Use of a Pulsed Terahertz Sensor for Coat Weight, Noncontact Caliper Thickness and Moisture

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May 1-4
PaperCon 2011
Northern Kentucky Convention Center

RETHINK PAPER:
Lean and Green

Overview

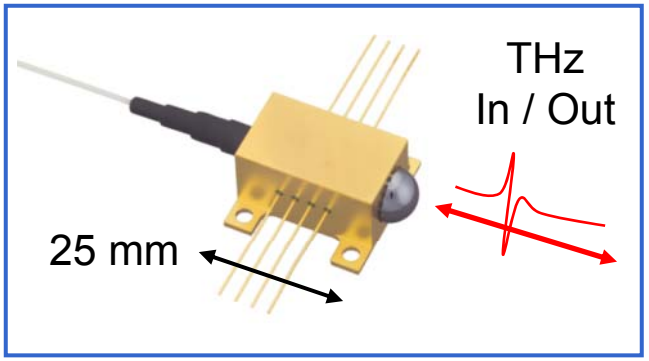
- Motivation for developing THz sensor
  - Capability of improved performance single sensor for multiple simultaneous measurements
  - Department of Homeland Security - reduce / eliminate procurement of nuclear sources due to security threats → they got you coming
  - Environmental Protection Agency - reduce / eliminate procurement of nuclear sources due to disposal issues → they got you going
- Pilot coater trial results
- Factory trial results

THz Sensor Comparisons

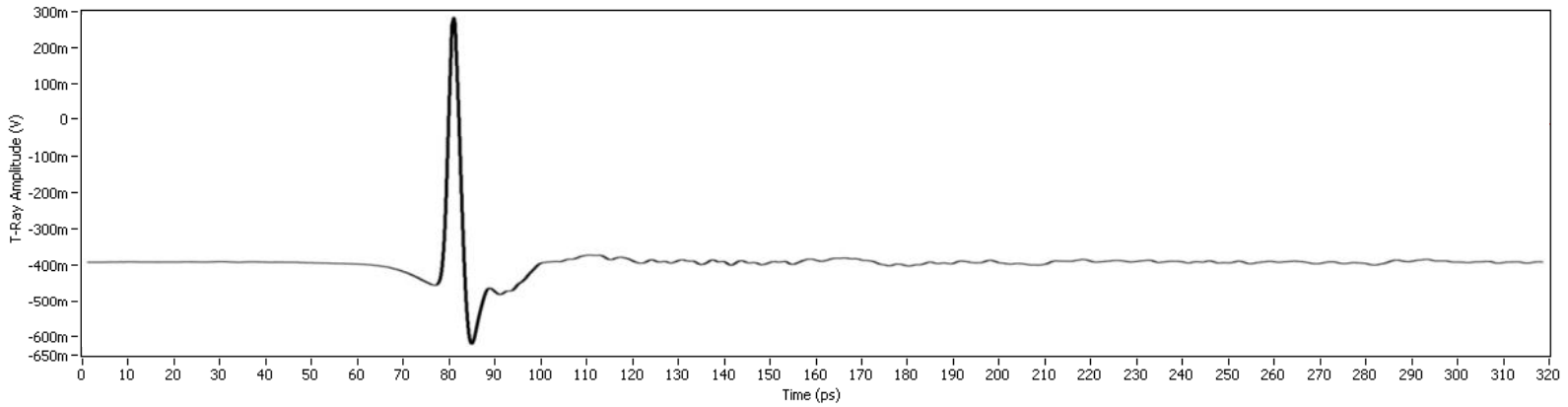
Compared to existing sensors, THz systems are:

- single sided,
- faster (up to 1 kHz),
- smaller, lighter,
- higher precision,
- completely safe, poses no regulatory burden or exposure concerns
- Offer simultaneous measurements with a single sensor

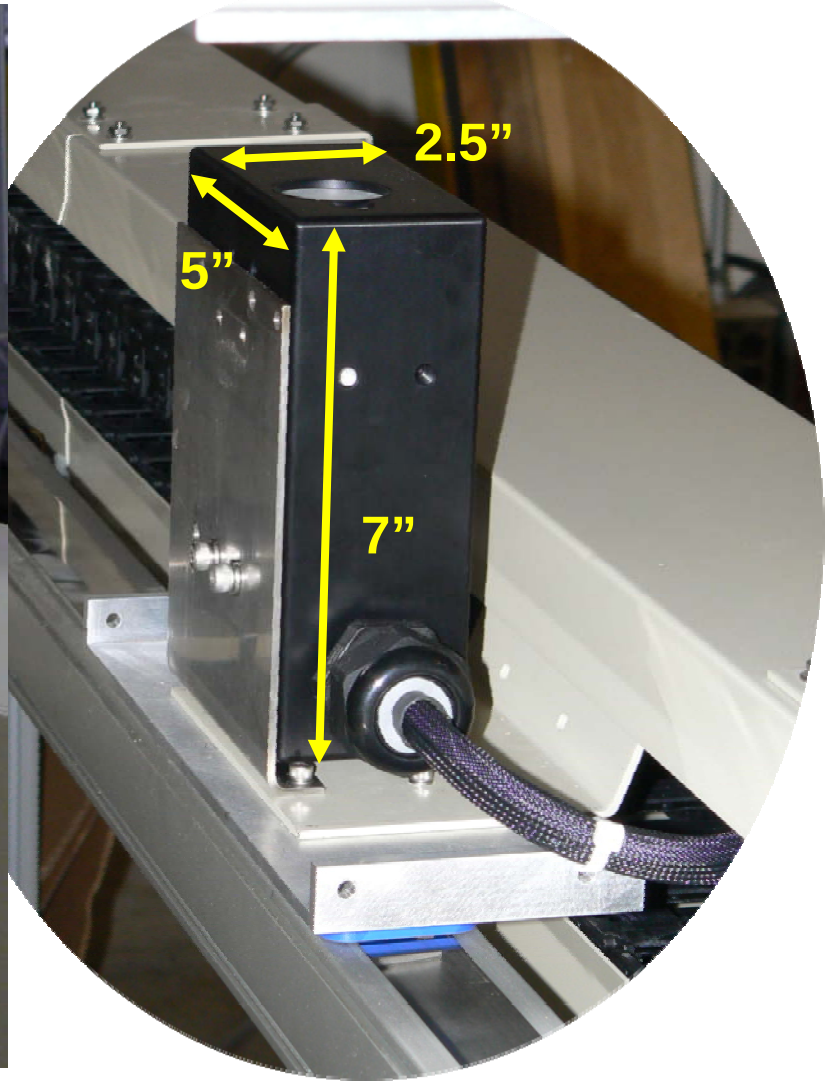
What is Terahertz



- In general:
  a portion of the EM spectrum between IR and microwaves
- In practice:
  Time-Domain Terahertz is a pulsed EM (< 1ps) method used for sample measurement, defect detection and imaging
- Often used like an EM analog of ultrasound



Industrial Sensor

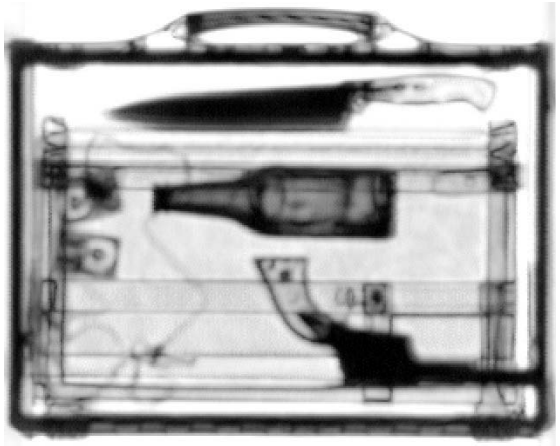


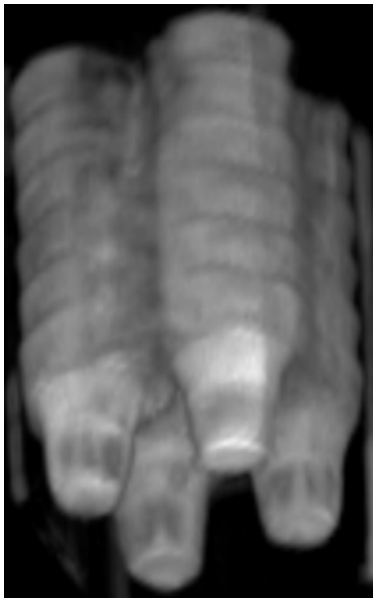
Terahertz Characteristics

- **Excellent penetration** through paper, coatings, foams, plastics, fiberglass, paint, insulation; nearly all dielectric materials
- **Non-contact**, transmission or reflection (1” – 12” standoff typical)
- **Fast Measurement Rate** (up to 1 kHz)
- **High precision** (exceptional for time based measurements)
- **Non-nucleonic, non-ionizing – Completely Safe**
- Additional measurement capabilities (caliper, moisture, formation?)
- Very insensitive to sample variations, environmental conditions
- Flexible sensor positioning (fiber coupled up to 60m)
- Imaging, more

