# Online tire ply thickness, fabric cord balance *(and other)* measurements using terahertz


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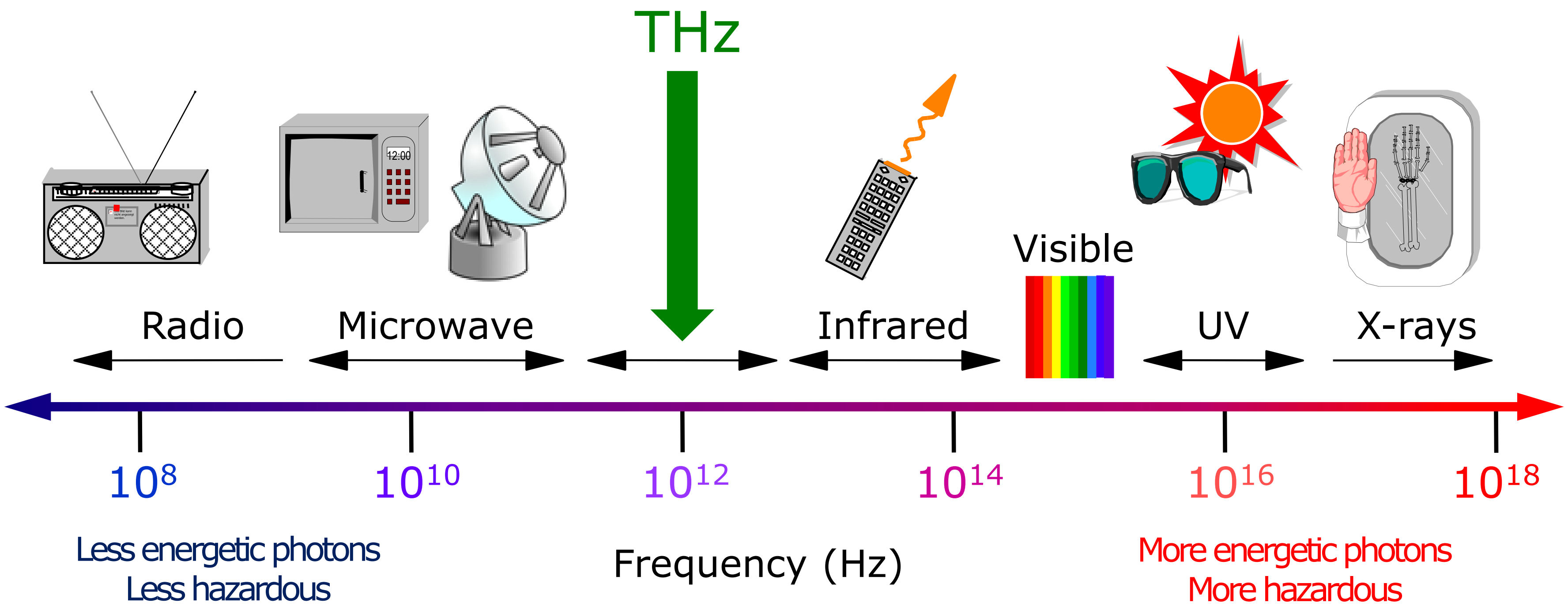
# Agenda

- Brief introduction to Terahertz (THz)
- Review results from partner presentation
  - Online measurements of fabric cord ply body
  - Primarily use of online calibration system (ERS)
- Consider calendaring processes and locations for THz measurements
  - Both fabric and metal cords
  - Possibilities for measurement include:
    - Fixed Point sensors to measure thickness of gum layers before lamination
    - A short length / high speed scanner to locate last cord position
    - A full sheet scanner to measure profile and balance
- Consideration of Benefits
- Conclusion

# Introduction to Terahertz (THz)

## Terahertz exists between the Far IR and Microwaves



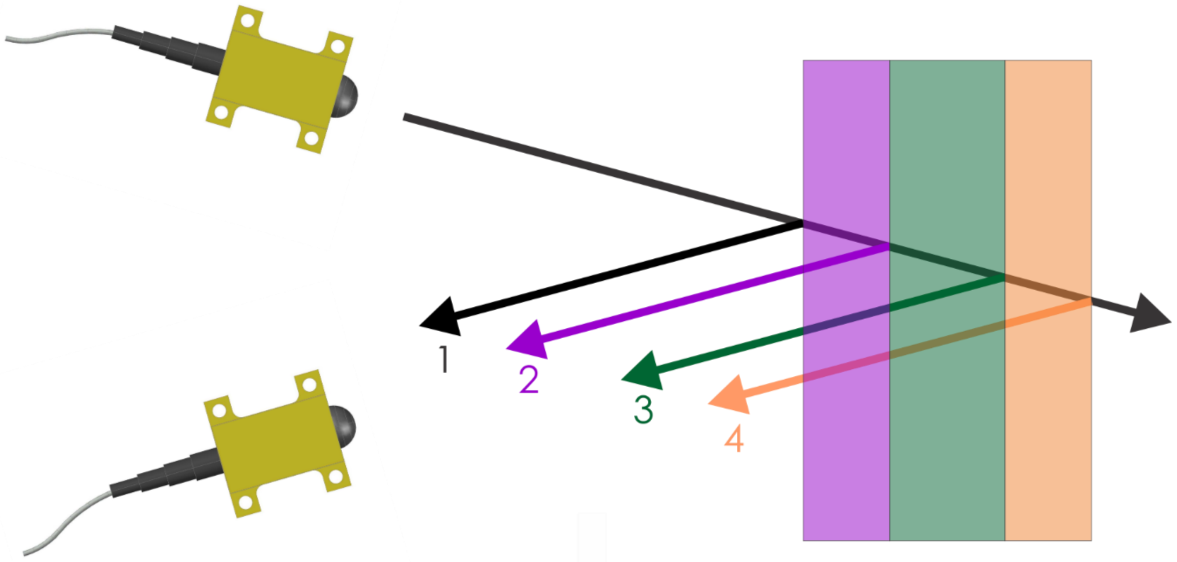

$\upsilon = 1\ \text{THz} \leftrightarrow \lambda = 300\ \mu\text{m} \leftrightarrow h\nu = 33\ \text{cm}^{-1} \leftrightarrow 4.1\ \text{meV} \leftrightarrow T = 48\ \text{K}$

