Development of APE System using Step-Frequency GPR

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A. ***A***dvanced ***P***avement ***E***valuation

- APE Developed for the Office of Pavement Technology (HIPT) to:
  - Demonstrate Sub-Surface Imaging and Continuous Material Calibration using SF-GPR
  - Develop Analysis Algorithms
  - Test and Evaluate Performance
- Pavement rehabilitation is a key focus area
  - Pavement evaluation
  - Rehabilitation selection

B. SF-GPR & APE System

Task Order 13
DTFH61-06-D-00021

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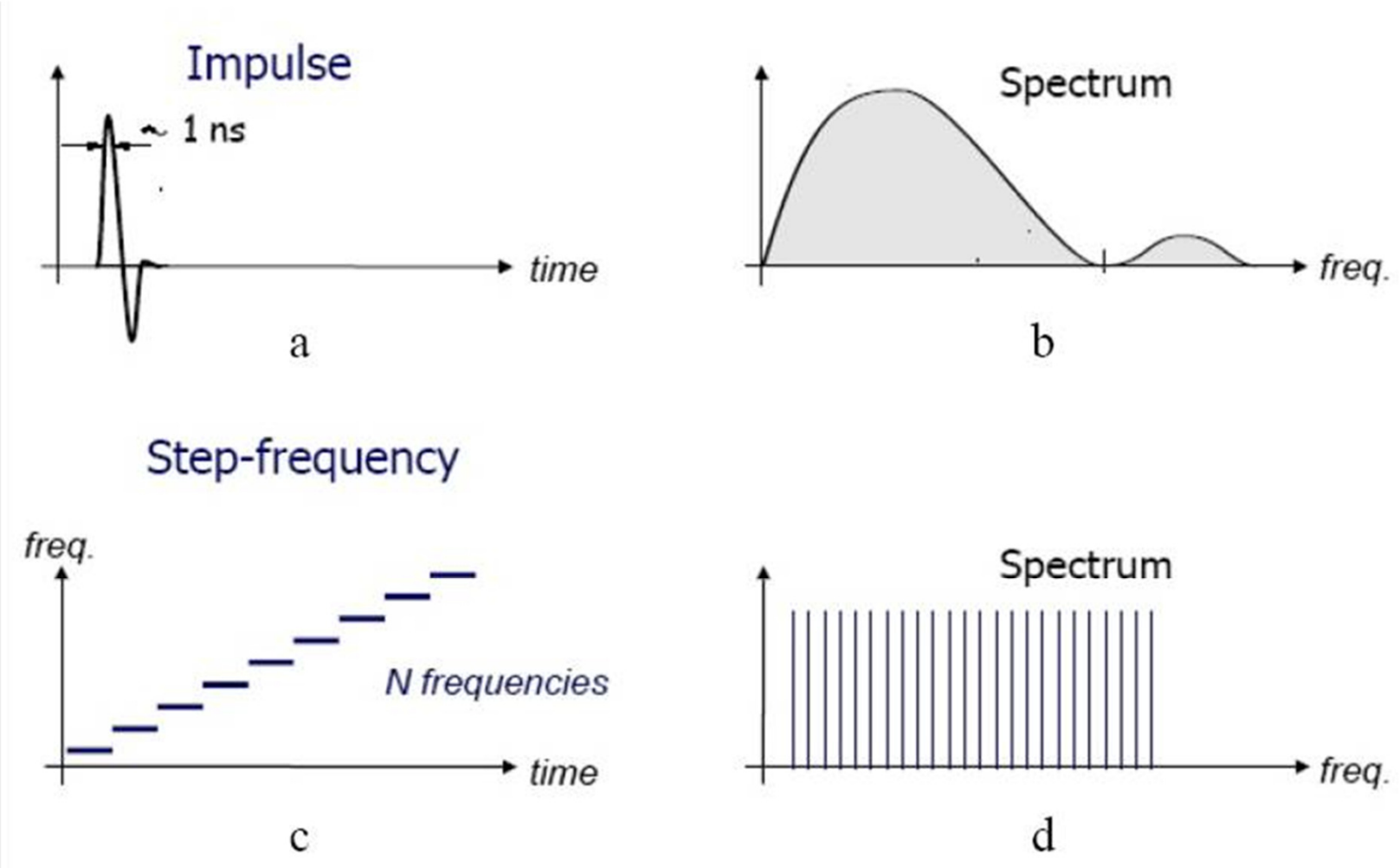
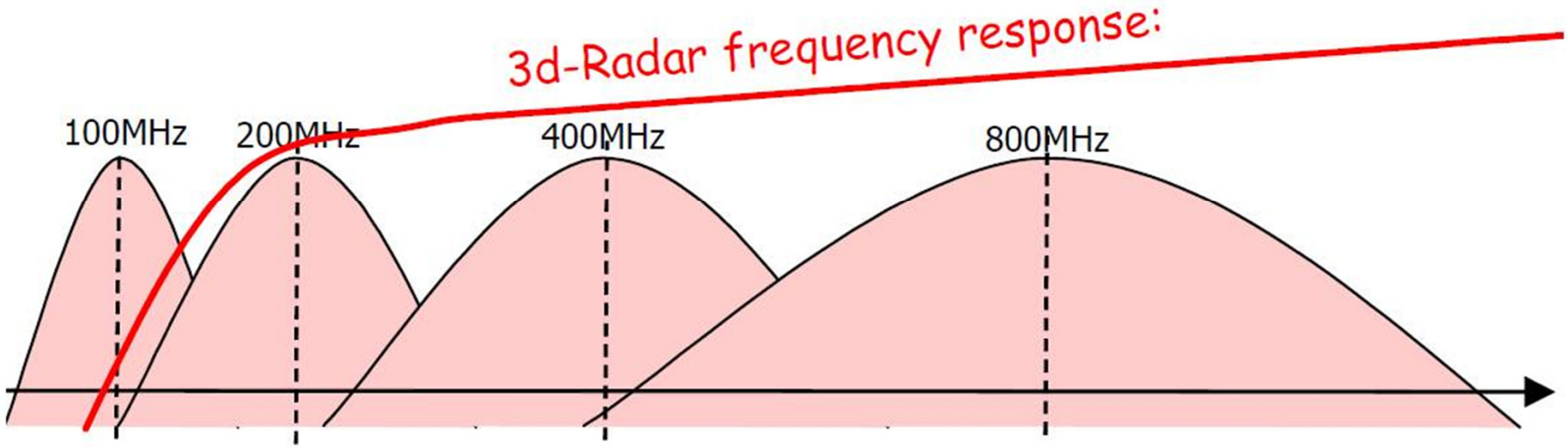
B.1. Impulse vs. Step-Frequency GPR