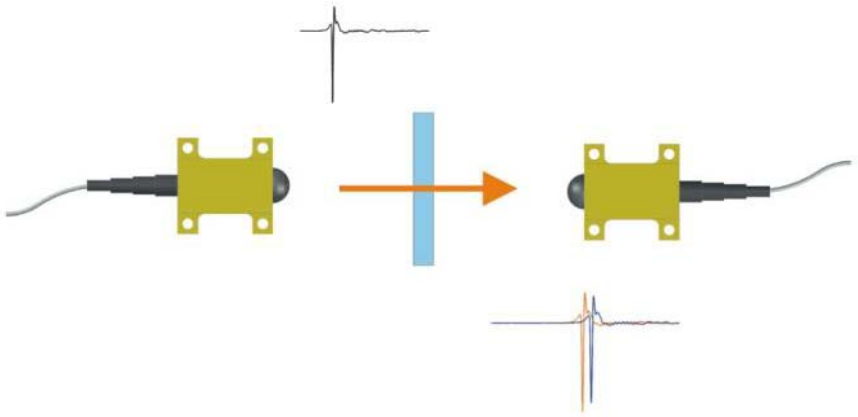
THz Applications

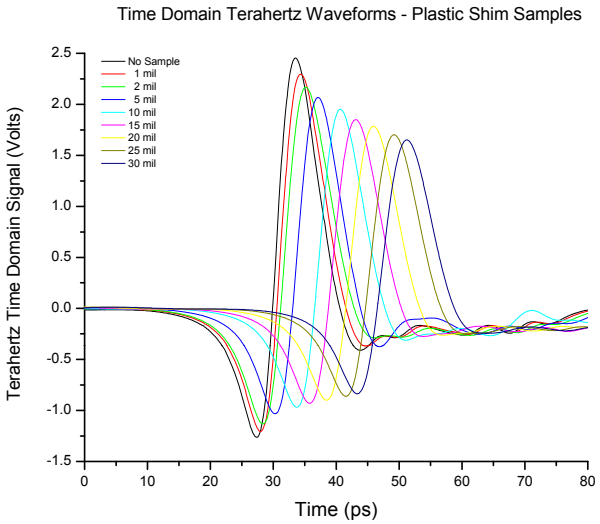
- Foam on Shuttle External Fuel Tank (adhesion, voids)
- Building materials in-process - rubbers, asphalt shingles
- Coatings - paper, pharmaceutical tablets, automotive, ceramic
  F-35 low observable materials
- Basis weight
- Non-contact Caliper
- Aerospace
- Security
- CT Imaging
- Art Inspection
- Defect Detection (voids, crack, disbonds)
- Pharmaceutical Products (compression force)

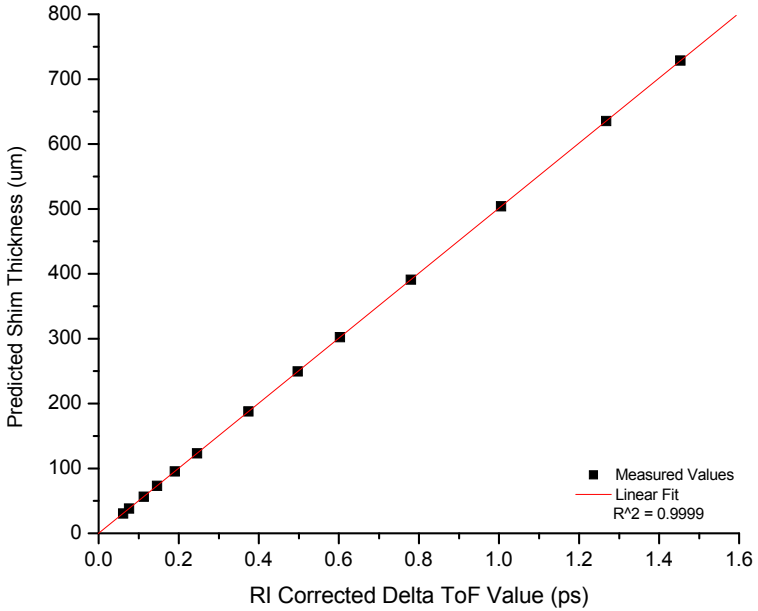




Transmission Measurements



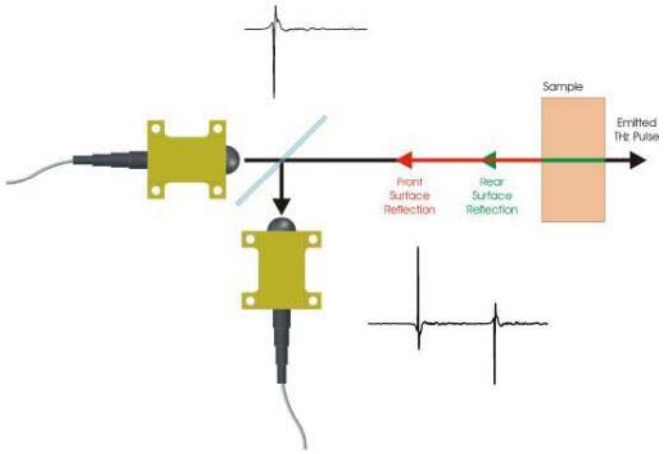


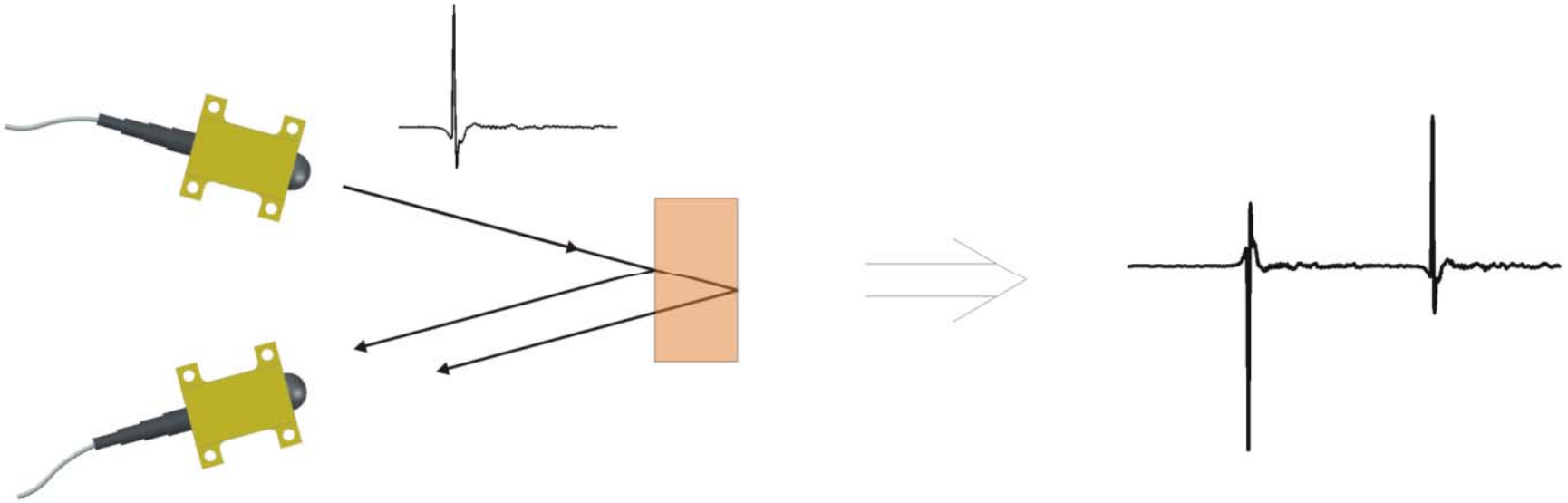


Establishes THz Time-of-Flight measurement to basis weight

Reflection Measurements

Reflection creates "self-referenced" measurement





THz Measurement Precision

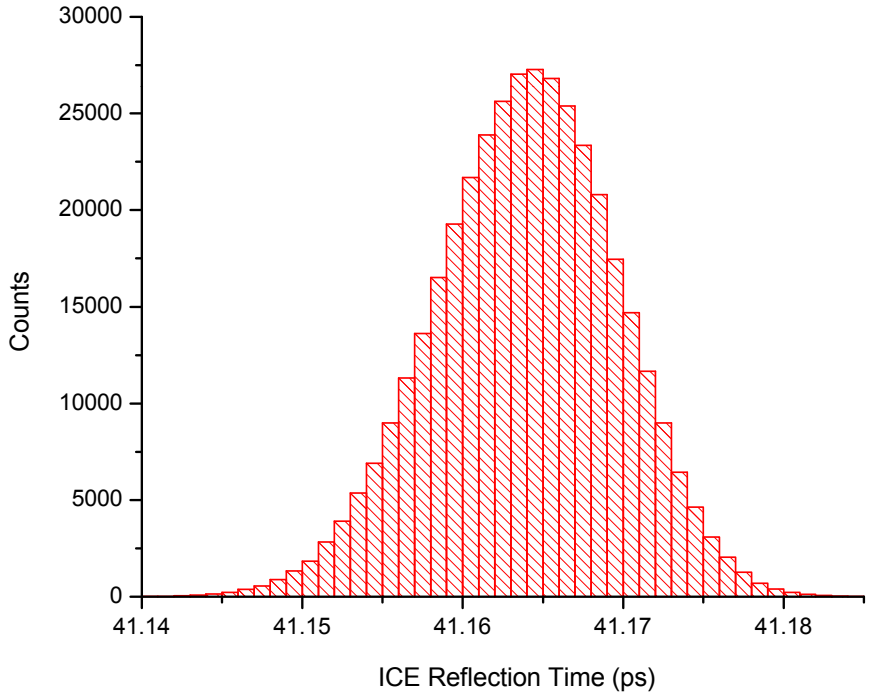
Sample: 0.125” thick Fused Silica
Sample Sets measured: 34
Total Measurements: **388,000**
Data Collection Time: 6450 min
(4.5 days)

Results for Reflection measurements:

Mean Value = 41.164 ± 0.010 ps (±2σ)

(0.014% RSD)