# Time-Domain Terahertz

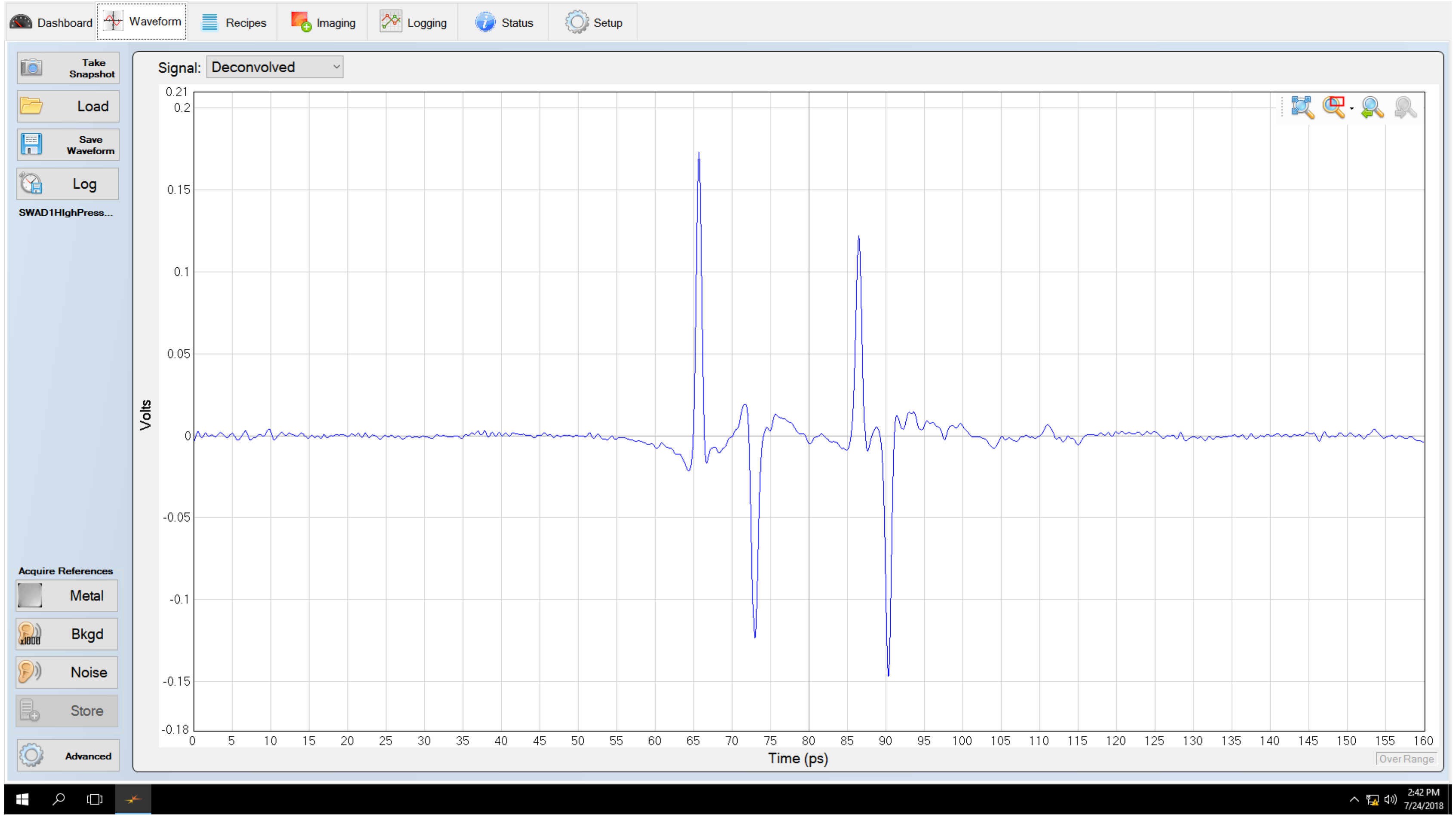
- A very narrow pulse (less than 1 ps wide) of completely safe energy is emitted
- Most materials are transparent to THz
- A portion of pulse energy is reflected at each interface in the sample
- The TIME between reflections (Time-of-Flight or ToF) is used to calculate layer thickness.
- Can measure multiple layers simultaneously

- Thickness calculation:

