Pavement Density Profiler

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Outline

- Who is Sensors & Software
- Some history
- Key aspects of GPR measurement
- Illustration of device
- Example Results
- Summary

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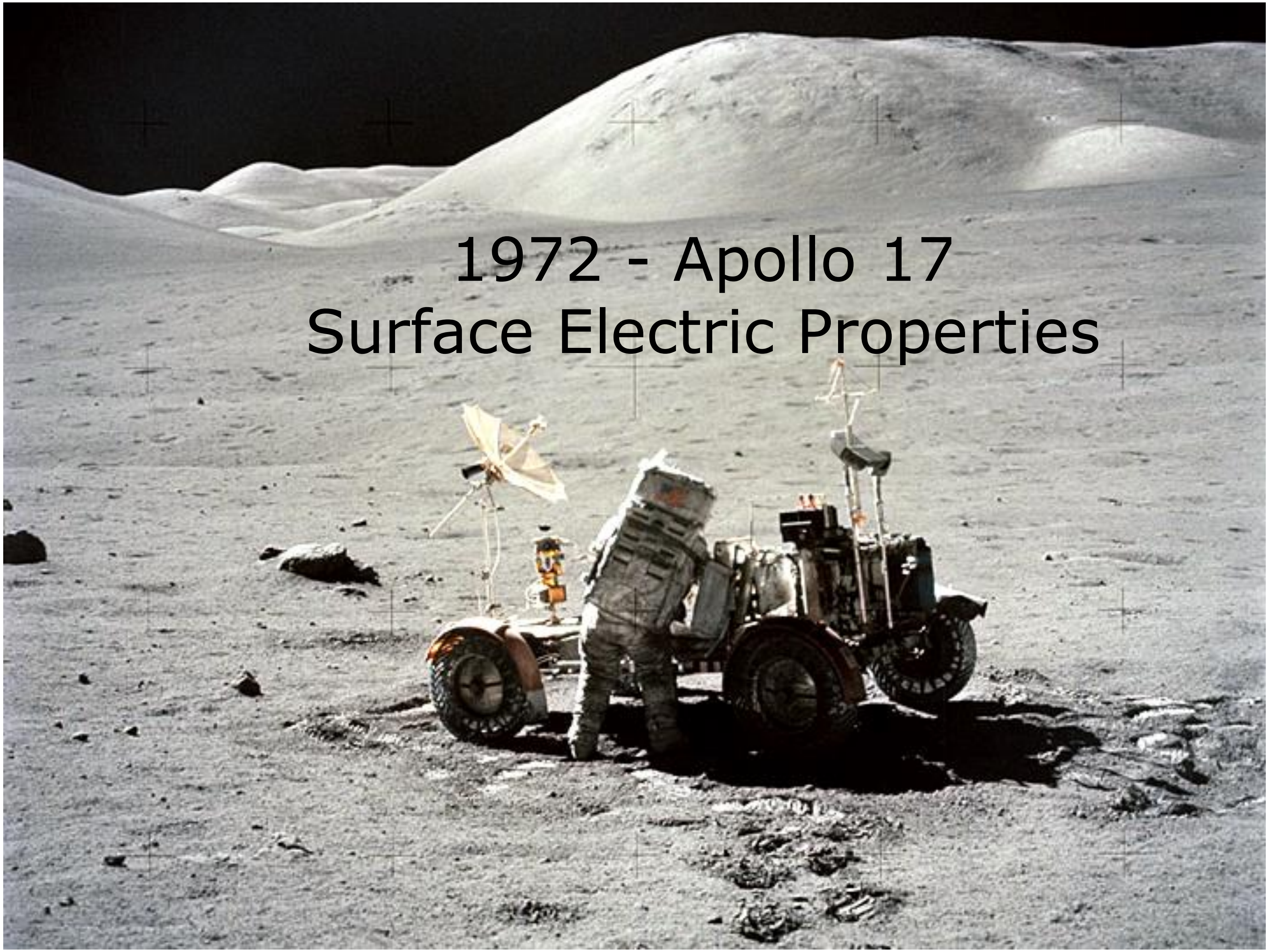
- Principals pioneered GPR in 1970's
- Sensors & Software formed 30 years ago
- Focus on high performance instruments
- Combine hardware and software to deliver practical solutions

1972 - Apollo 17
Surface Electric Properties



1975 - Arctic Pipeline GPR


1988
1992
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2018
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Pavement Assessment History

- Started development in about 2000
- Developed high speed ground coupled GPR – RoadMap
- Have looked at surface reflection for several applications