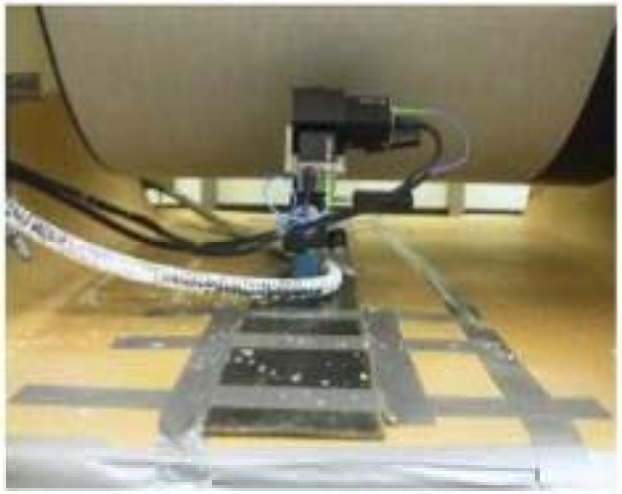
Range < 0.05 ps
over all 388,000 measurements



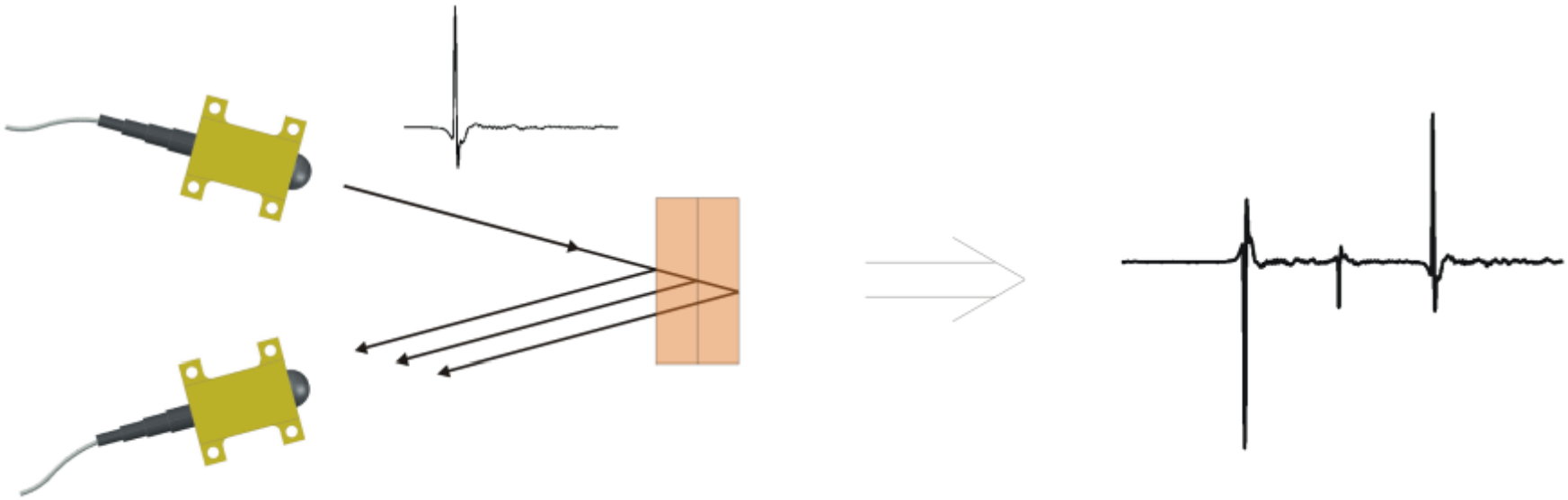
Reflection / Time Measurement Properties

- No effect with standoff distance variation
- Standoff distances from to 1” - 12” are routine
- No effect with pass-line variation
- No measureable effect with dirt / debris on sensor
- Time based measurement not affected by misalignment of sensor, source decay, other signal loss modes

Sensor on Coater – Western Michigan Univ.

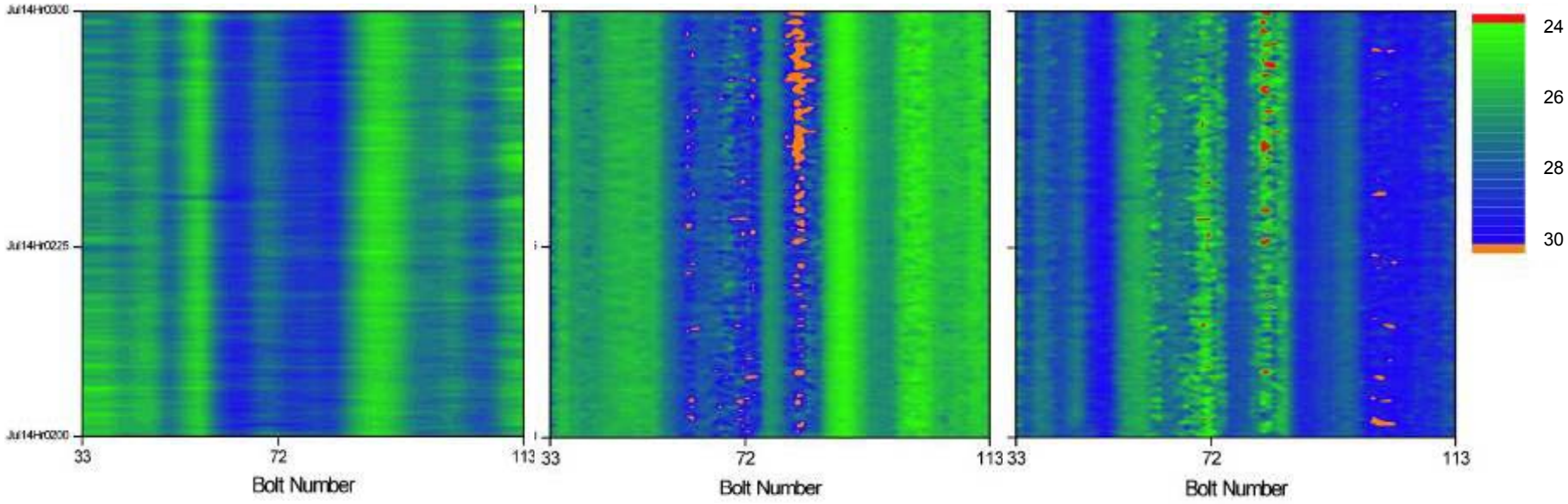


Multilayer



Multi-layer Measurement

Web profile over 1 hour (approx 30 100 ft product rolls)



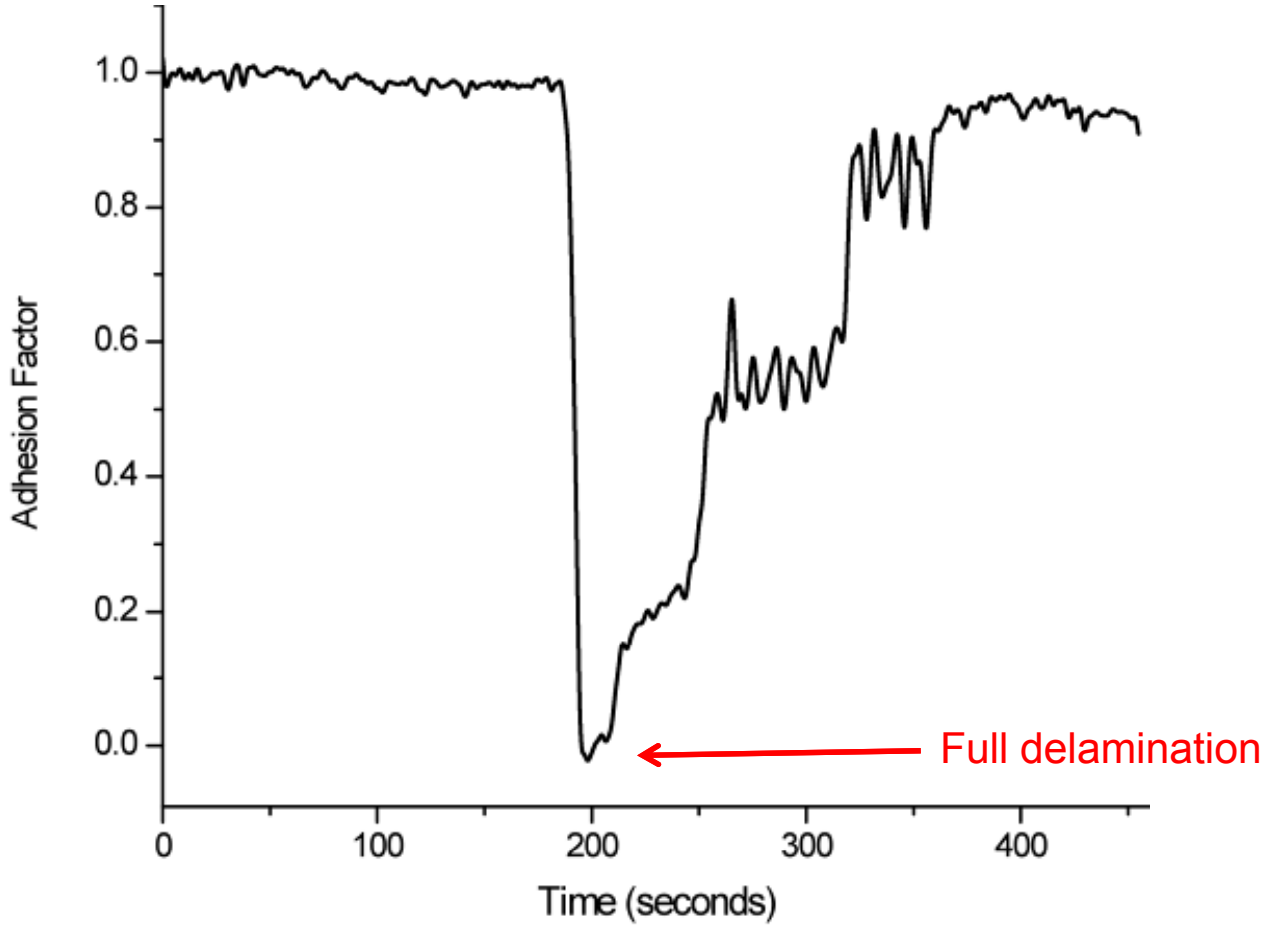
Total

Upper

Lower

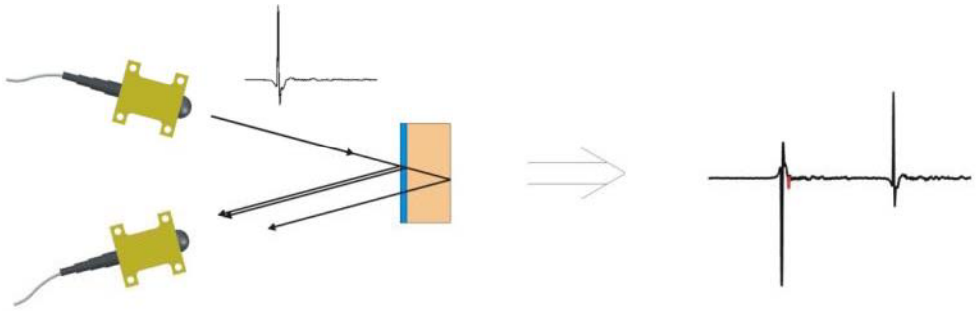
Low Adhesion Detection

- Complete delamination was created.
- Slowly returned to proper operation.