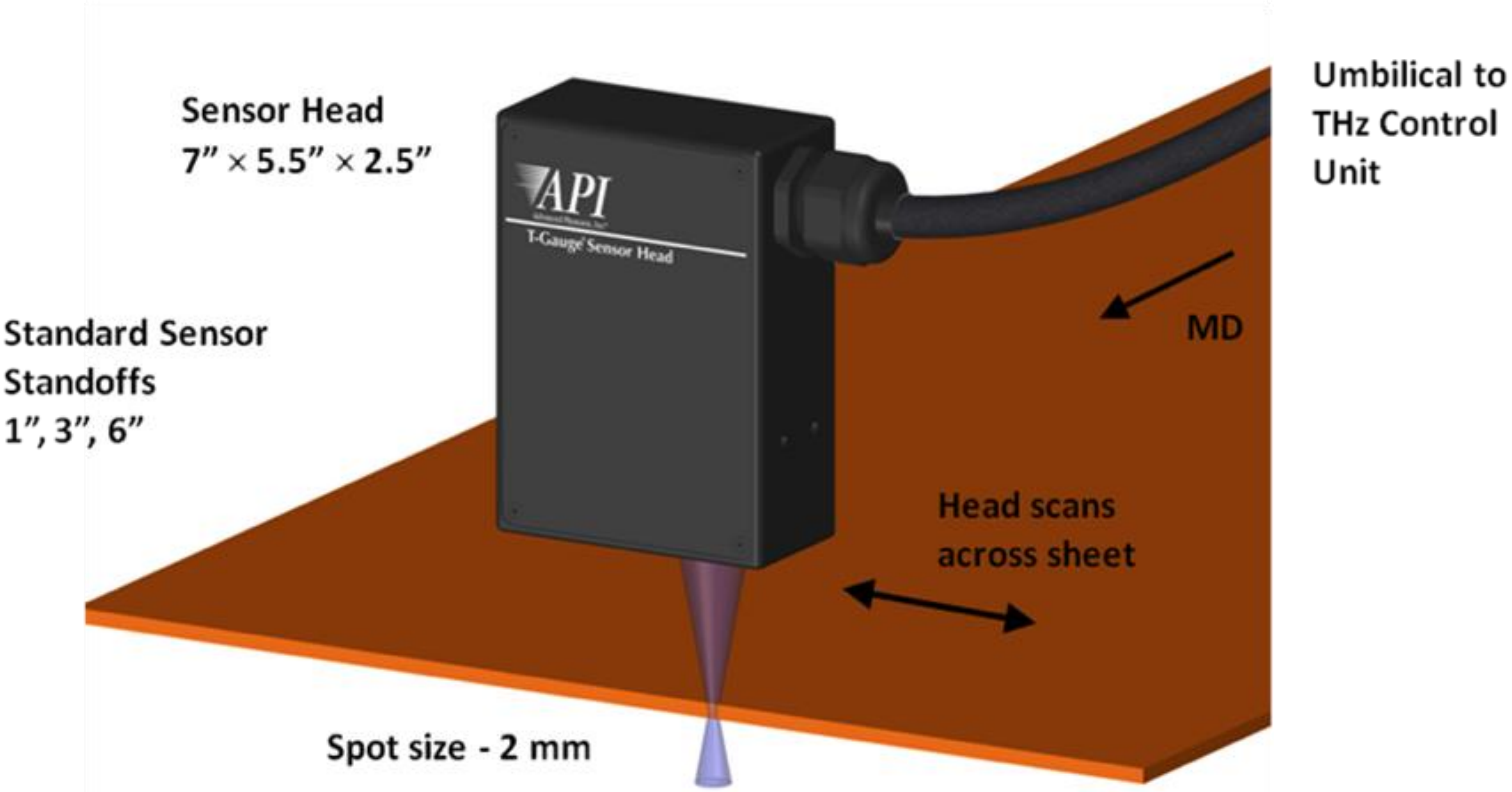
  Thickness = ToF / 2 * c / *Refractive Index*