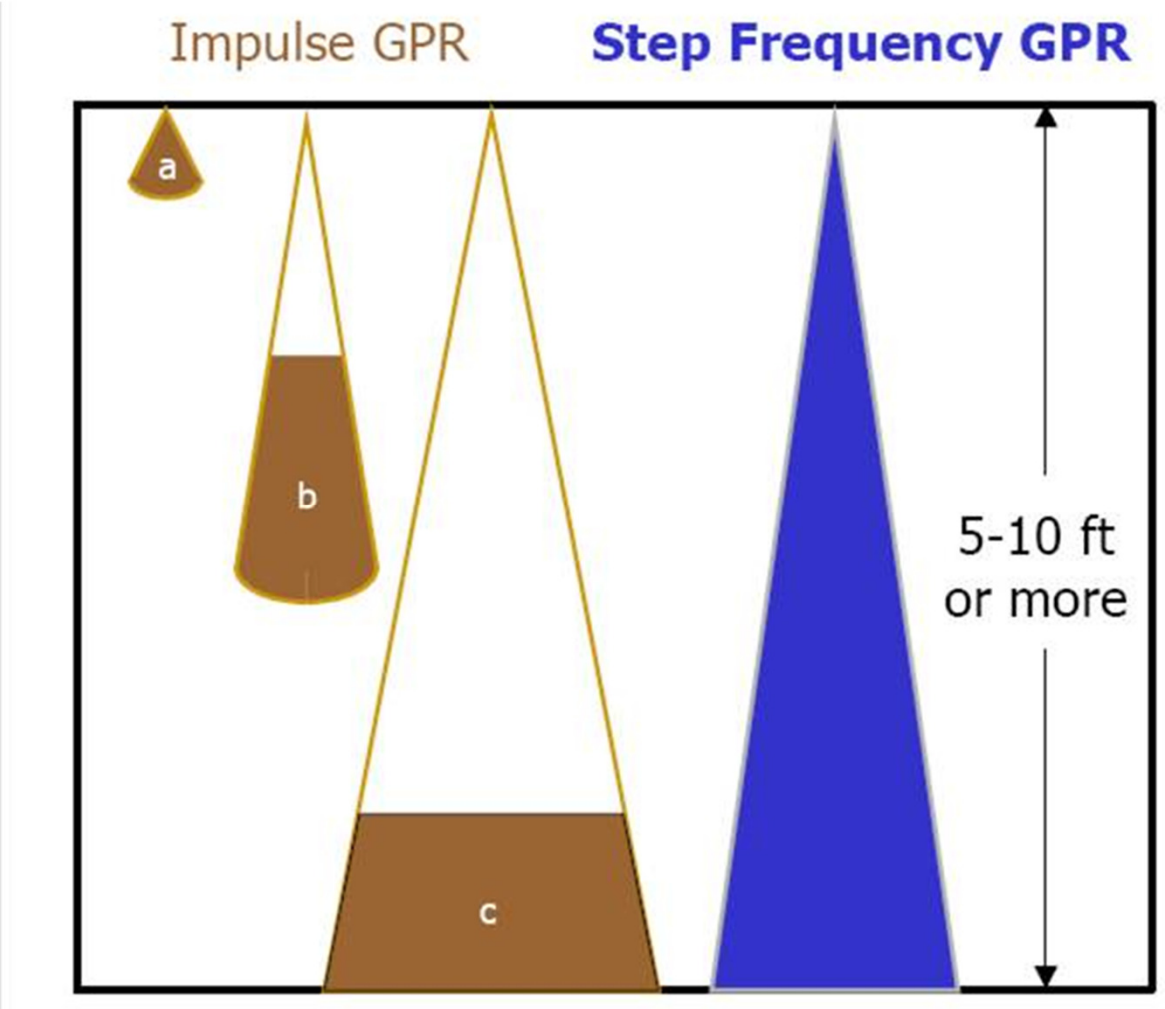


B.1. Impulse vs. Step-Frequency GPR

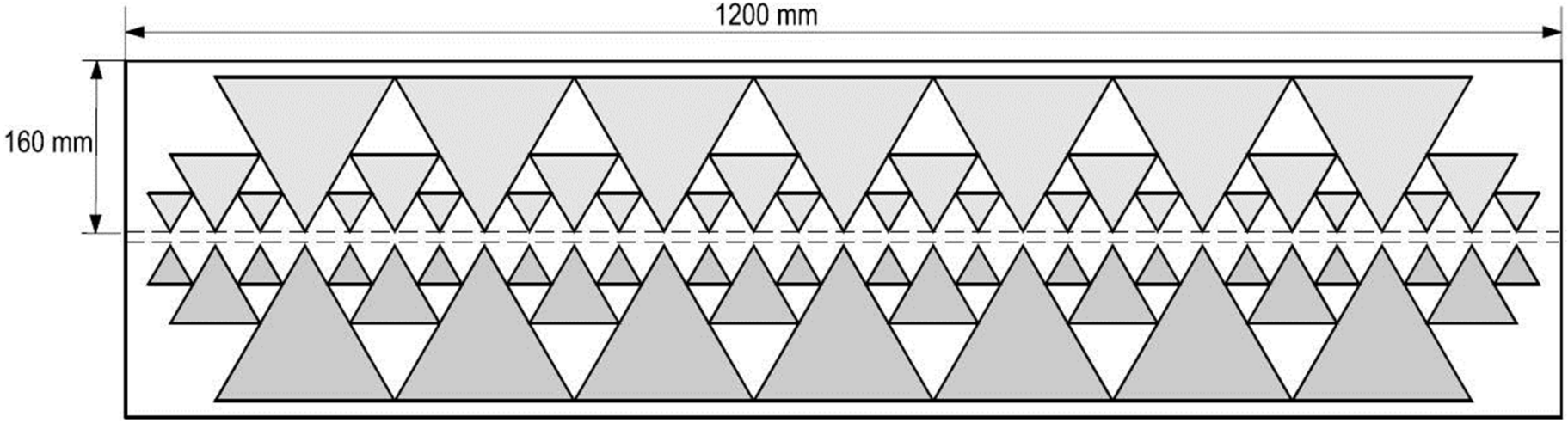


Impulse radar frequency response

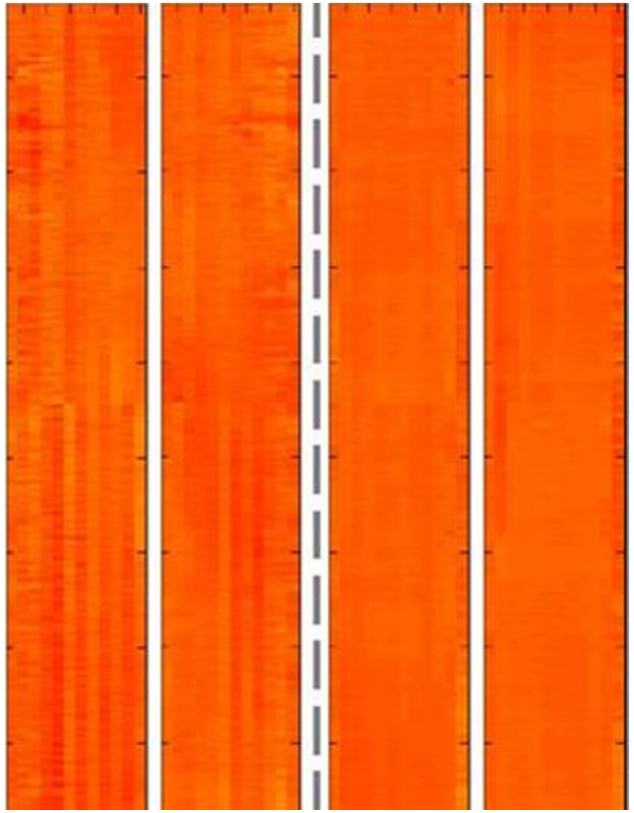
B.1. Impulse vs. Step-Frequency GPR



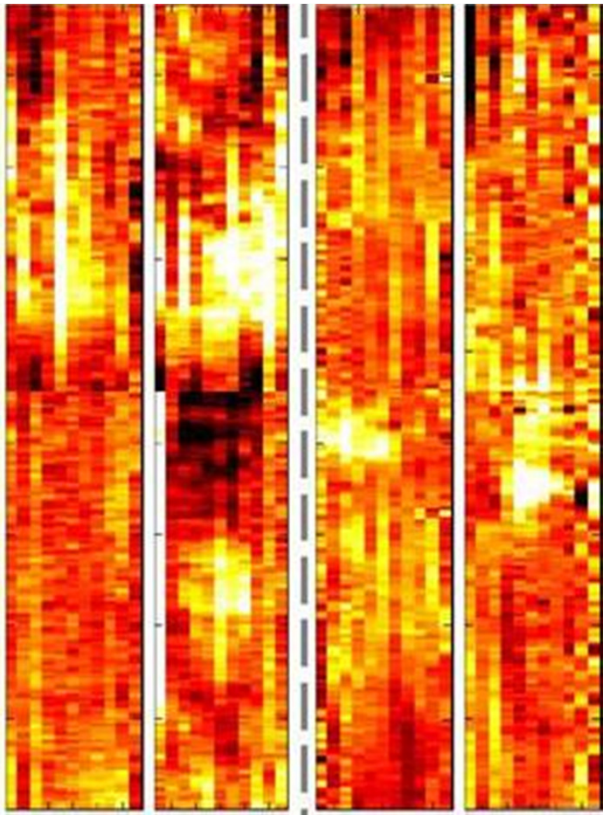
B.2. SF-GPR antenna array



B.3. SF-GPR – scan images

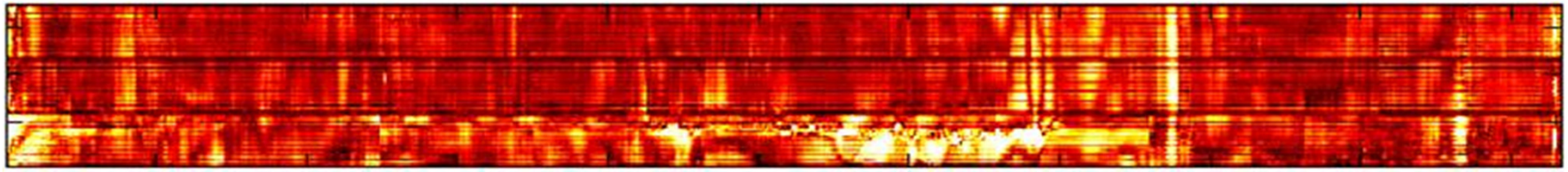


Surface – no distress



Layer interface showing inconsistent condition and presence of water

B.4. Voids under composite pavement