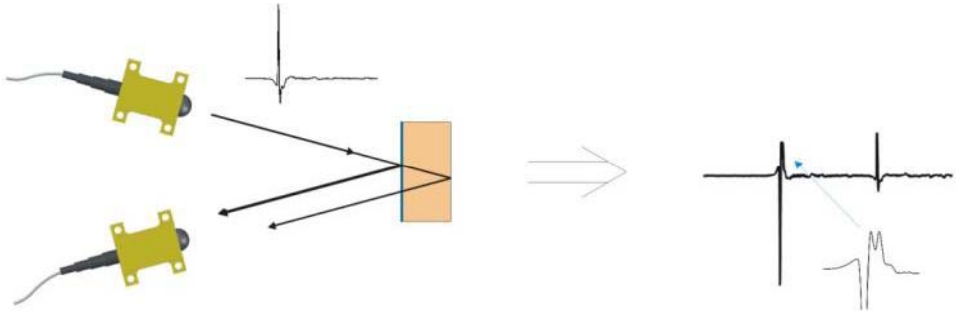


Coatings

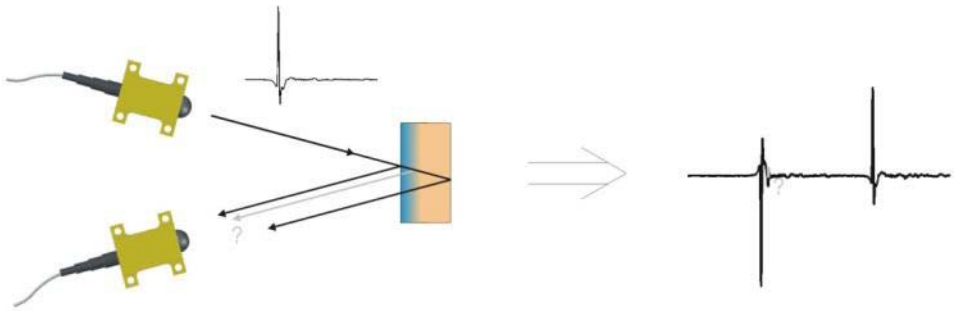
Thick Coating



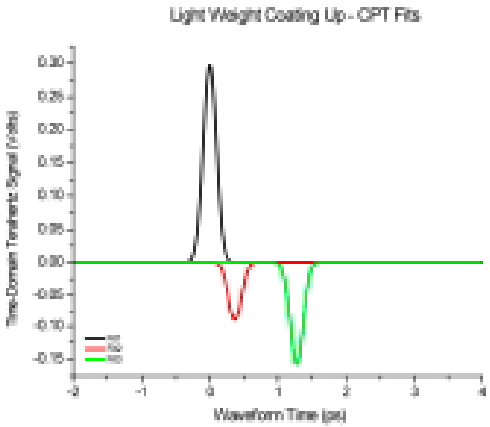
Thin Coating

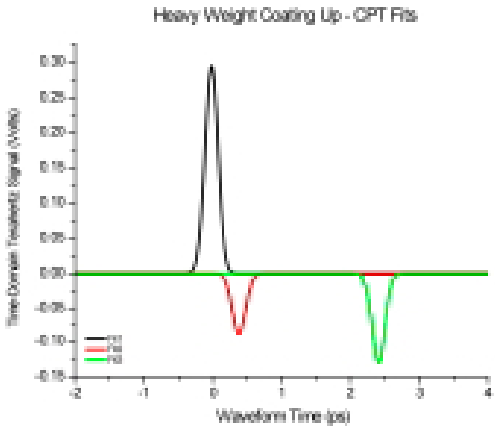


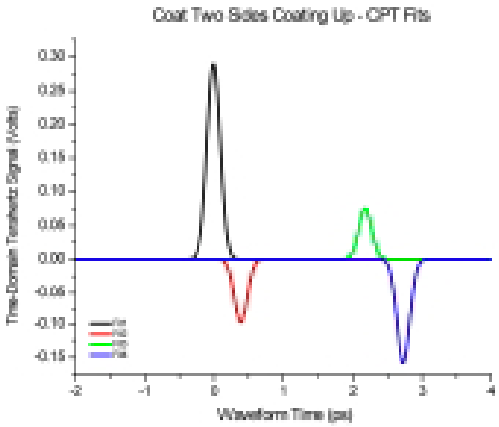
Penetrating Coating

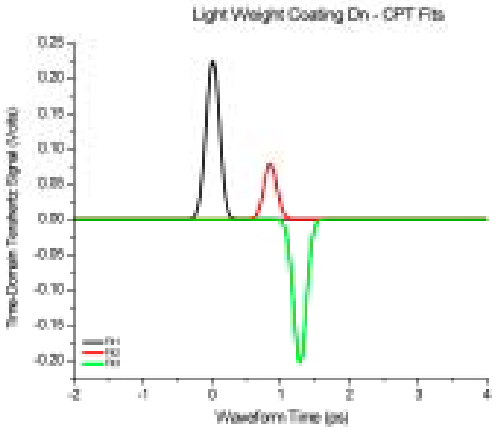


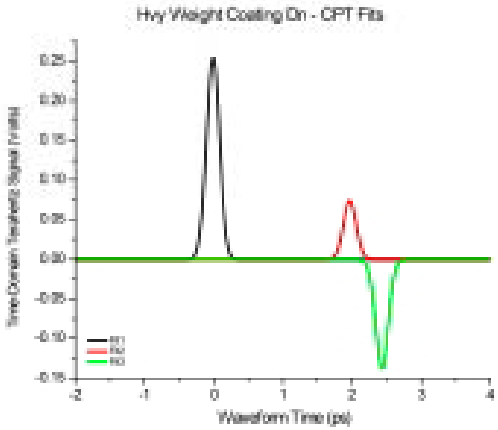
Two-Sided Paper Thick Coating

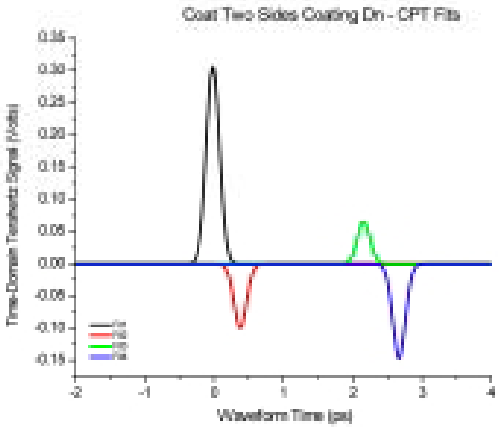












Measurement Classes

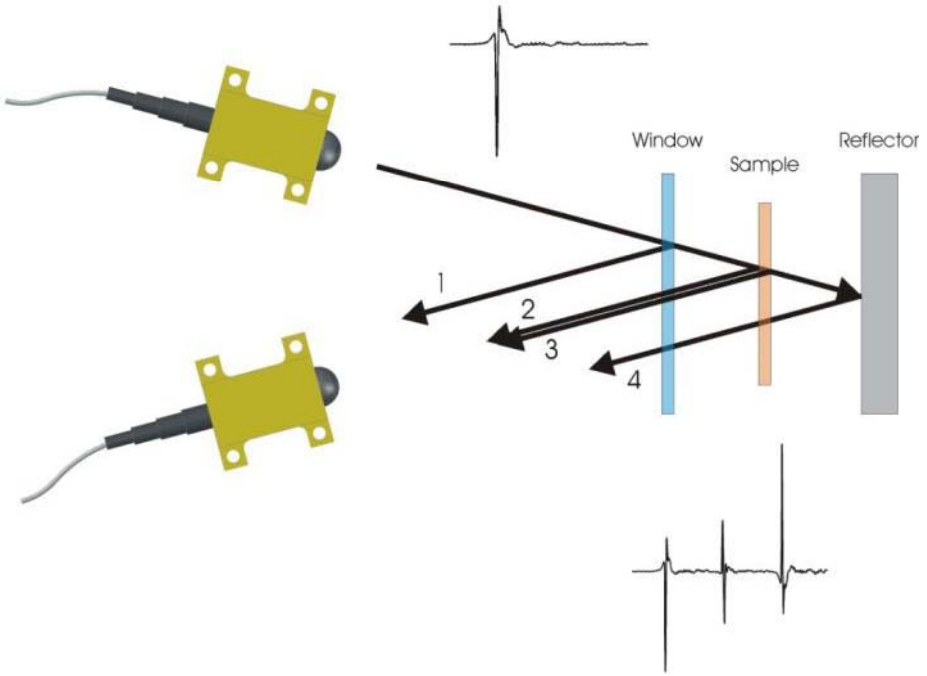
- Reflection Only
  - Basis weight
  - Coat weight (thick non-penetrating coatings)
  - Moisture
- Differential Reflection Measurements
  - Coat weight for thin or penetrating coatings
- External Reference Structure (ERS) Measurements
  - Non-contact Caliper thickness
  - Basis weight + thickness $\Rightarrow$ Density (formation?)
  - Improved basis weight
  - Improved moisture