# Example Reflection Waveform from a Three Layer Product

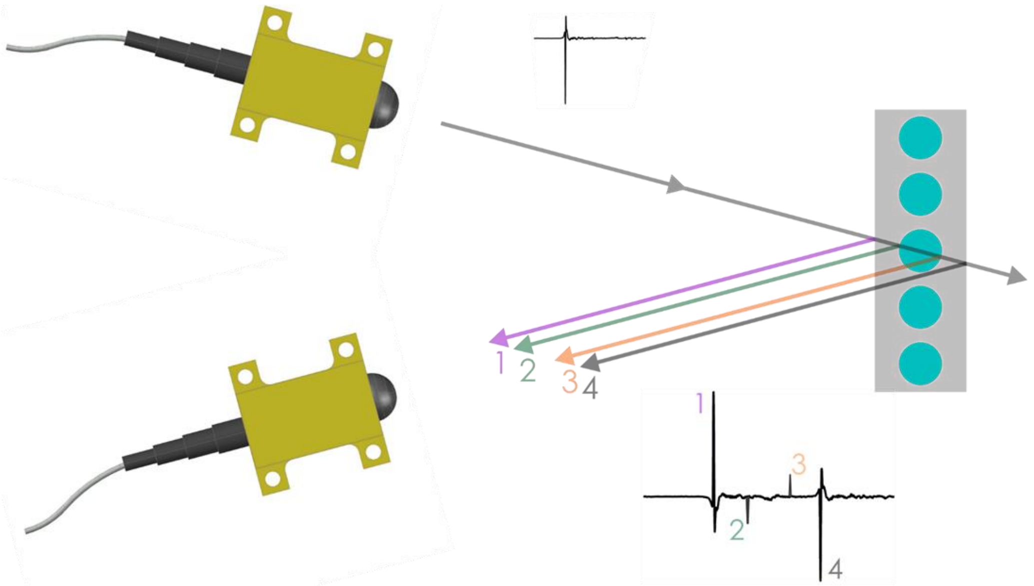


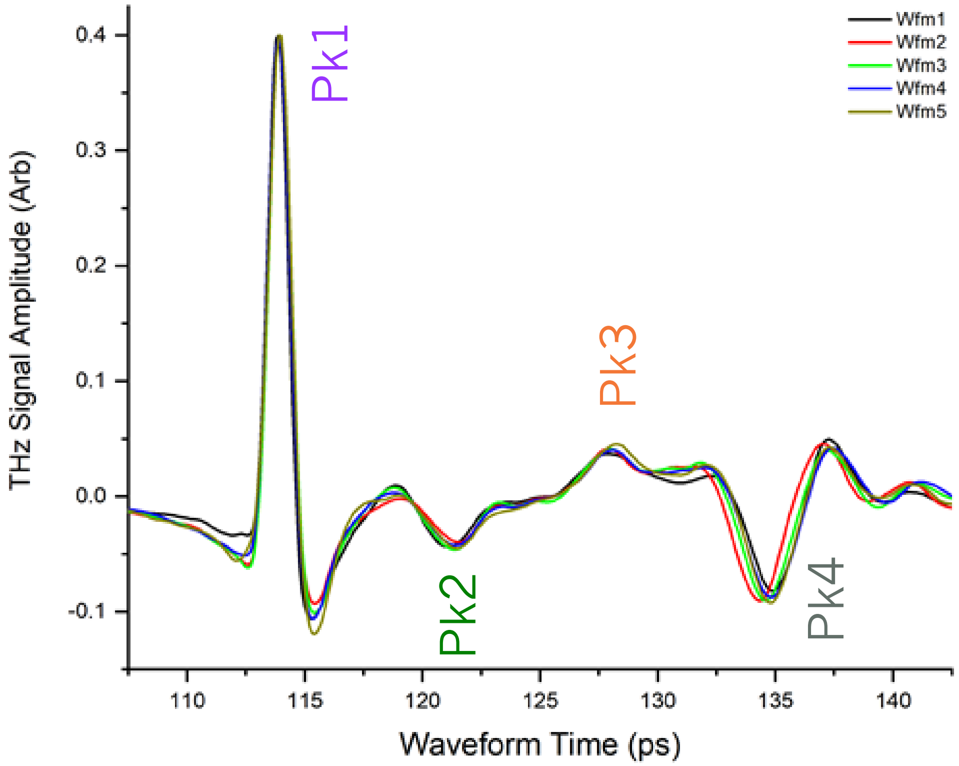
# T-Gauge® On-line Web Geometry



# Fabric Cord Body Ply

- Four Reflections are seen
- Thus, the following layers can be simultaneously measured with a single sensor
  - Top Skim
  - Bottom Skim
  - Total Ply

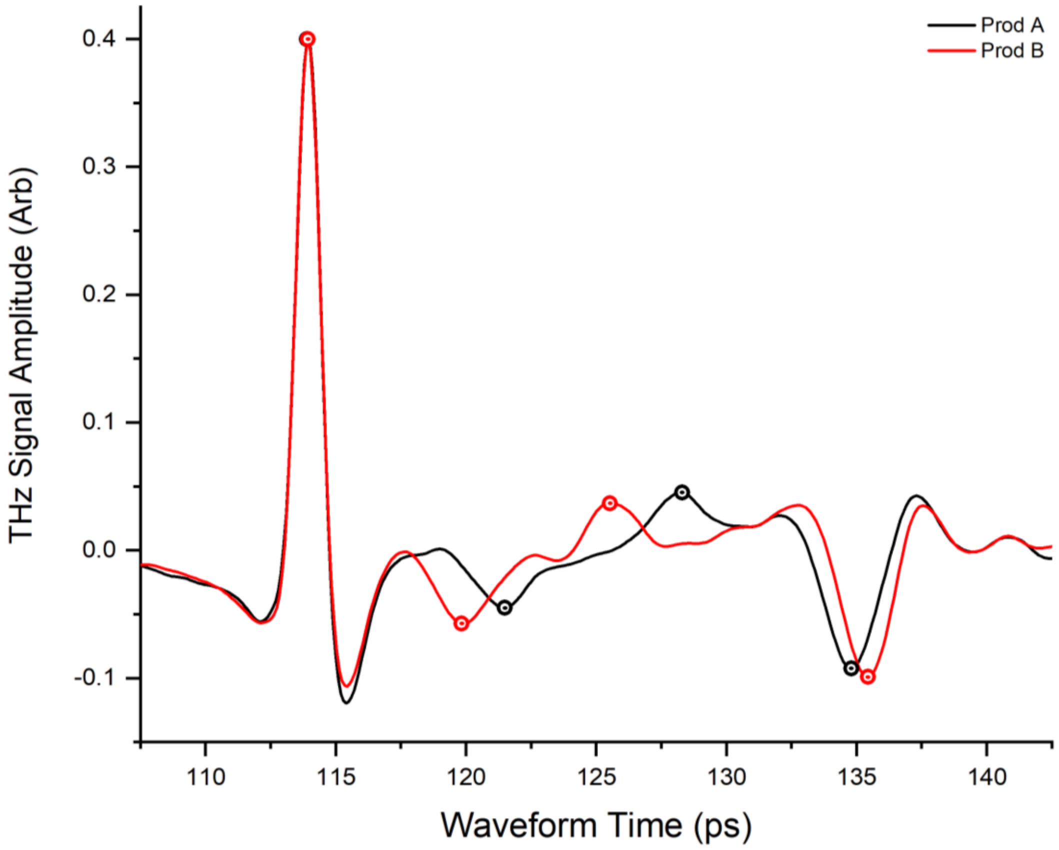


# Example THz Waveforms Fabric Cord Body Ply

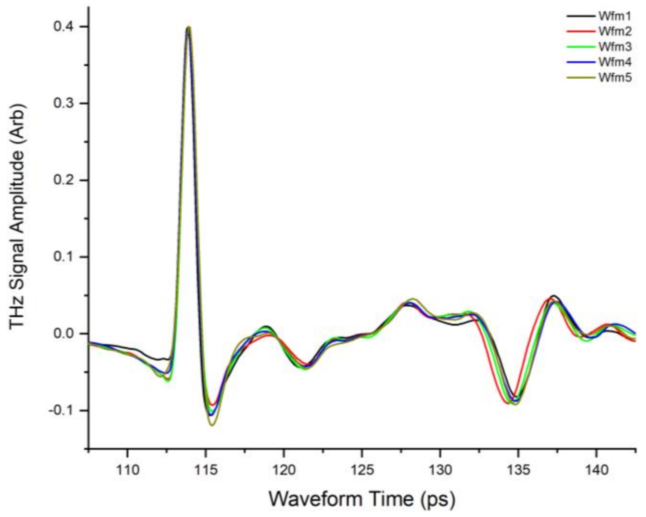
## Comparing Products A and B

Clear differences are seen between Products

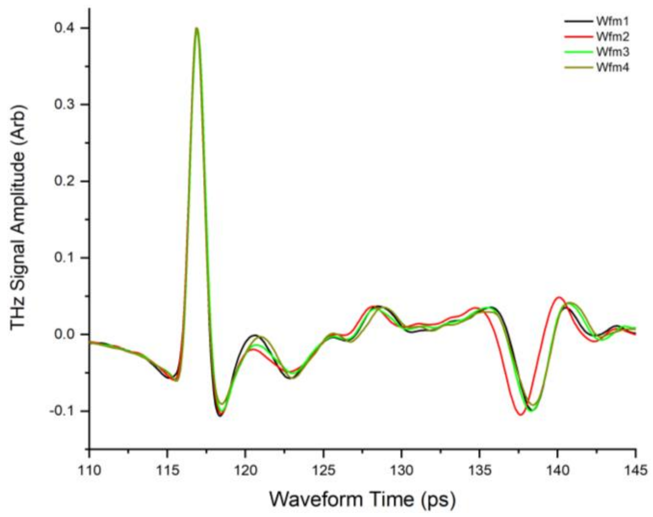



Multiple waveforms for individual Products show both overall consistency and normal expected variation within a Product

