with the company for 10 years working within the manufacturing group on capital projects and a variety of process and material developments.

Jeffrey White, Ph.D.
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Biography: Jeff is senior research scientist at TeraMetrix, a division of Luna Inc, in Ann Arbor, MI. His background consists of varied instrumentation research and development. He has a PhD in Chemistry from the University of Illinois at Urbana-Champaign. For the last 15+ years he has been working with Terahertz (THz) sensing and its application to online and offline measurements over a wide range of applications (space shuttle inspection to asphalt shingle manufacture).

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