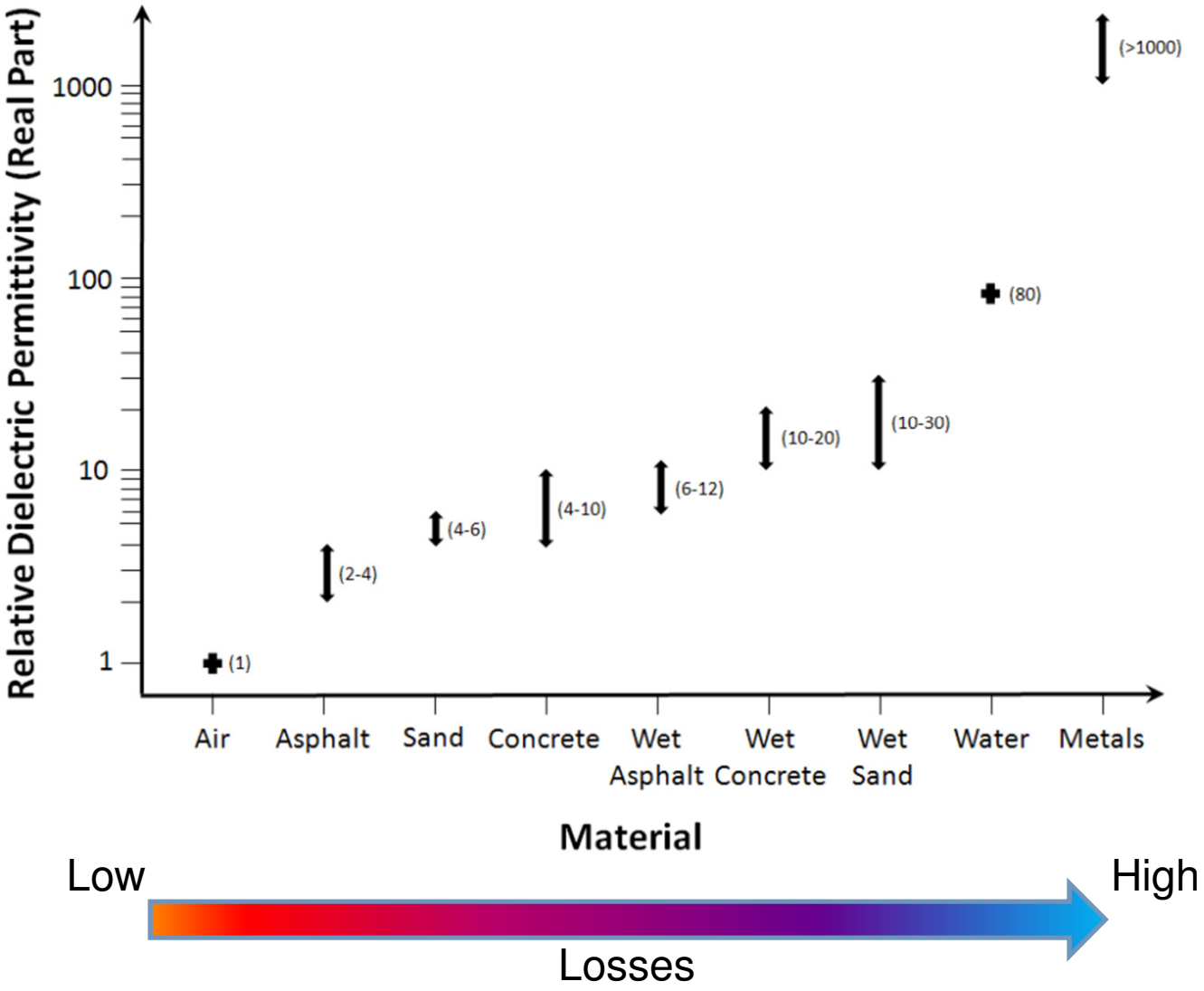


135+40

144+00

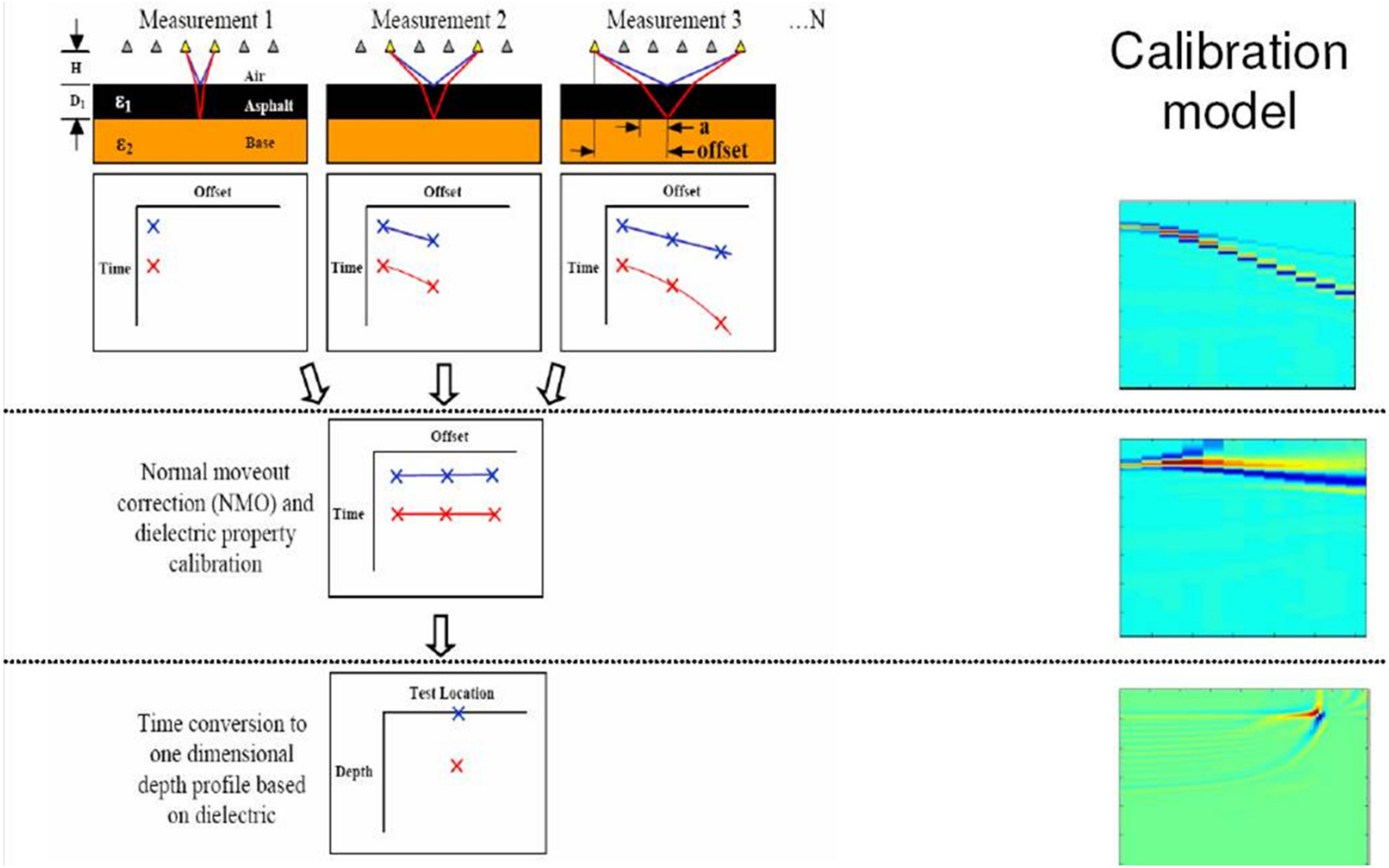
B.5. Dielectric Properties

Table of Relative Dielectric Permittivity for A Selection of Materials



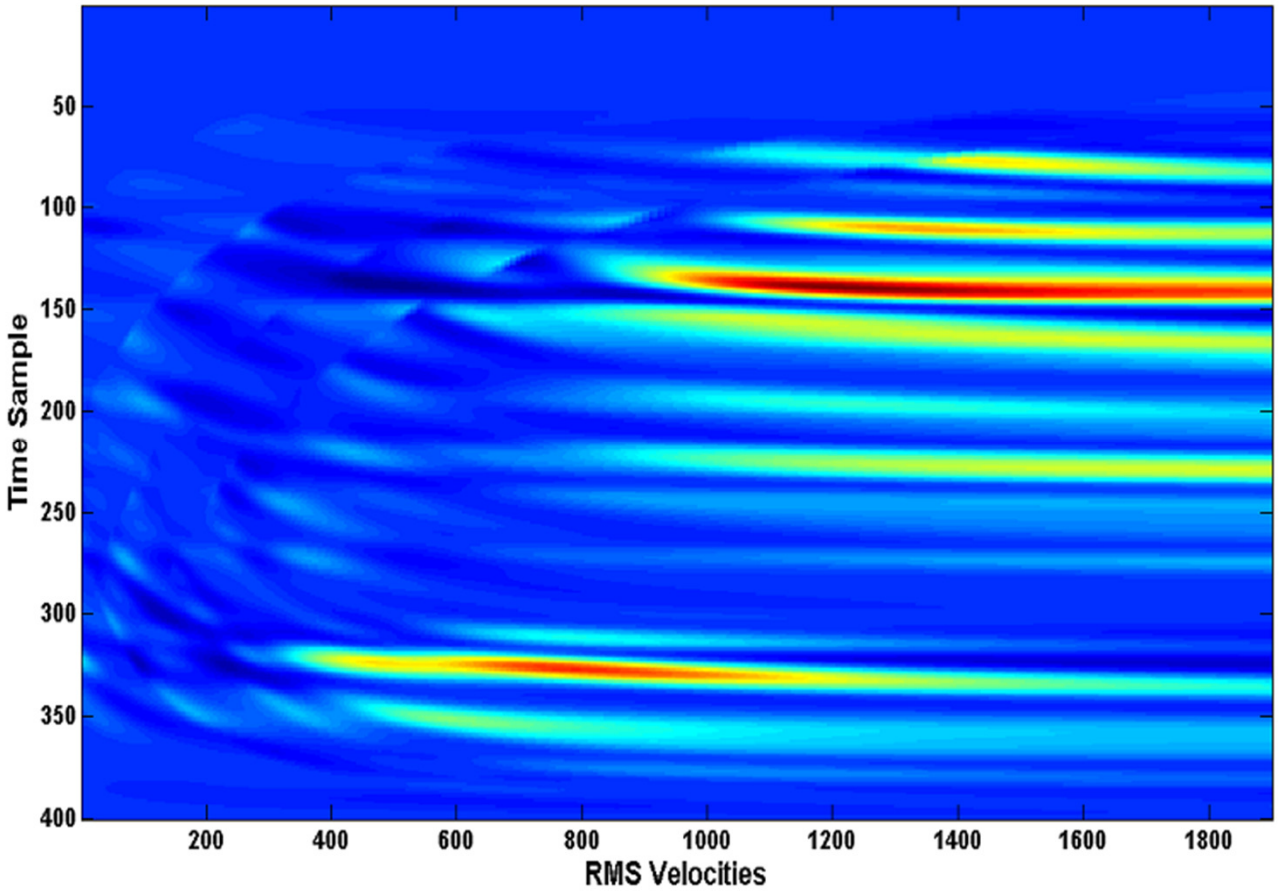
B.6. Continuous calibration

Continuous calibration by common midpoint (CMP) method without coring



B.6. Example Semblance Plot

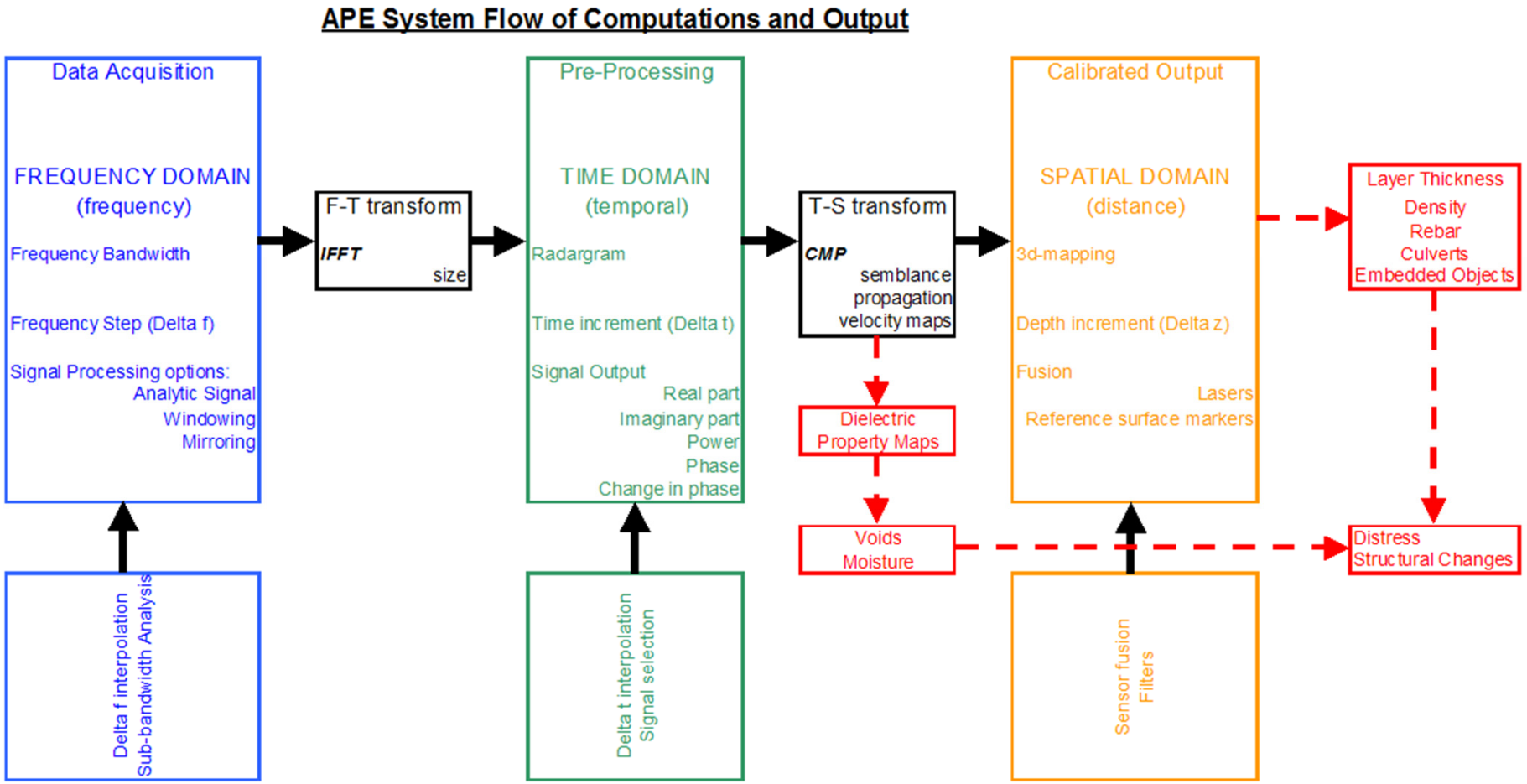
Semblance Plot Used for Estimation of Dielectric Properties and Layer Tracking