Product A




Product B



# Importance of Refractive Index (RI) Value

The equation to calculate the thickness of a layer is:

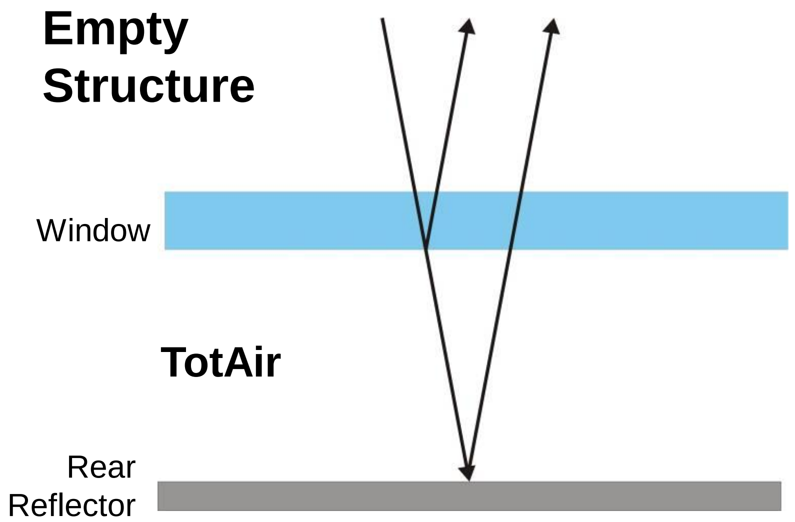
$$\text{Thickness} = (\text{ToF}) / 2 * c / \text{RI}$$

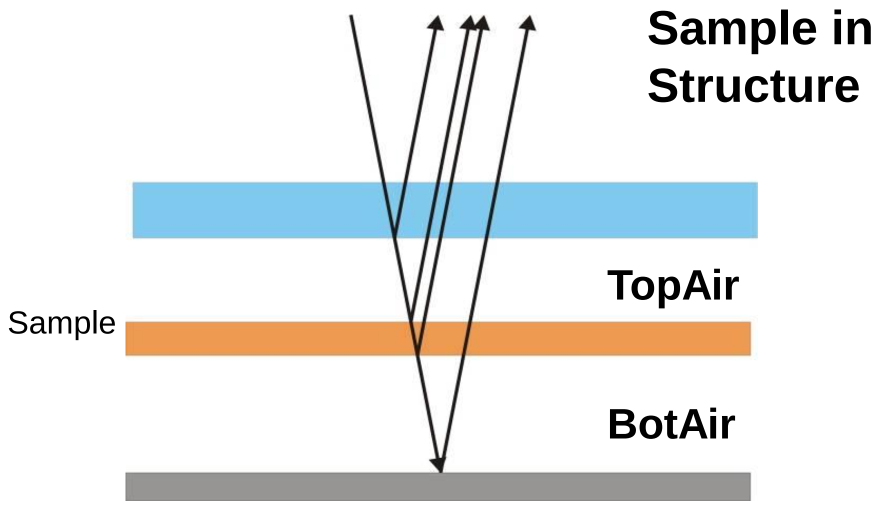
- RI stands for Refractive Index
  This value is divided into the speed-of-light to find the velocity of the THz pulse through the sample material
- C is the speed of light
- Refractive Index values are typically incredibly stable
- Thus, RI values are typically only measured once
- However, a widely 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 possible to measure a material's instantaneous RI value

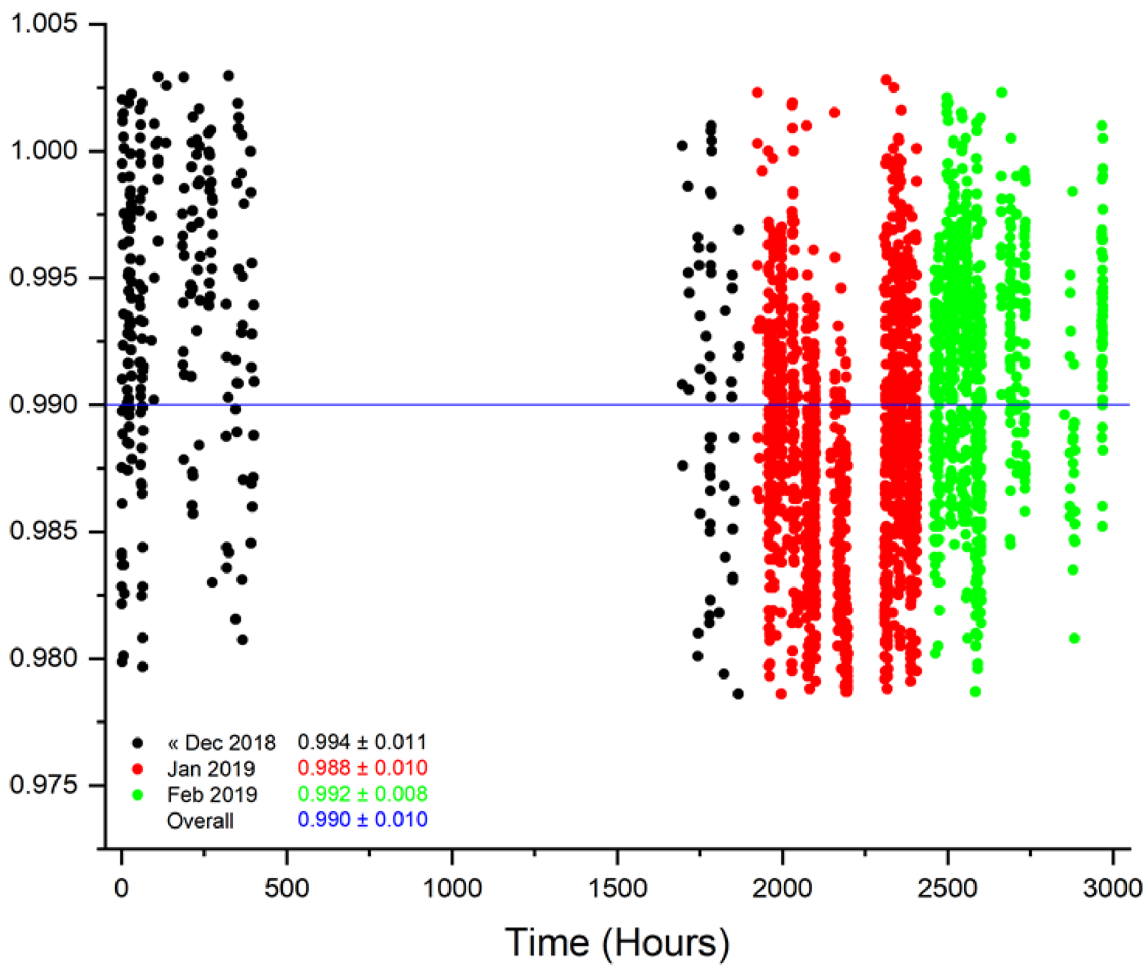
- Add a window above the sample and a metal plate below the sample to create an defined thickness Empty space
- Measure and store the "Thickness" of this space (TotAir)
- Insert sample and measure the thickness of the air above the sample (TopAir) and the air below the sample (BotAir)
- Sample thickness = TotAir – TopAir – BotAir
- With knowledge of the sample thickness, the sample material RI can easily be calculated