The ERS

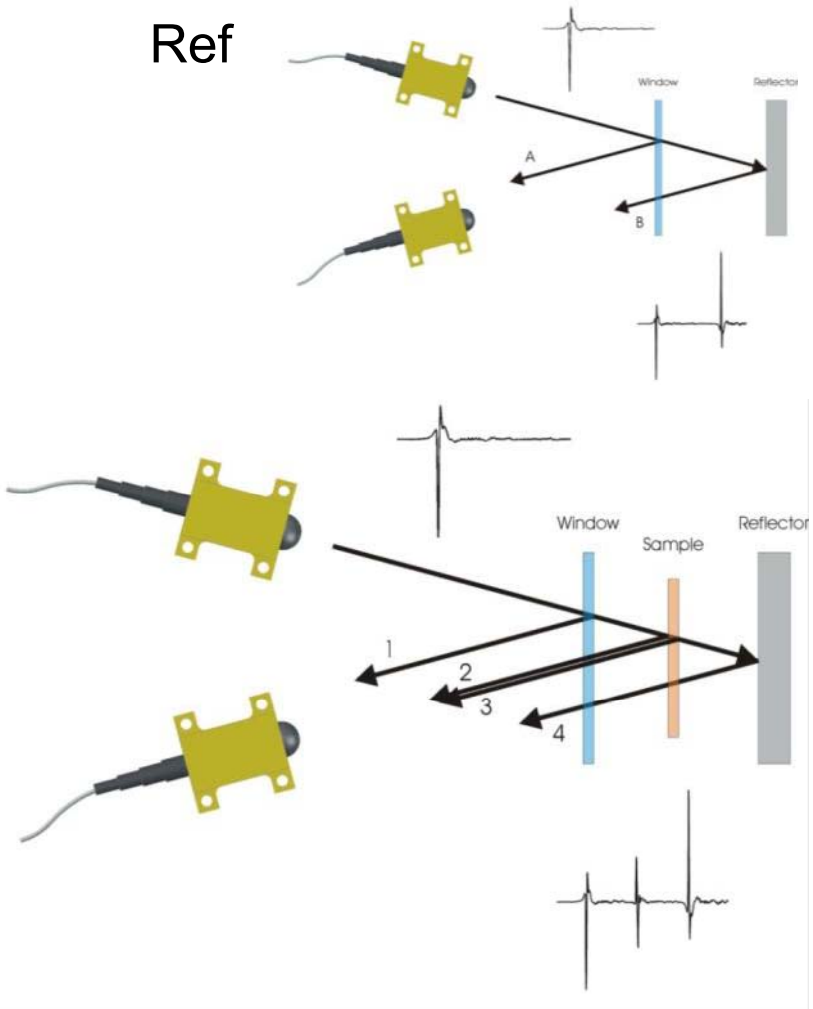
- An external structure consisting of a window in front of the sample and a reflector behind the sample. The spacing between the window and reflector is used in calculations and has to be known or measured.

Uses

- Non-contact Caliper
- Mass / Thickness ⇒ Density
- Improved transmission ToF measurement (basis weight)
- Improved Moisture

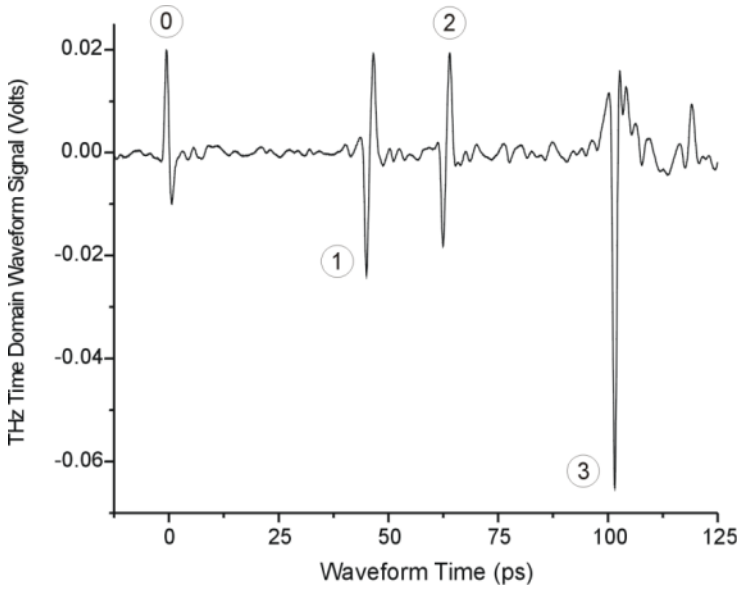


Double Pass Transmission Caliper Measurement



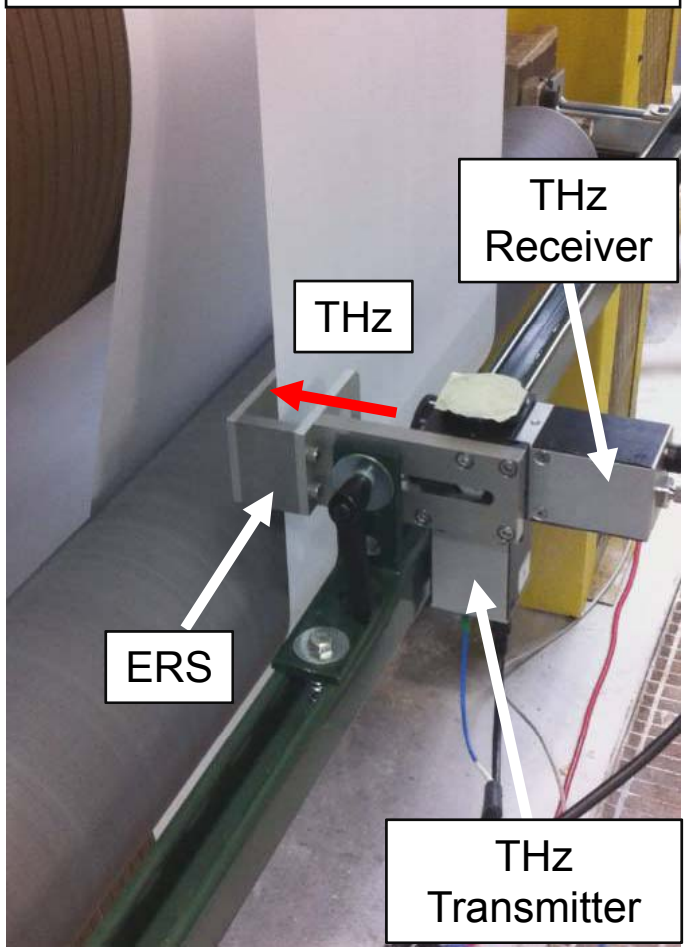
Double Pass Transmission
(Ref - Pk3 + Pk0)