Layer Interface

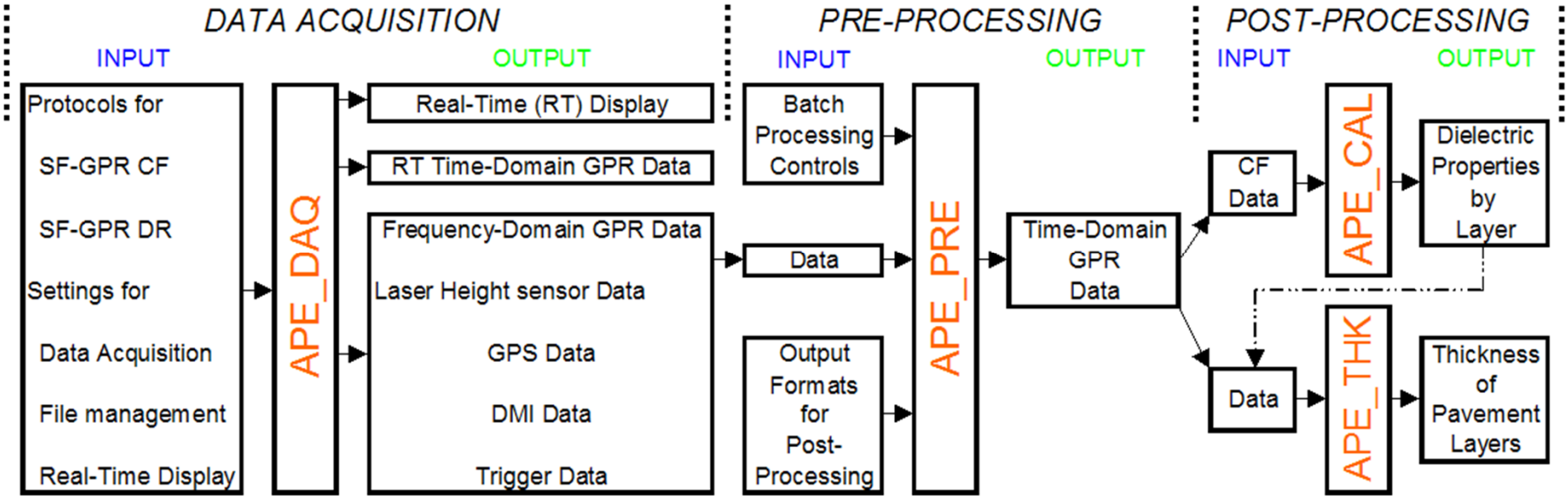
Layer Interface

B.7. APE Analysis Domains



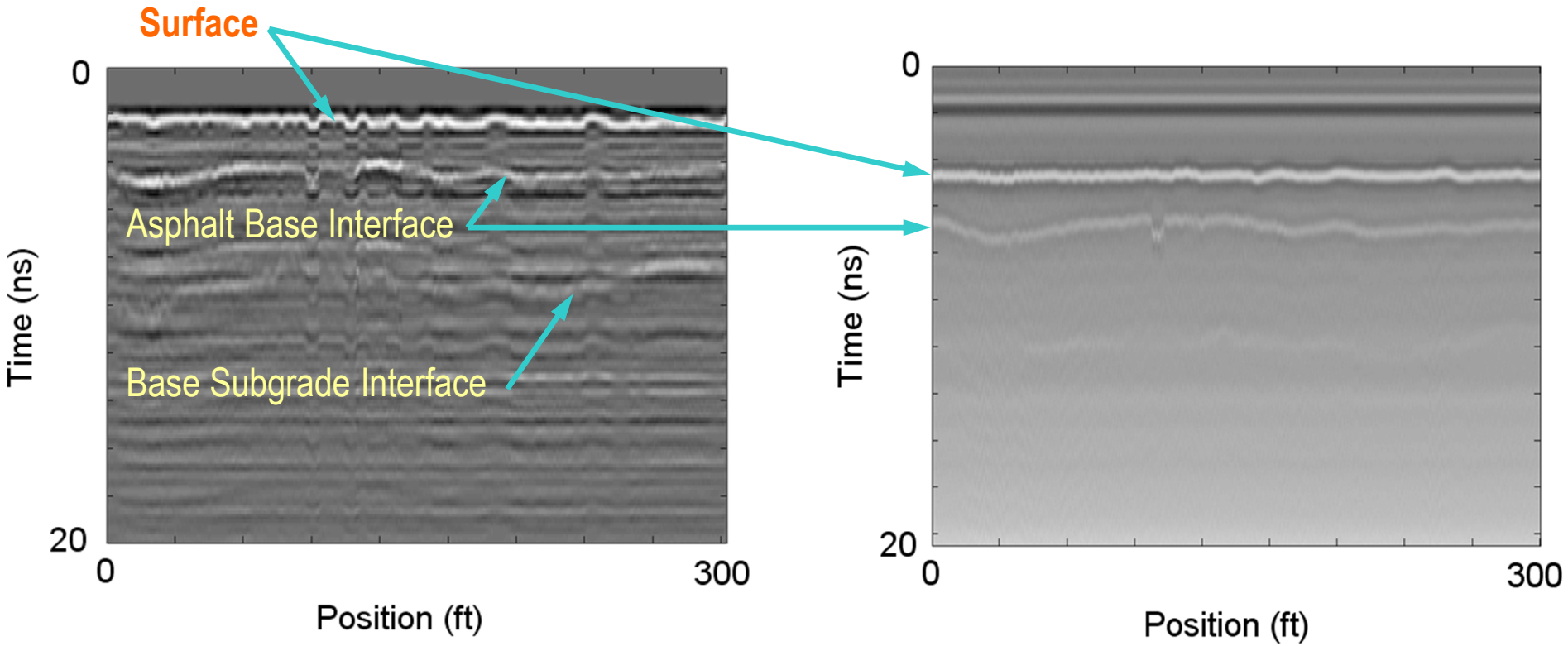
B.8. APE Software Modules

Version 0.2 – Analysis Pipeline



B.9. Direct Comparison of APE and GSSI Systems

B.9. Performance Comparison

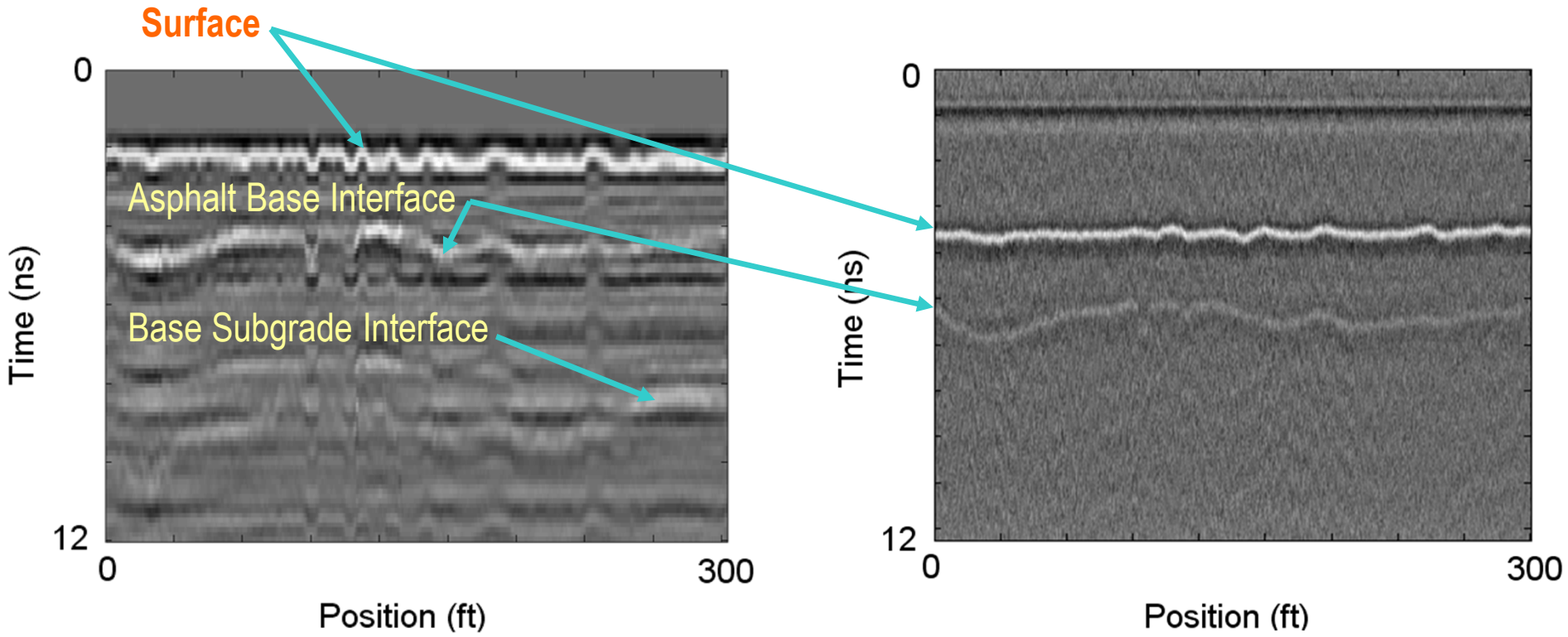


APE System (Single Antenna)

1 GHz GSSI

Cell 84

B.9. Performance Comparison



APE System (Single Antenna)