# Higher Accuracy Thickness Measurements

- The RI value of the running product was measured and stored over a period of 3 – 4 months
- The results revealed a small, but critical, variation in the material's RI value
- The uncorrected variation in RI would result in an accuracy error of ±15 μm in total thickness measurement
- Thus, the use of the ERS to determine the RI value for the material in production currently remains necessary



# Extending THz Measurements to other Calendering Operations

- The ability of a single THz sensor to make simultaneous multiple layer thickness measurements is the techniques most cited advantage
- However, the sensor also has other capabilities that would be useful for measurements at other locations in the Calendering process
  - very high measurement rate (100 measurements/sec)
  - very high precision and accuracy (precision easily < 0.1 mils or 2.5 μm)
  - ability to linearly scan measurement at high speeds (for a short distance ~ 4 inches)
  - demonstrated ability to perform instantaneous calibration for a variable material product
  - easily detect voids or delaminations in a sheet
  - Completely safe, no radioactive, ionizing or very high energy photon energy emission
  - Large standoff (3 or 6 inches) from sheet
  - Measurement of TIME is very helpful, virtually nothing affects time. Thus the sensor is very insensitive to most environment interferences such as: temperature, dust, noise, ambient light, debris on lens of sensor, vibrations and passline variation.

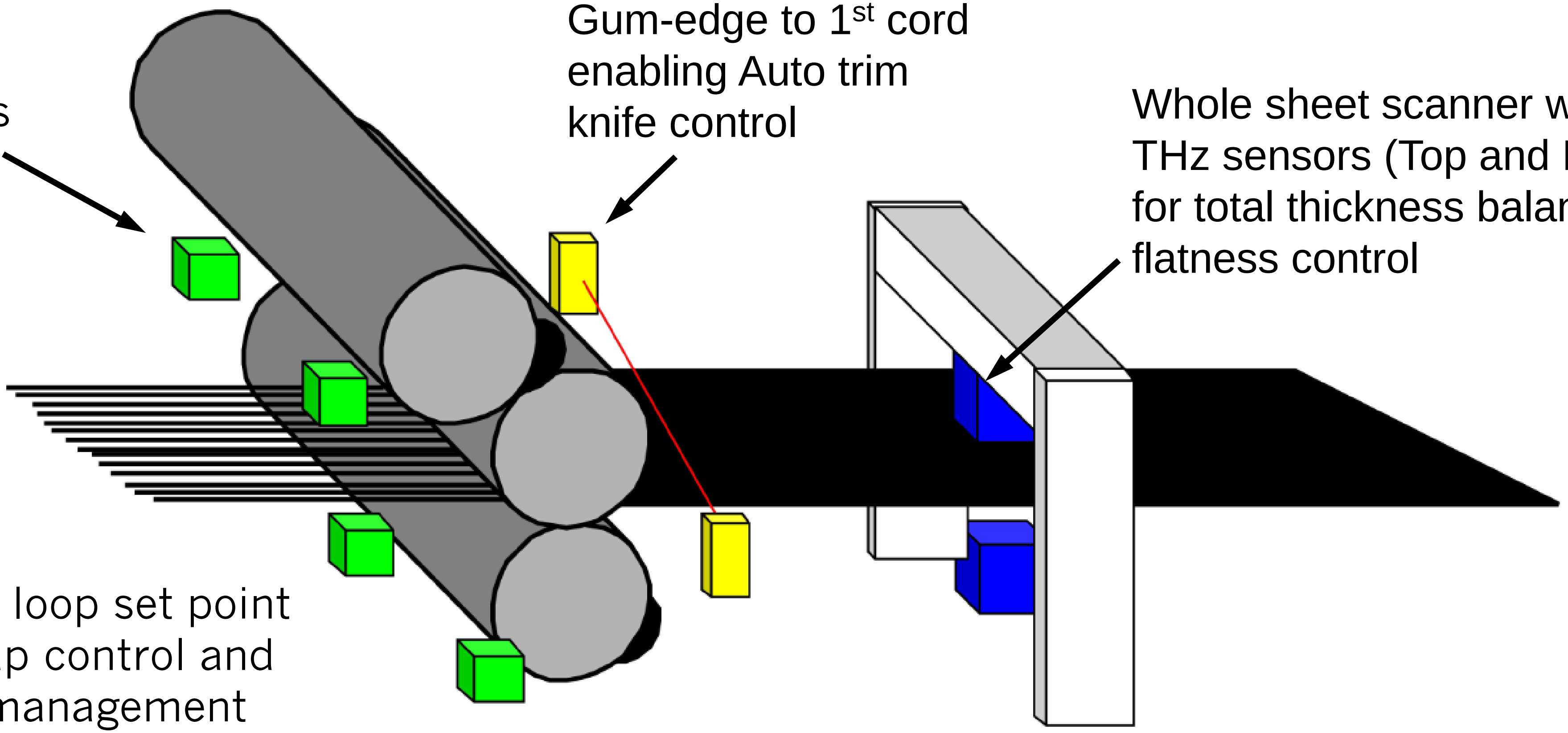
# THz Measurements at Other Locations

These advantages would be beneficial for measurements at other calendaring locations