Caliper thickness
(Ref - Pk1 - Pk3 + Pk2) × c

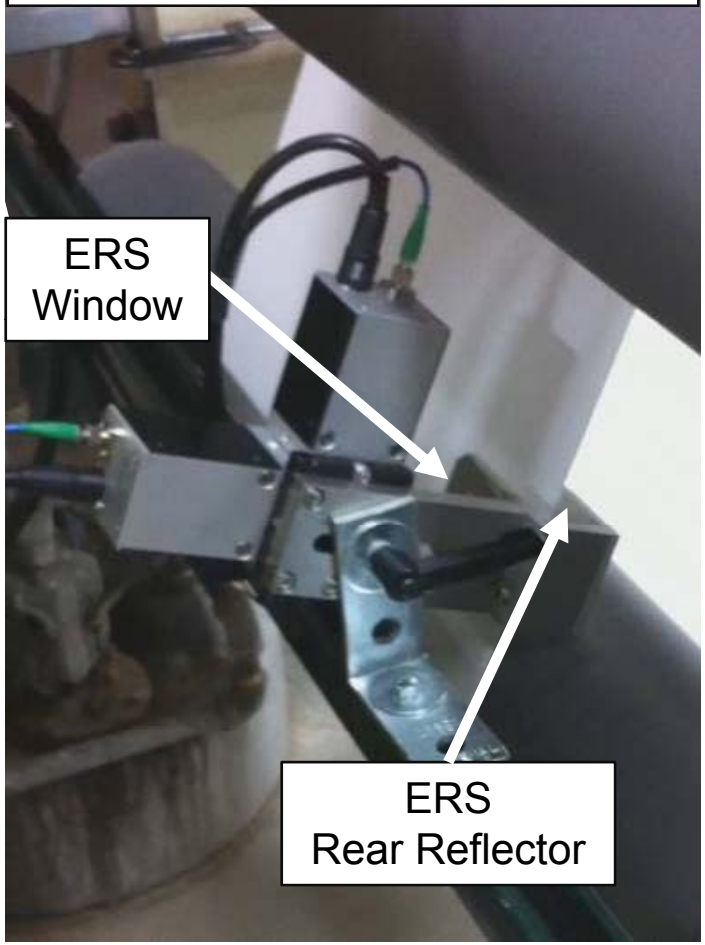


Spot External Reference Structure

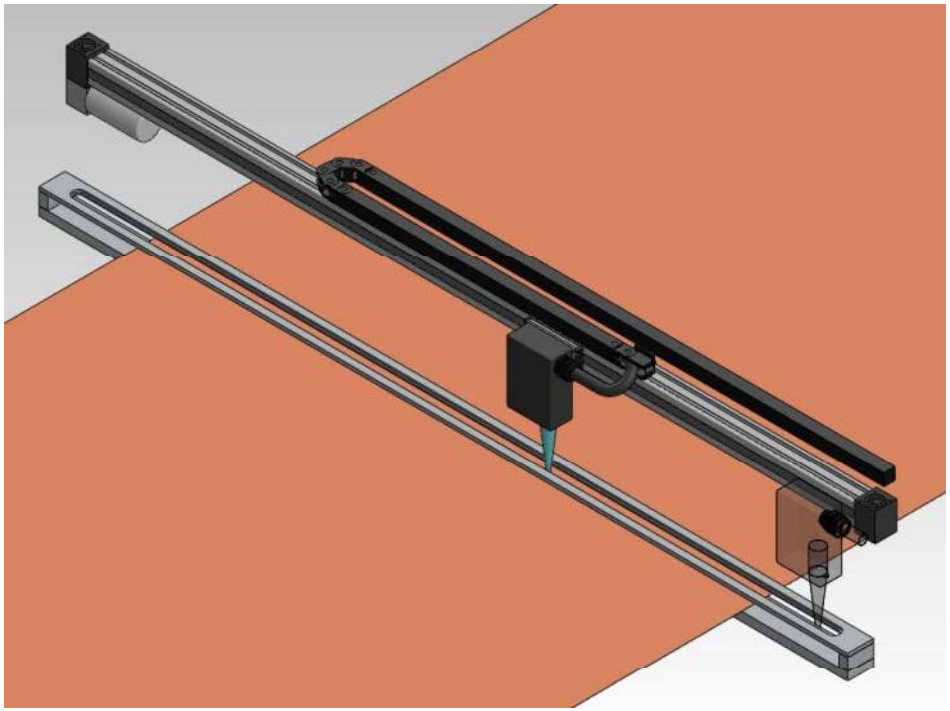
Stock inspection at unwind

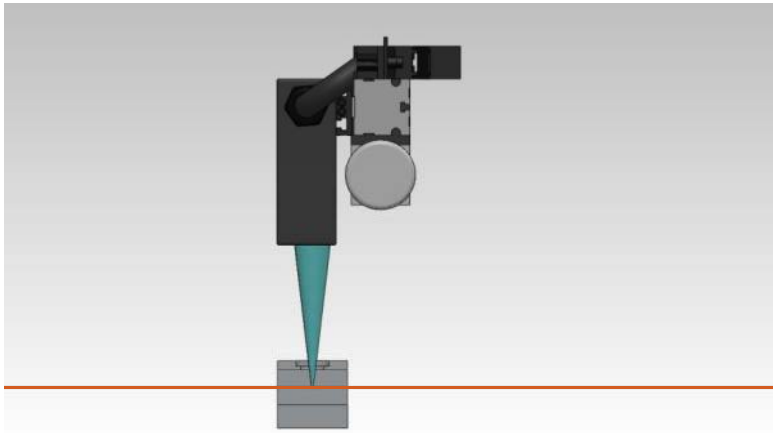


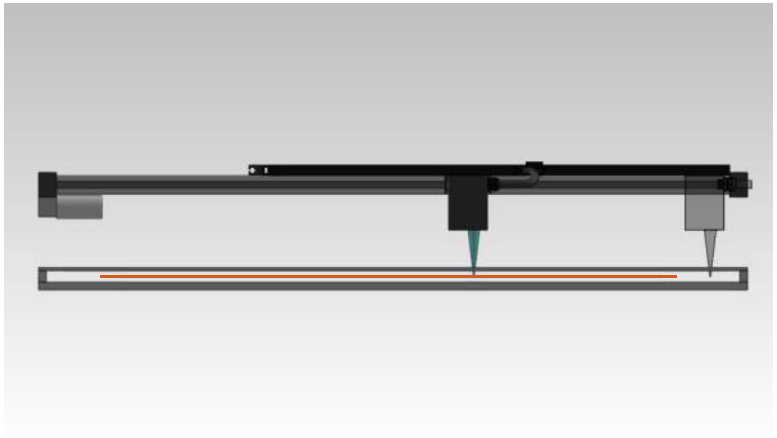
Coated Product Inspection



Scanning with ERS





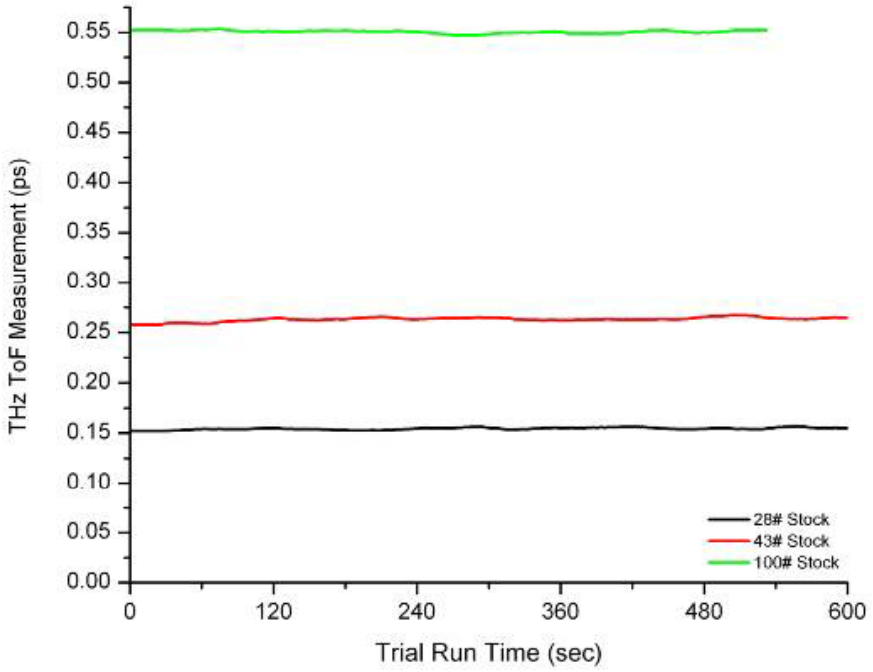


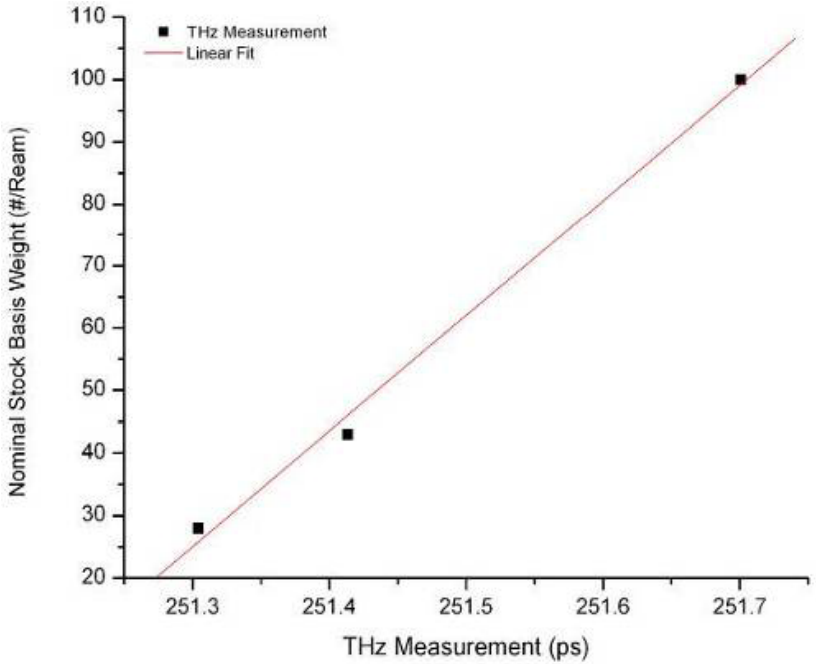
Pilot Coater Trial

Objective: demonstrate on-line measurement of: basis weight, coat weight, caliper thickness and percent moisture

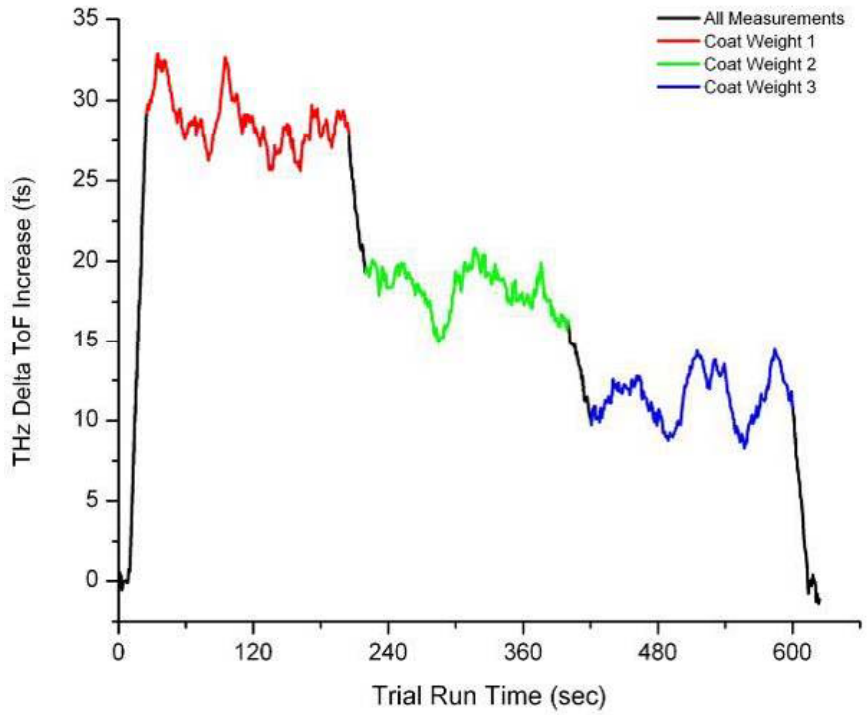
- Two sensors: unwind, windup
- Three differing stock materials
- Two differing coatings
- Two differing applicators
- Three or four differing coat weights, caliper thickness or percent moisture measurements.
- Typical data collection: 3 minutes per setting