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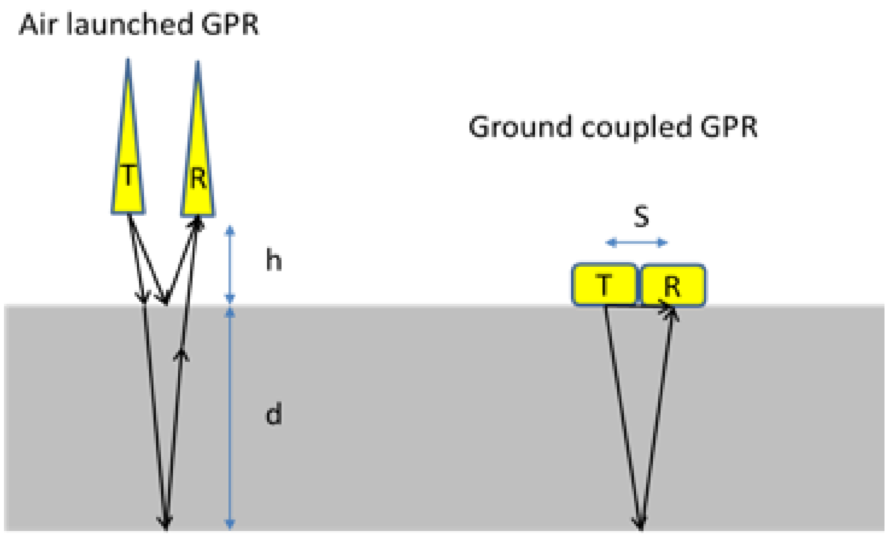
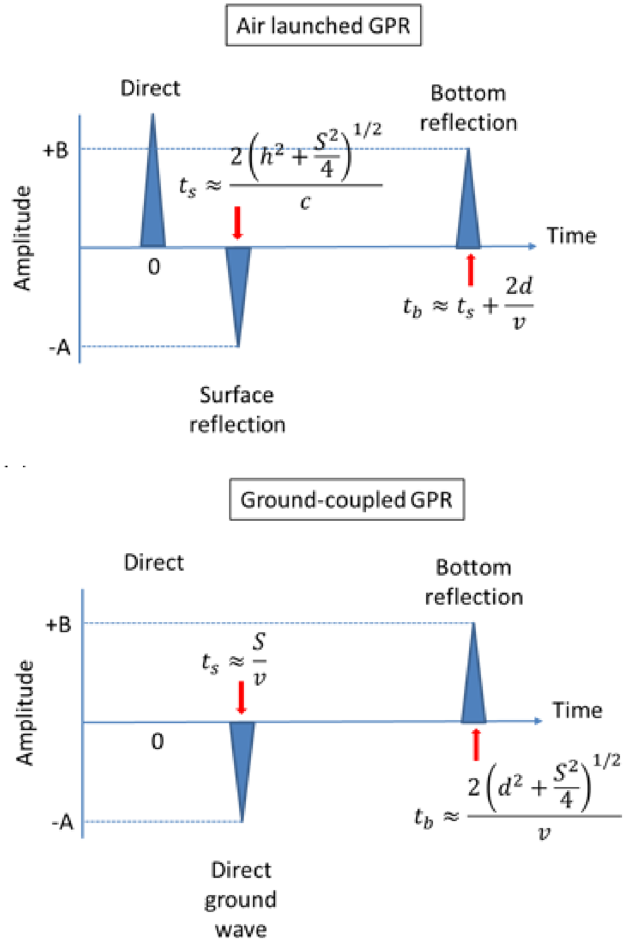
GPR Concepts





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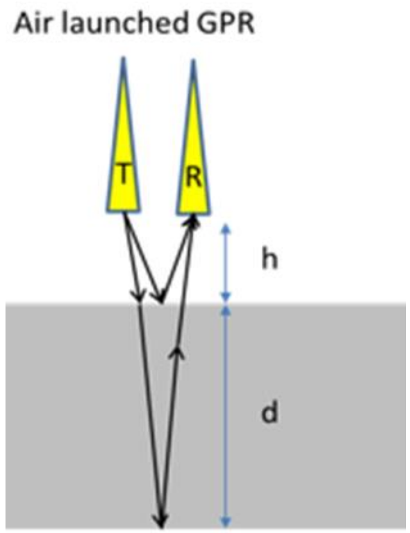
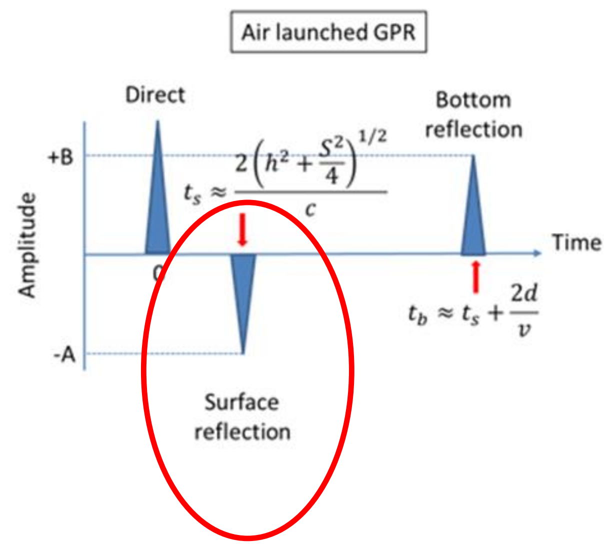
Air Launch based on Surface Reflection