- Use fixed point sensors to measure thickness of two gum layers before lamination. The THz measurement will be:
  - precise and repeatable,
  - have a large standoff from the sheet (3 – 6 inches)
  - High data rate, 100 measurements/sec rate
  - established method to calibrate on running product
- The THz spot can be quickly scanned over a short distance at a high rate. The sensor could be used to detect the last cord and report position for auto trim knife control.
- The sensors on scanning frame report thickness, balance and profile
  - If Cords are steel, then either and assumption of Cord diam. or a second will be needed to determine Bottom Skim layer thickness
  - If Cords are fabric, a single sensor can measure Top and Bottom Skim and Total

# Calendering - Additional Measurements Locations

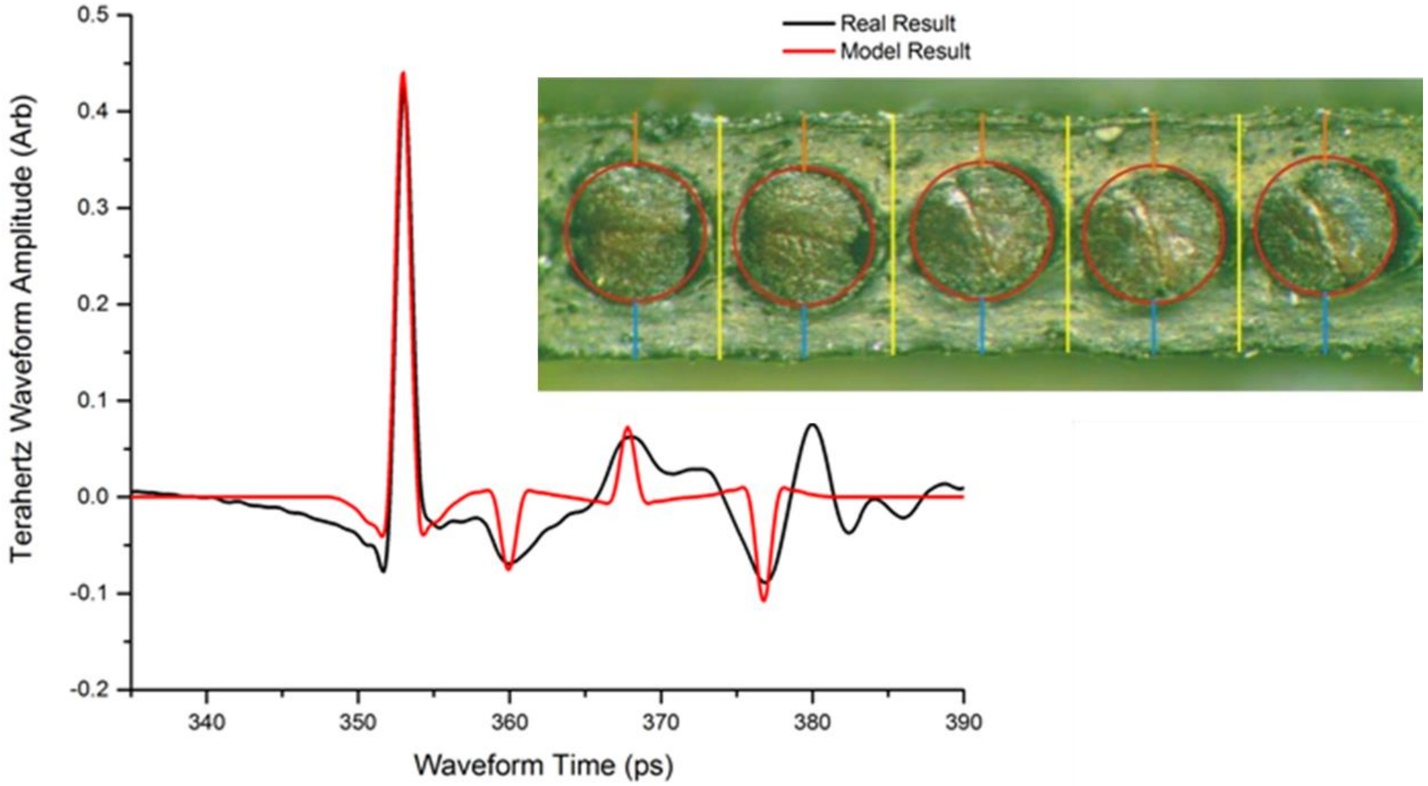
- Layer thickness, and other information, is needed at various points in the Calendering process