2 GHz GSSI

Cell 84

C. Measurement of Layer Thickness Using APE System

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DTFH61-06-D-00021

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October 2010

C.1. Sample from Minnesota Project

- Cell 33
- B1847
- 150MHz to 3GHz
- 47 antenna pairs

C.1.1. Reference thicknesses – cell 33

Length = 500 feet

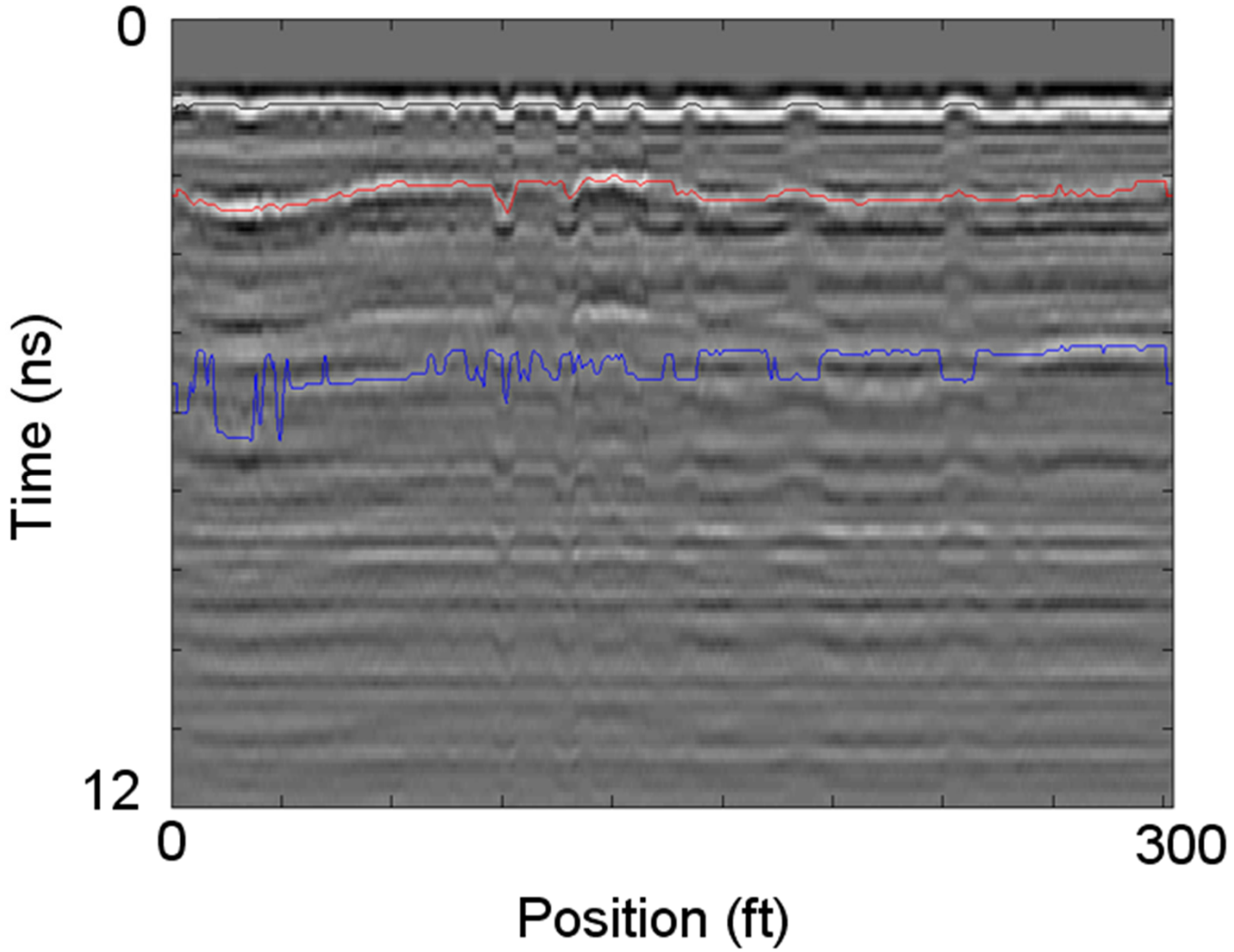
Asphalt	4 inches
Base – Class 6	12 inches

Source: Design Criteria

Cores 33-5 @ 5.0 inches and 33-6 @ 4.5 inches

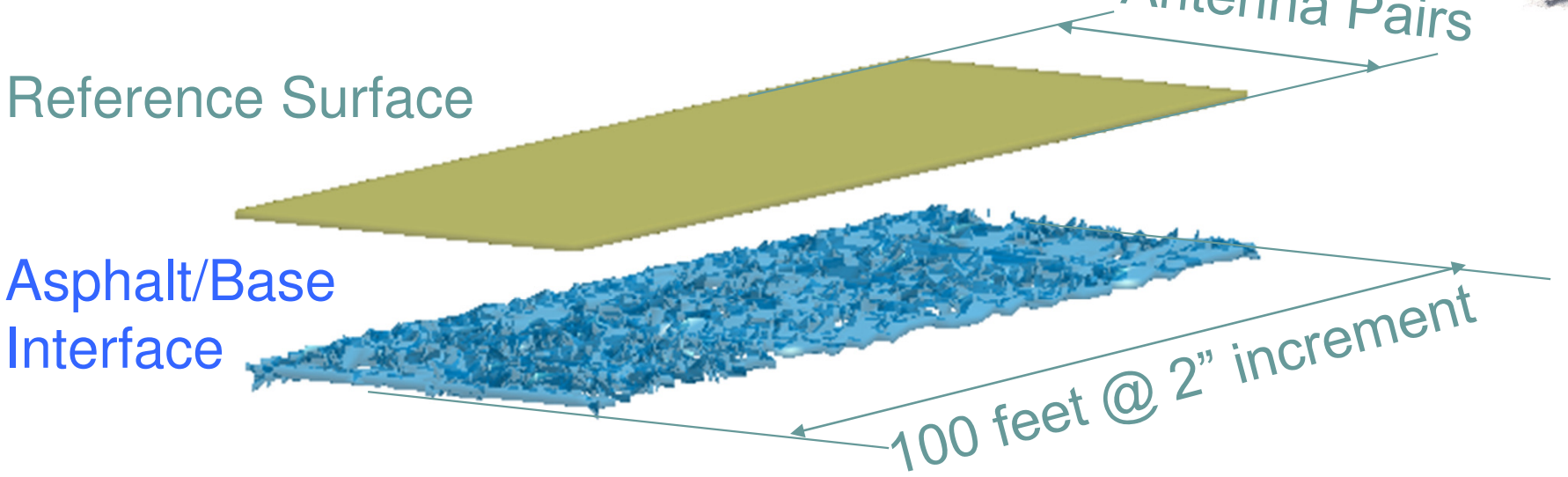
Cell 33

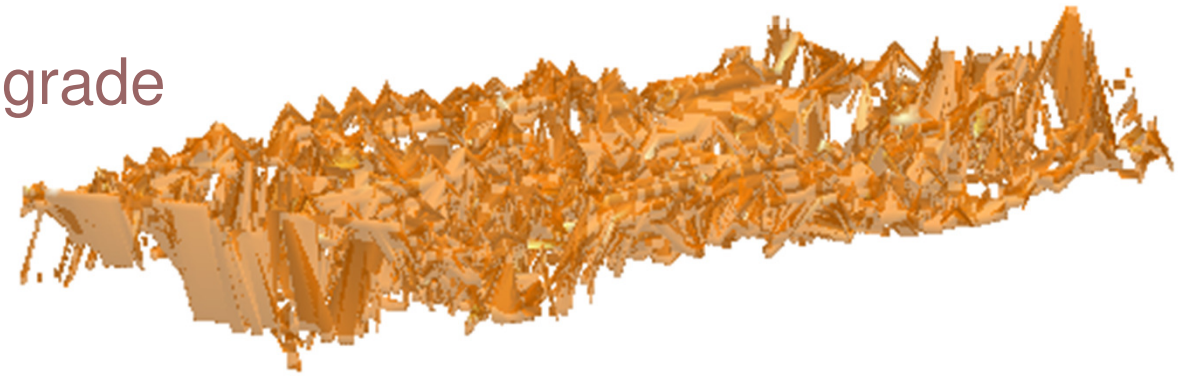
C.1.1. APE Layer Detection and Tracking



Cell 84

C.1.1. Layer Measurement

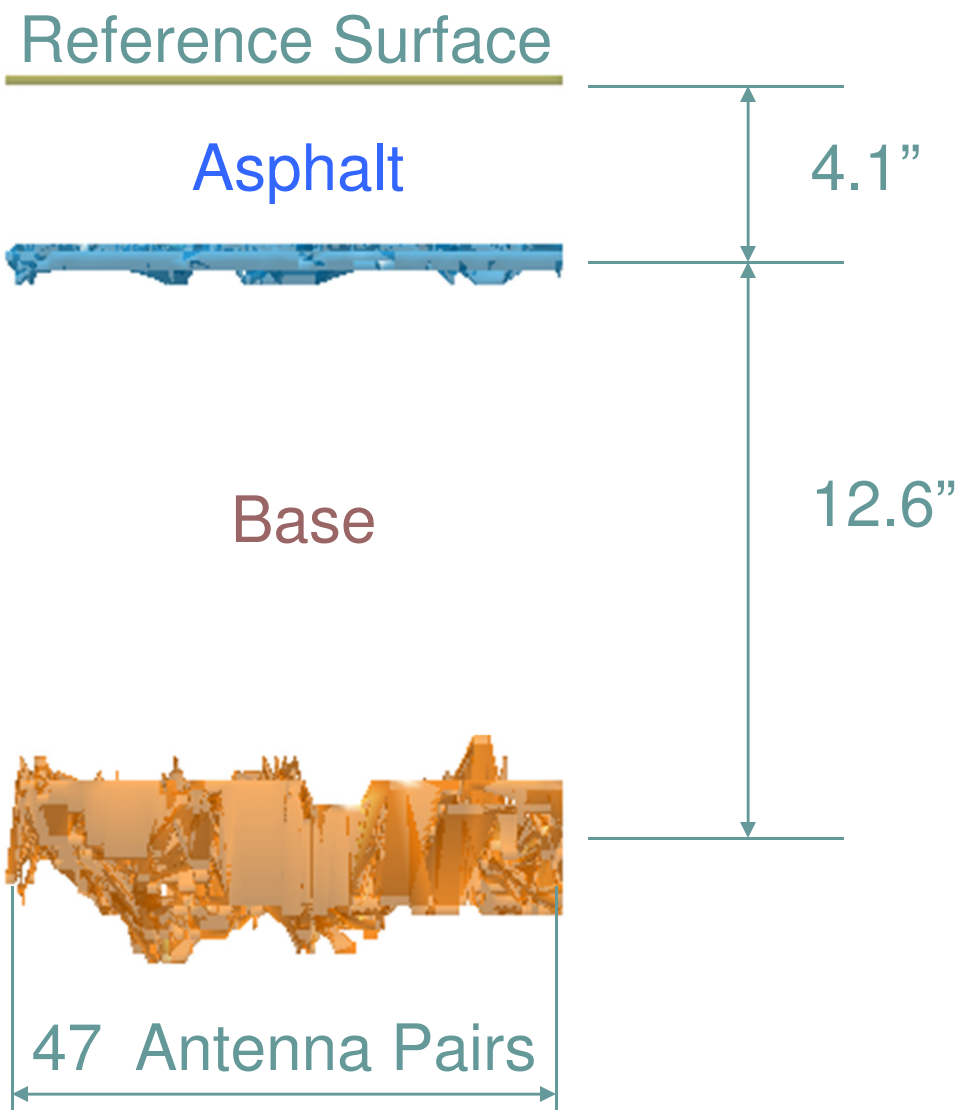




Cell 33

Orthotropic View

C.1.1. Layer Measurement



Cell 33

Cross-Sectional View

C.2. Evaluation of APE System for Pavement Thickness Measurements Using Metal Plate Experiment