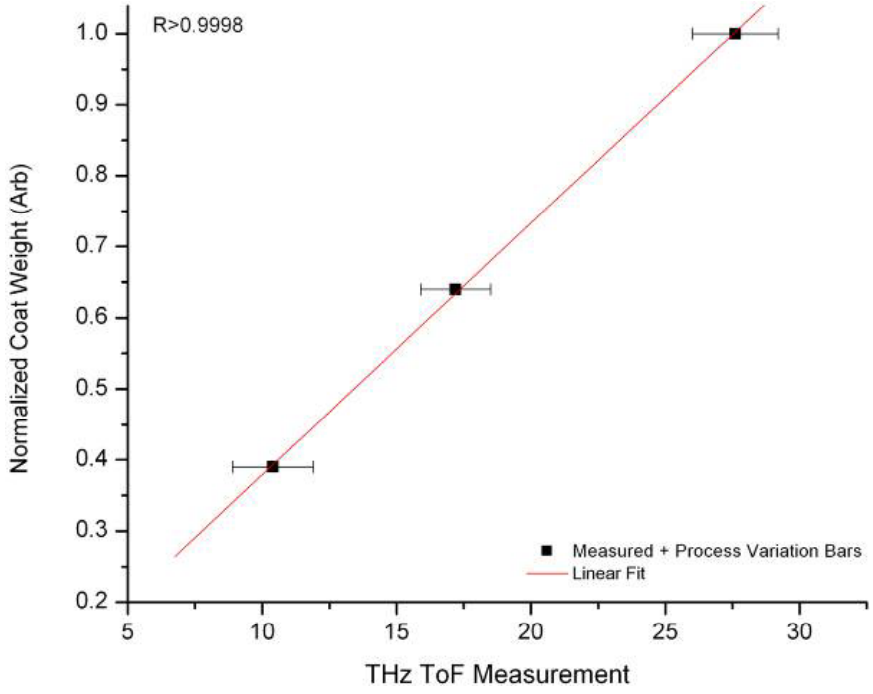
Stock Nominal Basis Weight



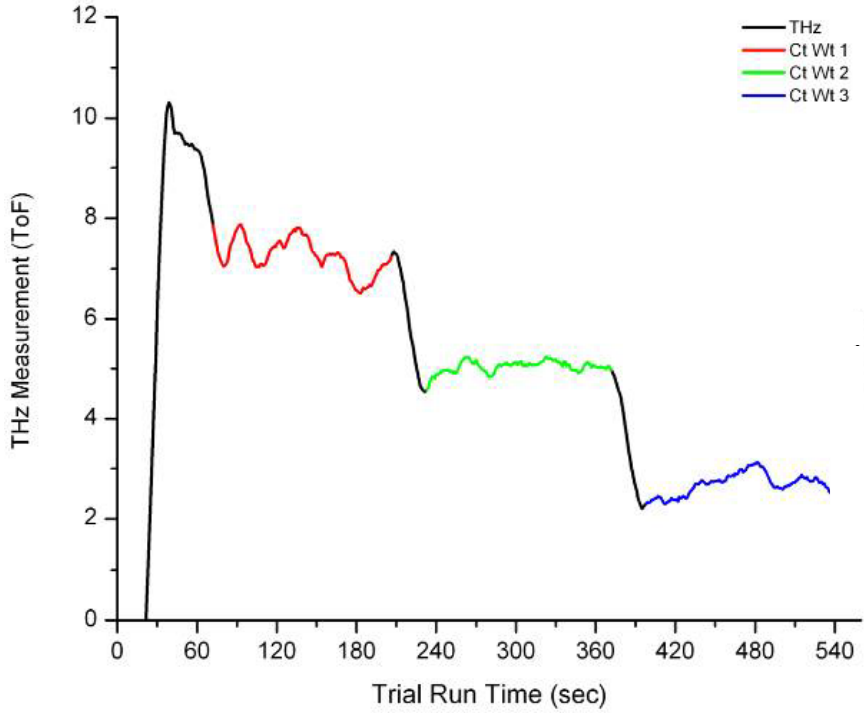


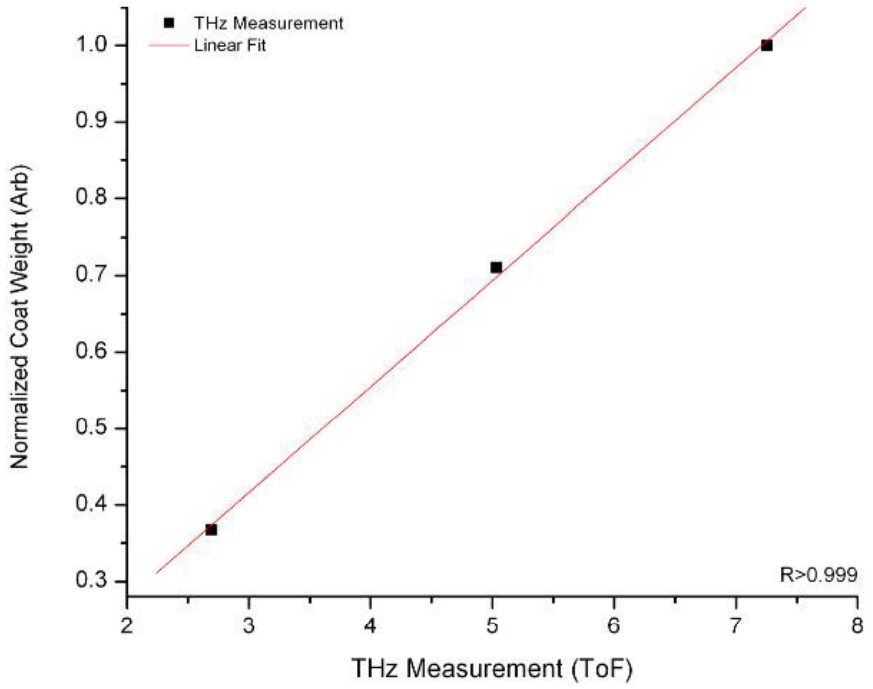
High Pigment Coat Weight



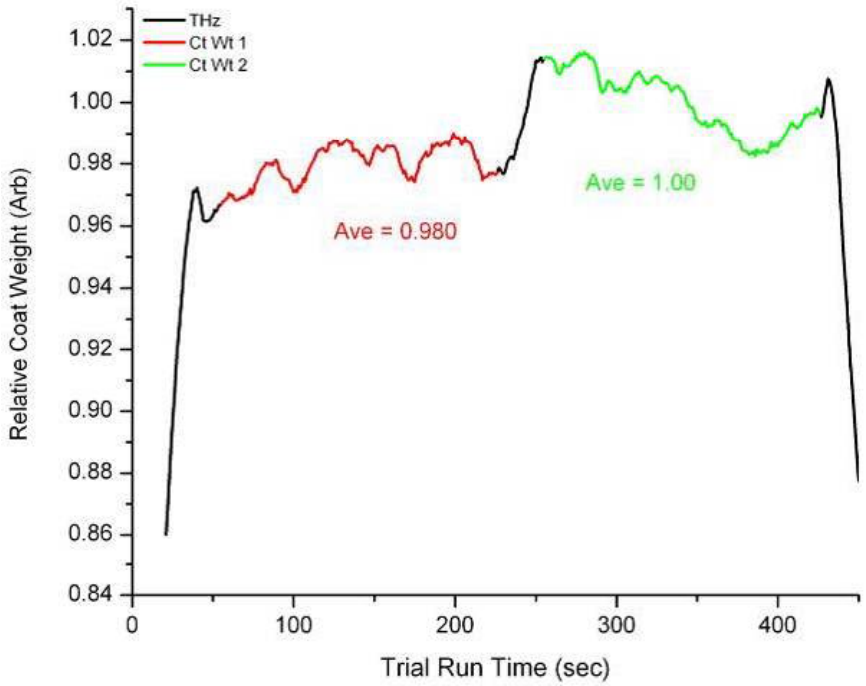


Low Pigment Coat Weight

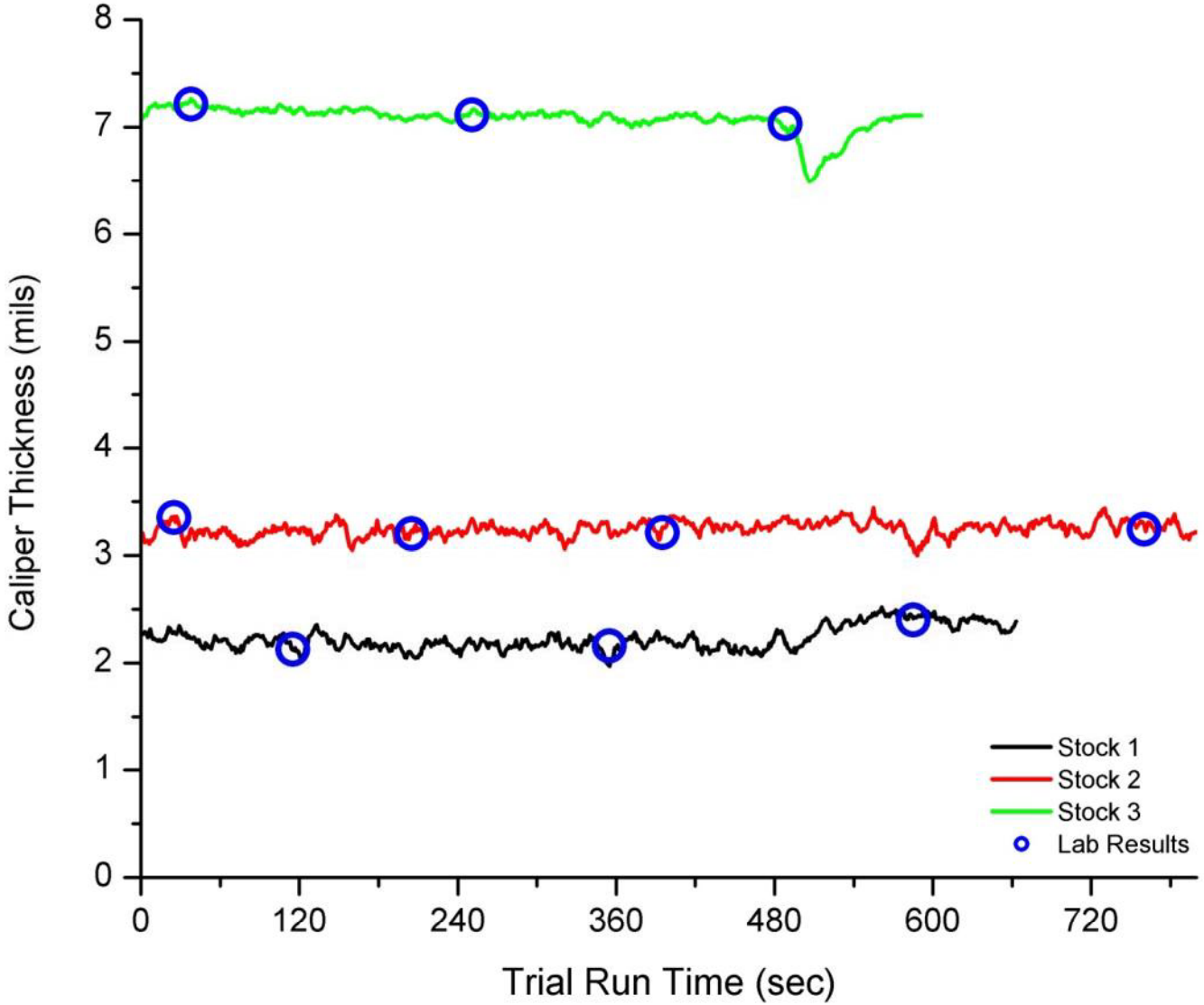




Low Pigment Coat Weight – Rod Coater

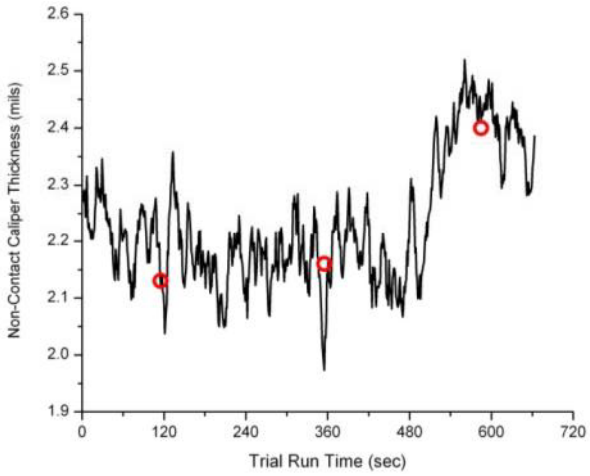


Non-contact Caliper – All Grades

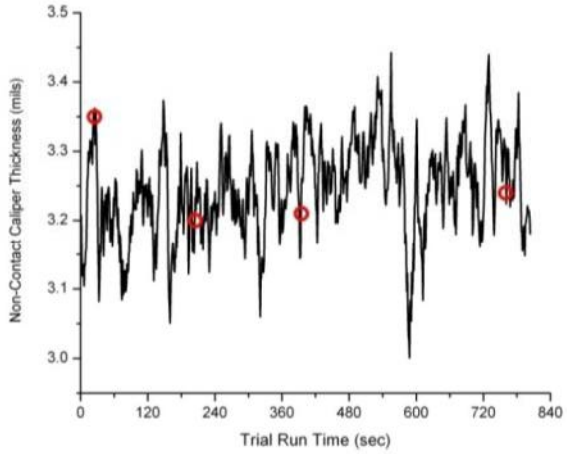


Non-contact Caliper – Individual Grades

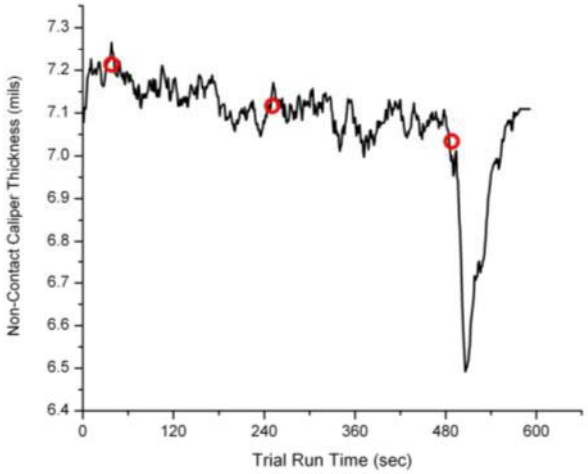
#28 Stock



#43 Stock

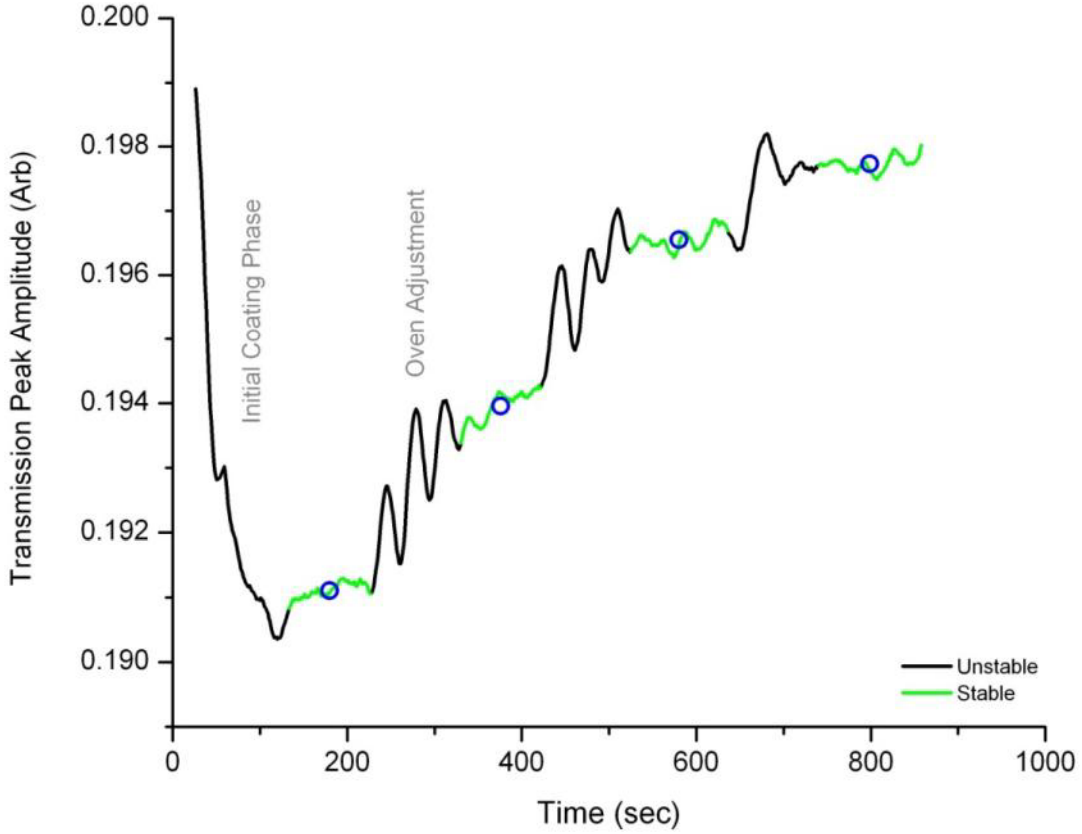