# Fabric Cords Allow Measurements of More Parameters

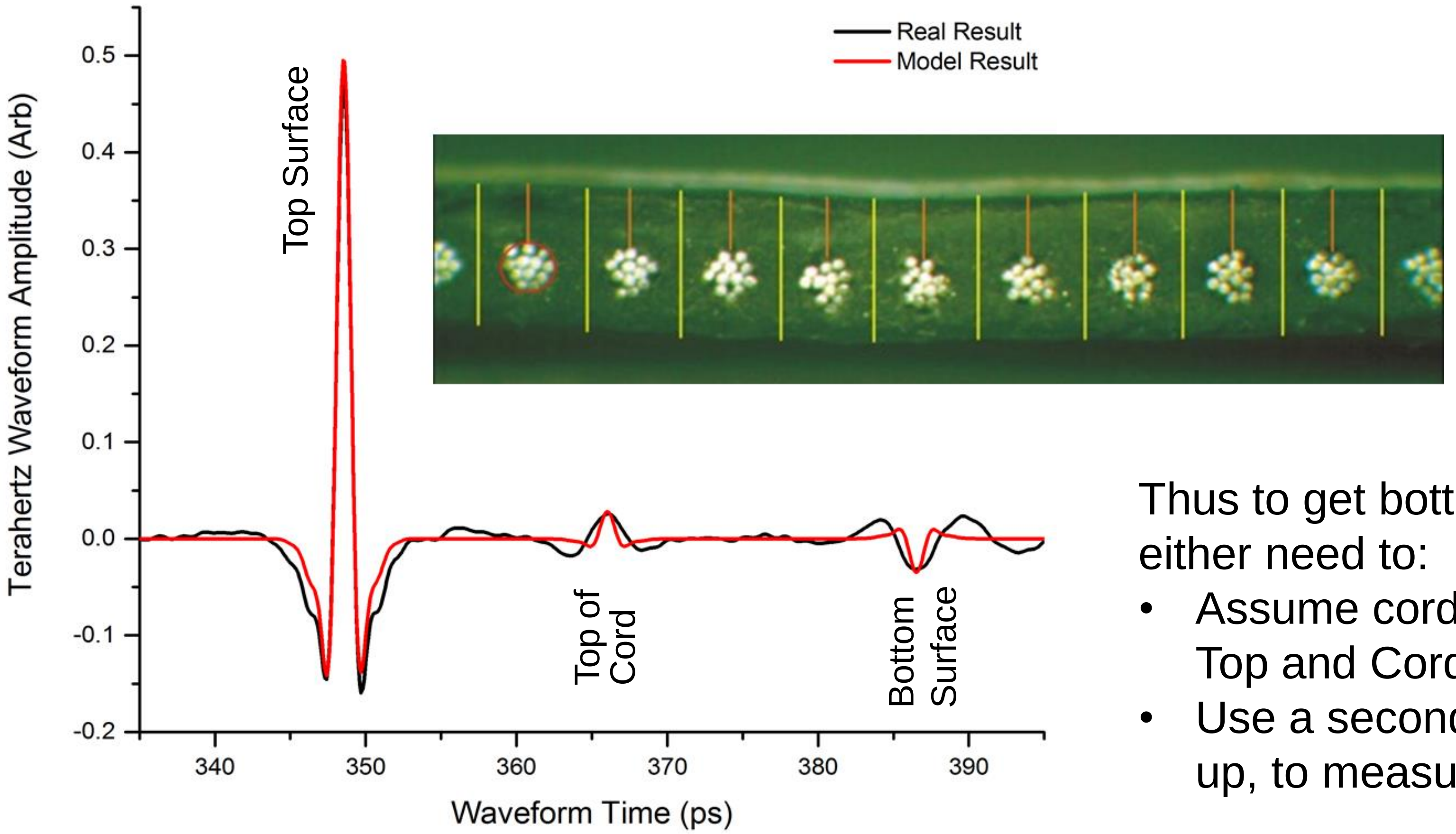
Because the THz pulse can penetrate through the cords, the four (4) reflections observed provide simultaneous thickness measurements for three (3) layers.

THz waveform data, real and modeled, from a single-sided reflection sensor.



# Metal Cords Reflect Entire THz Pulse

Steel cords present a challenge because the THz pulse cannot penetrate through a conductive material.  Thus, the thickness of two layers can be found simultaneously.




Thus to get bottom skim thickness either need to:

- Assume cord diam. and subtract Top and Cord from Total, or
- Use a second sensor, pointing up, to measure Bottom skim

# Static Point Sensors

Would be used to measure single gum layer thickness. Such a measurement would be quite straightforward for THz sensor.

Four (4) sensor would be required for the two sheets. Control at the central position is better handled with results from the scanning frame.

One big advantage is the ability to determine the calibration factor for the material in production in real time. Higher accuracy measurements.

Another advantage would be Sensor is not sensitive to temperature. Or most any other environmental interference: dust, noise, ambient light, debris on lens of sensor, vibrations, passline variation.

The sensors have proven to be very reliable in many differing type of industrial environments

The large sensor standoff means the sensor is completely non-contact and does not need a air pressure flying tip.

# Line Scan THz Sensors

THz inspection spot to be quickly scanned in a line. Scan length of 2 – 4 inches at 6 scans per second

Thus, such scans could locate the gum edge to first cord and last cord to gum edge, for either metal or fabric cords

Useful for setting knife trim positions

The typical THz focus spot is 2 mm in diameter. Relatively small diameter spot useful for resolving spatial position along linear scan.

# Additional Measurements at Scanning Frame

The sensor(s) on the scanning frame provide previously reported multiple measurements:

- Total Thickness
- Top / Bottom Skim Thickness
- Thus, Balance and
- Profile / flatness

In addition, THz can easily detect voids or delaminations in the sheet.  Both are detected by unexpectedly large amplitude reflection signals from within the sheet.

THz reflection amplitude depends on the difference between the two materials (e.g., gum / poly cord).  The bigger the difference, the larger the reflection peak amplitude.

Air is the most different material that can be present.

Thus, the presence of air within the sample will generate very large amplitude peaks.

# Consideration of Benefits

The main of the presentations was the ability to make measurements on steel and fabric cords with the same sensor.

Multiple simultaneous measurements have been demonstrated

The sensor is very reliable in industrial environments

Very high measurement rate (100 Hz) can be used to improve control or provide better profiles or simply averaged to provide more reliable measurements

The system is completely safe

The large standoff (3 – 6 inches) makes the sensor truly non-contact and easier to position in the process

Measurement not affected by most environment interferences

Measurement is always very precise. Ability to determine calibration factor for a variable material in real time while being produced improves accuracy.

Detection of voids, delaminations (even low adhesion before delam) very straightforward

# Conclusions

Demonstrated performance at industrial installation (Bridgestone, Aiken SC).

Total thickness, Top and Bottom Skim thickness (thus balance) and sheet profile measurements

Deployment of sensor at other Calendering locations shows promise and strong benefits

Thank you for your attention

- Jeffrey White, TeraMetrix
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