C.2.1. Ground Truth

MIT-SCAN T2

C.2.1. Ground Truth

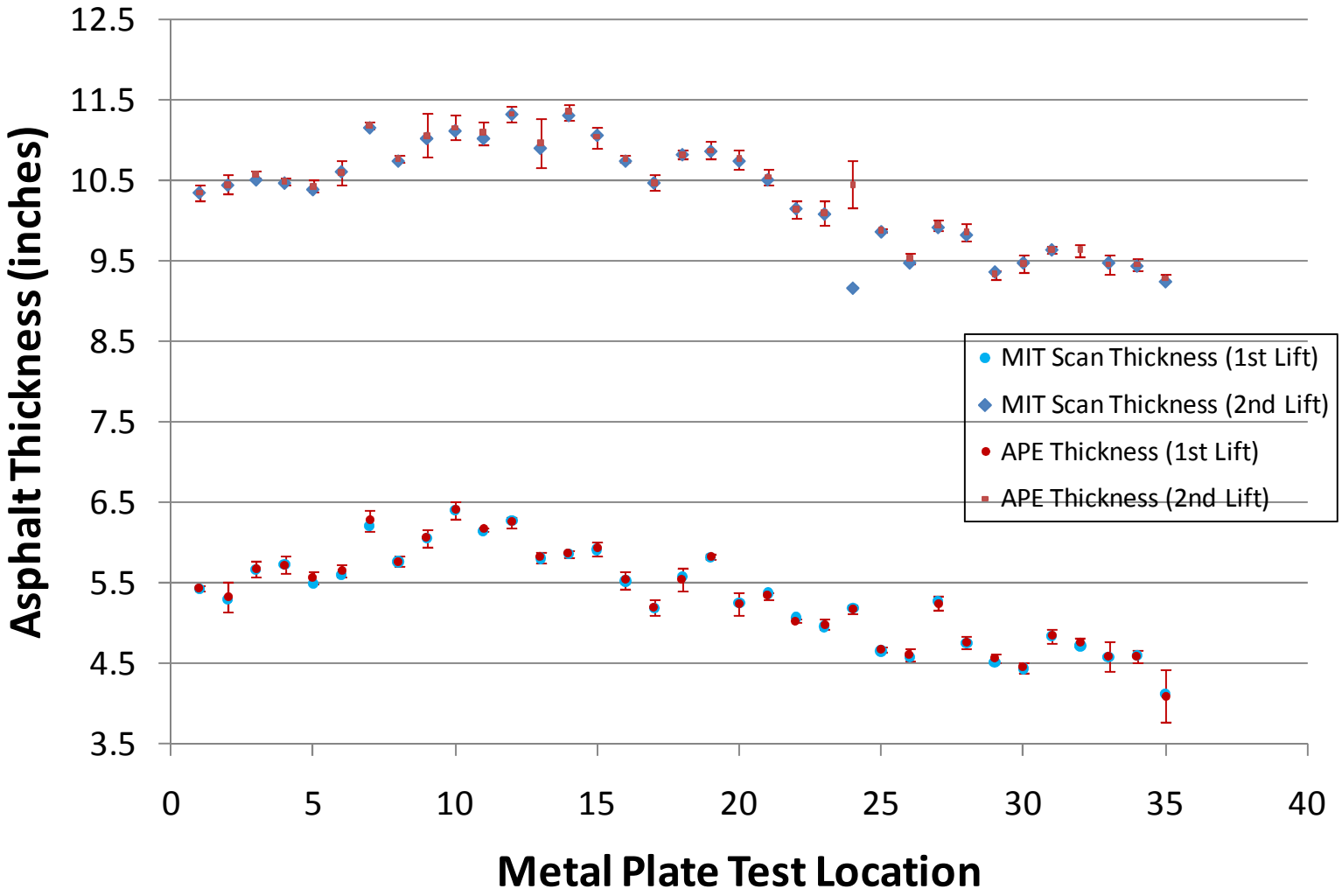
- NDT device for pavement layer thickness measurements
  - Pulse-induction technology
  - Measures vertical distance to pre-positioned metal targets
  - Measurement range: 0 to 20 in
- Specified accuracy
  - 0.5% of the measured depth +1 mm
  - Translates to 0.1 in (less than 3 mm) for 13 in pavement
- Consistently less than 2-mm (0.08 in) error were observed in the field

C.2.2. Comparing Thicknesses

MIT-SCAN T2 vs. APE

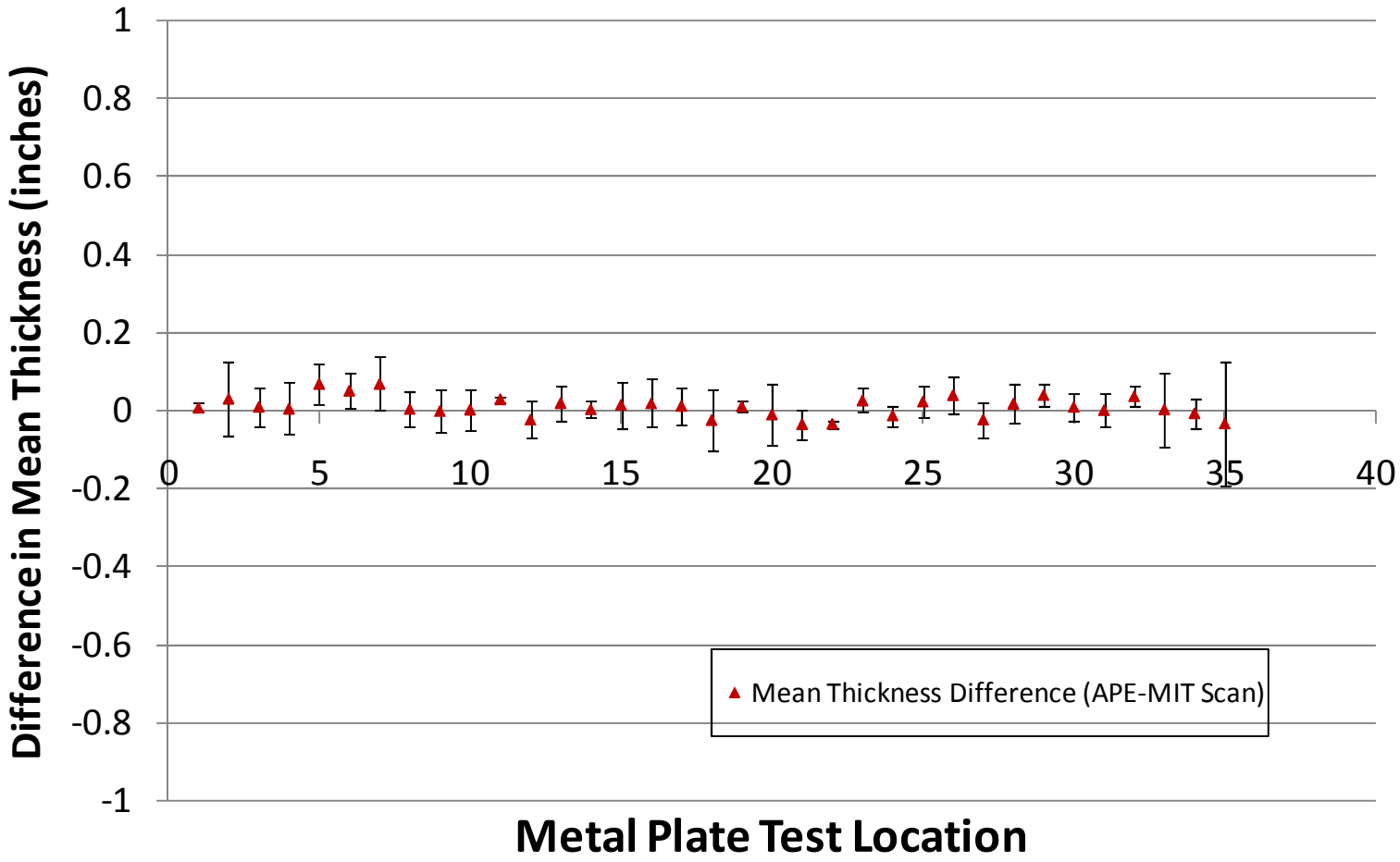
Mean Pavement Thickness Based on Large Plate Measurements (First and Second Lift)

±3σ Intervals (99.74% Certainty) Shown for APE Thickness (Red Bars)



APE Mean Thickness – MIT Scan Mean Thickness (for Large Plate Measurements, 1st Lift)

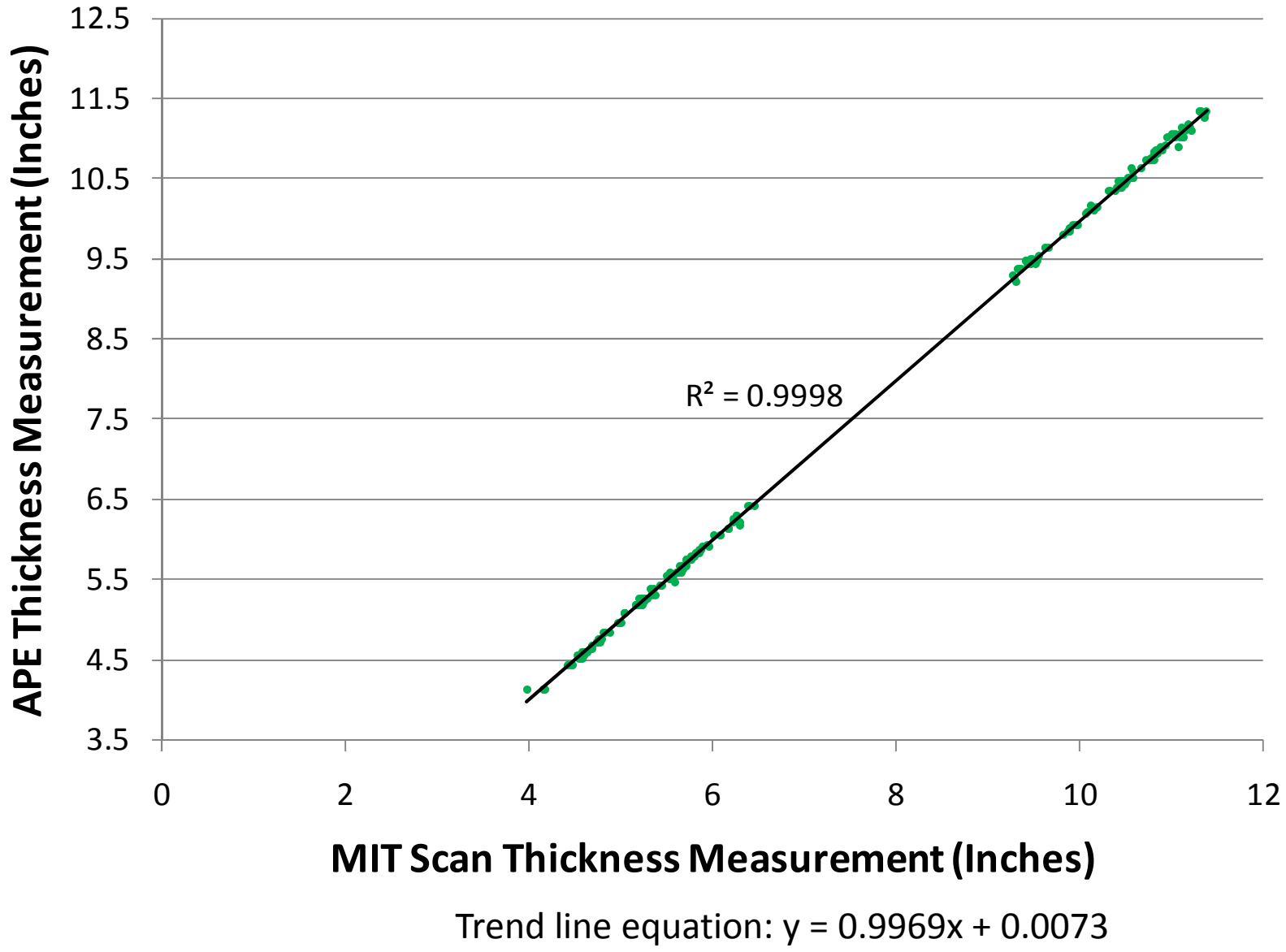
(Including 99% Confidence Interval Estimate of the Difference Between Two Independent Means)