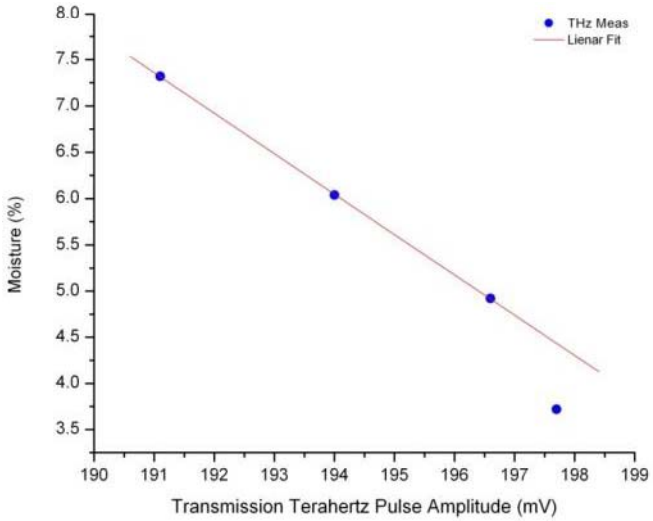
#100 Stock



Moisture

- Moisture levels adjustments made with oven and fan parameters, not line speed
- Adjustments made from higher moisture levels to lower





Summary

- Single THz sensor able to simultaneously measure:
  - Basis Weight
  - Non-contact Caliper Thickness
  - Percent Moisture
- Dual Differential THz sensors for Coat Weight
- No regulated nuclear material, no exposure concerns, no high voltages
- Completely safe
- Very fast, high precision measurements
- Optimized for operation in factory environment.