*Analysis based on Kachigan, pp. 151-153, 1986

Plot of MIT Scan Thickness Measurement vs. APE Thickness Measurement (Large Plates)

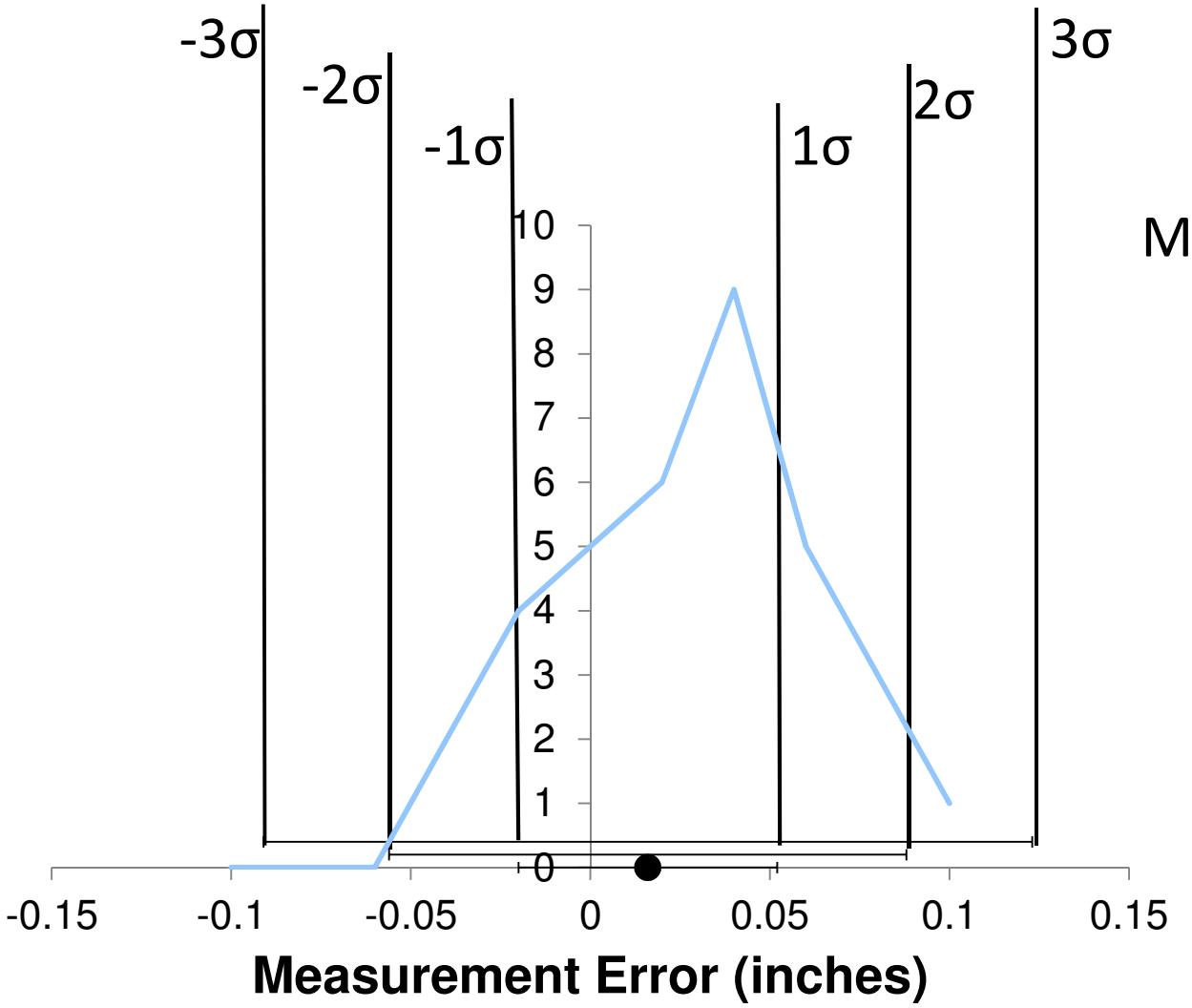
(Including Regression Line and Corresponding Correlation Coefficient)



C.2.3. Estimating Accuracy and Precision

MIT-SCAN vs. APE

Error Histogram (APE Measurement – MIT Mean)
Day 1, First Lift, APE Test Run 1



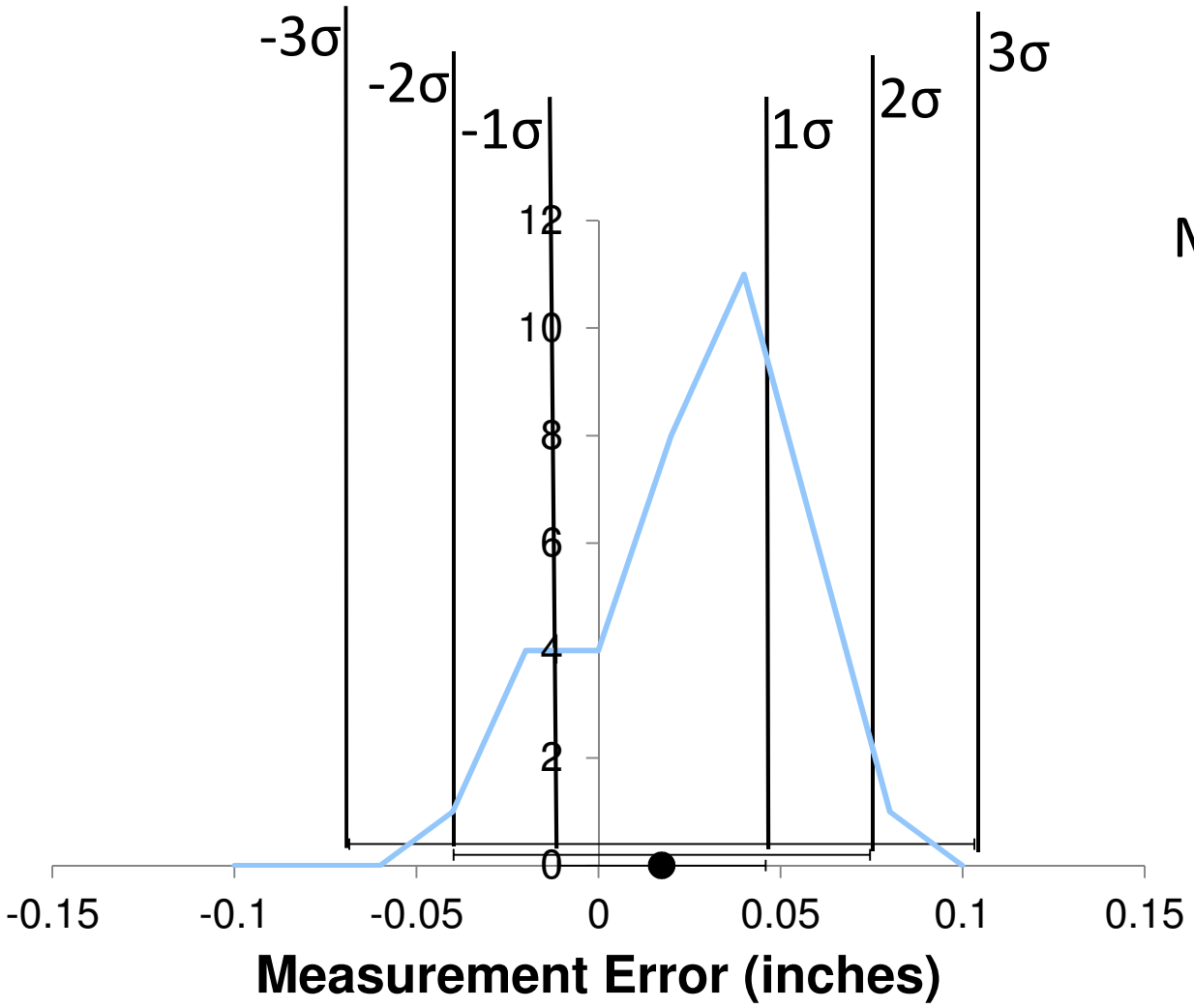
$Mean_{error}$ = 0.02 inch

σ = 0.04 inch

2σ = 0.07 inch

3σ = 0.11 inch

Error Histogram (APE Measurement – MIT Mean)
Day 1, First Lift, APE Test Run 2



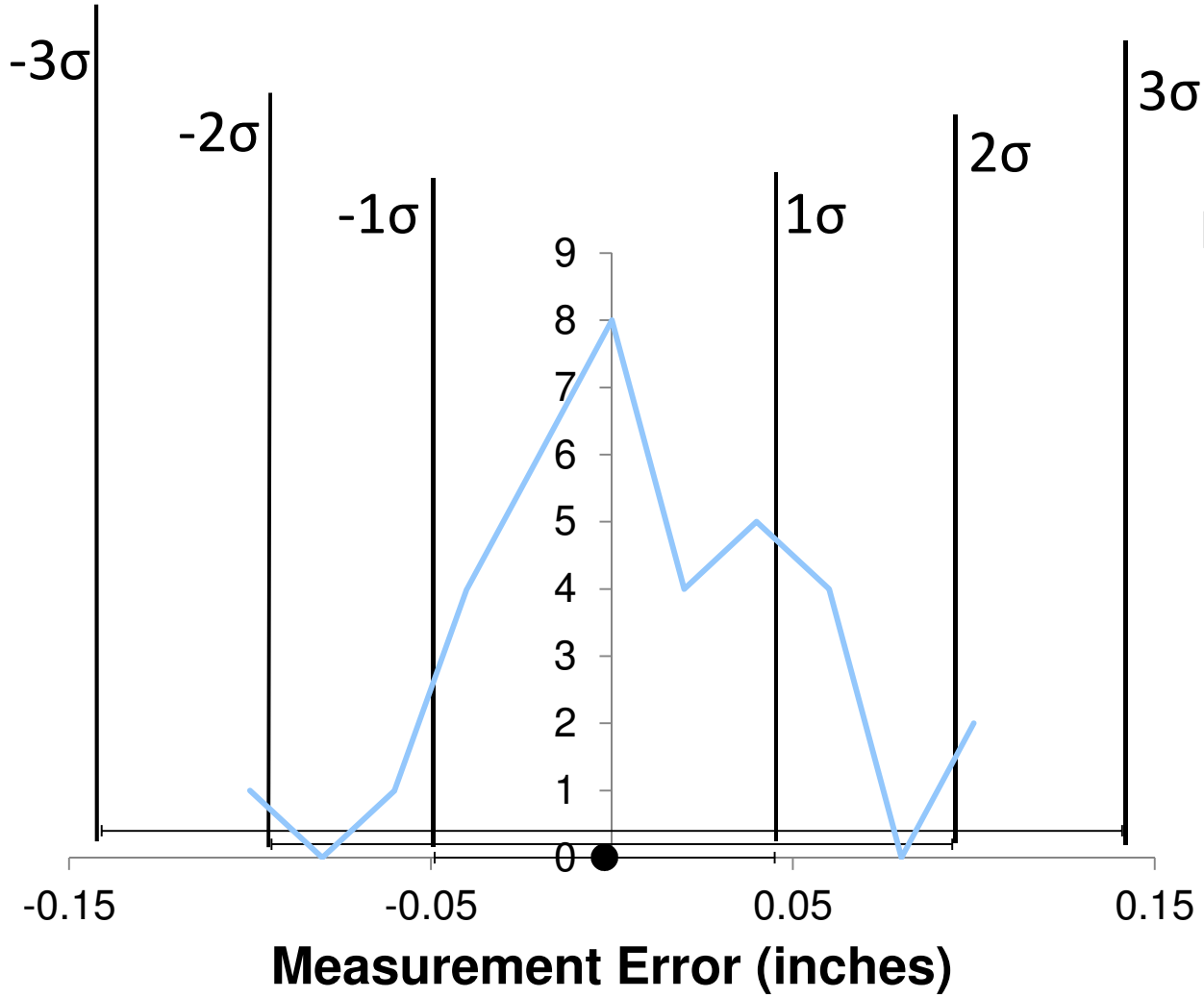
$Mean_{error}$ = 0.02 inch

σ = 0.03 inch

2σ = 0.06 inch

3σ = 0.09 inch

Error Histogram (APE Measurement – MIT Mean)
Day 1, First Lift, APE Test Run 3



$Mean_{error}$ = 0.00 inch

σ = 0.05 inch

2σ = 0.09 inch

3σ = 0.14 inch

C.2.5. Summary of Results

Ground truth and APE measurement are virtually equivalent.

Metal plate experiment establishes value of continuous calibration using Common Mid-Point implementation in APE

Repeated Accuracy of 0.11 to 0.14 inches (Mean+3 sigma)

Repeated Precision of 0.09 to 0.14 inches (3 sigma)

D. Measurement of Material Density Using APE System

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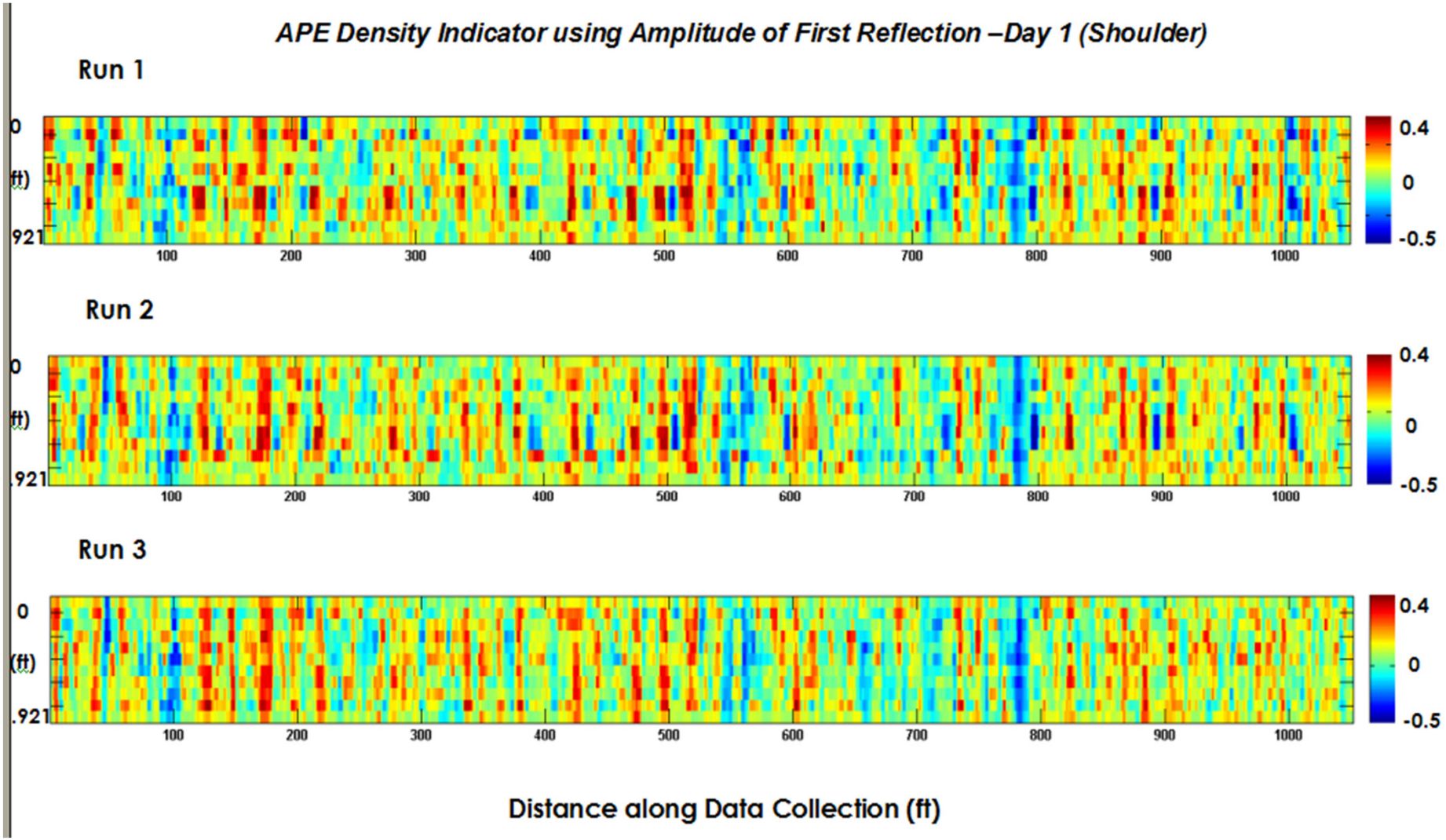
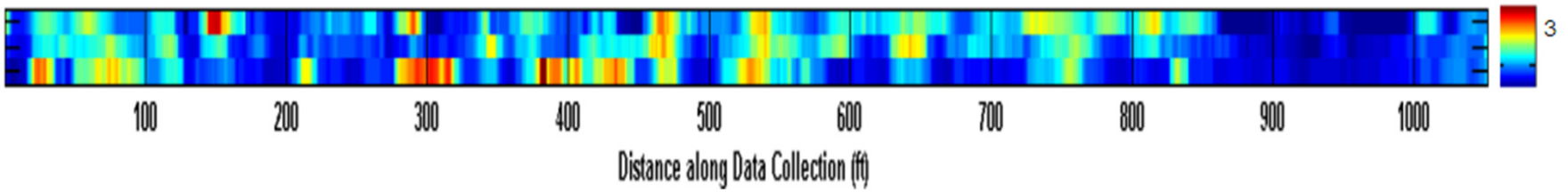
D.2. Density Indicators



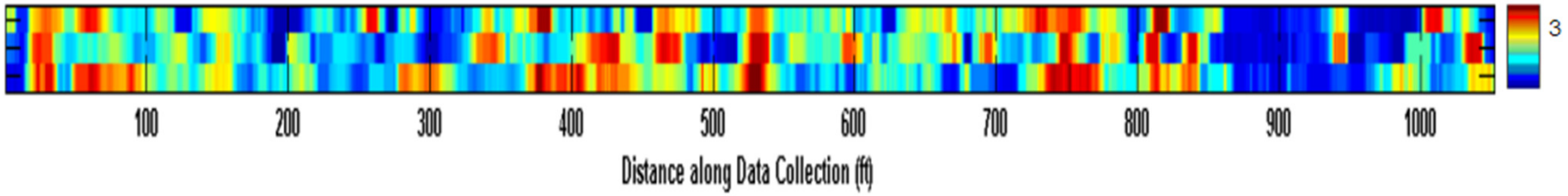
D.3. Density Indicators

APE Density Indicator using Relative Permittivity of surface layer (After filter) –Day 1 (Shoulder)

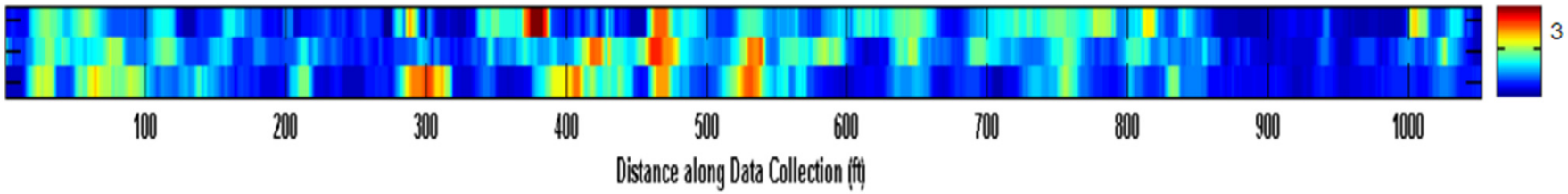
Run 1



Run 2



Run 3



E. Current status of APE

- Current applications – pilot implementation in FY10/11
  - Pavement layer thickness
  - Moisture detection
  - Void detection
  - Rutting evaluation (2-D & 3-D imaging)
- Future applications
  - Variations in material properties (AC density) **[4]**
  - AC stripping **[3]**
  - Layer debonding **[5]**
  - Detection and quantification of cracking **[4]**
  - Depth of dowel bars, tie bars, and reinforcing steel **[2-3]**