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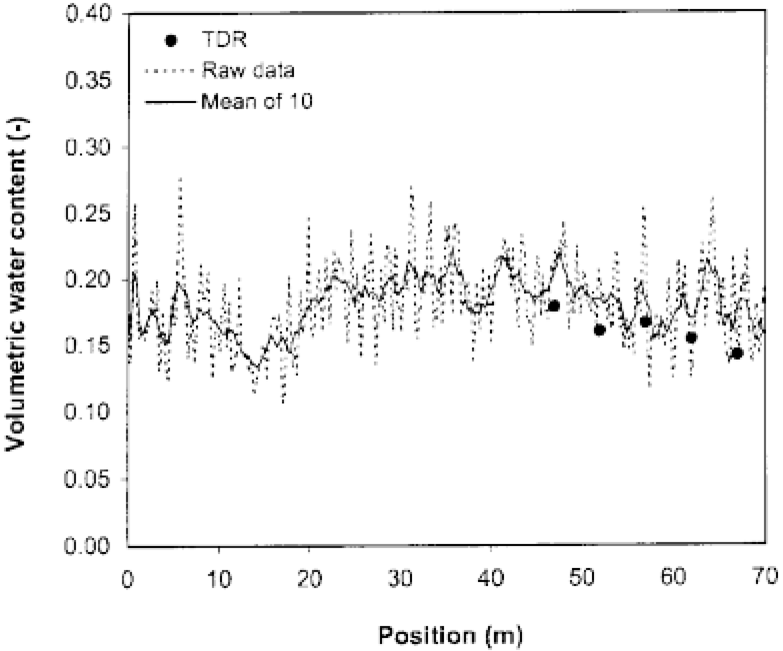
Surface Reflection for Soil Moisture ~ 2002



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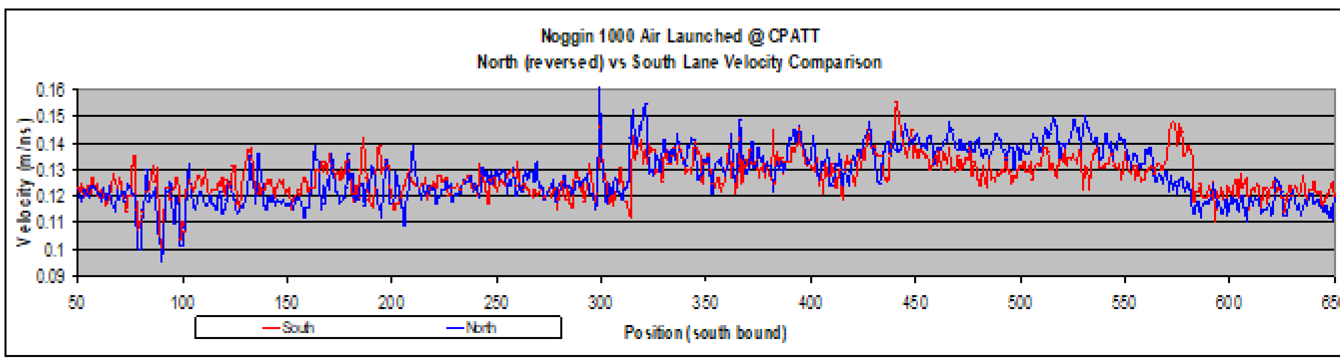
Pavement Permittivity Estimate (RoadMap ~2008)



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Pave Density Profiler - PDP

- Recent interest in pavement density measurement
- Based on our prior work, decided to make a practical tool
- Started about 1 year ago
- Goal today is to demonstrate the

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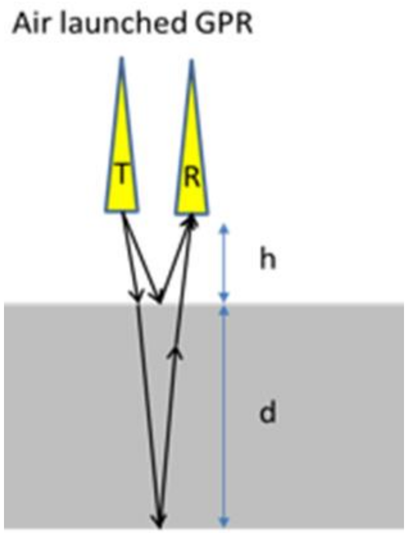
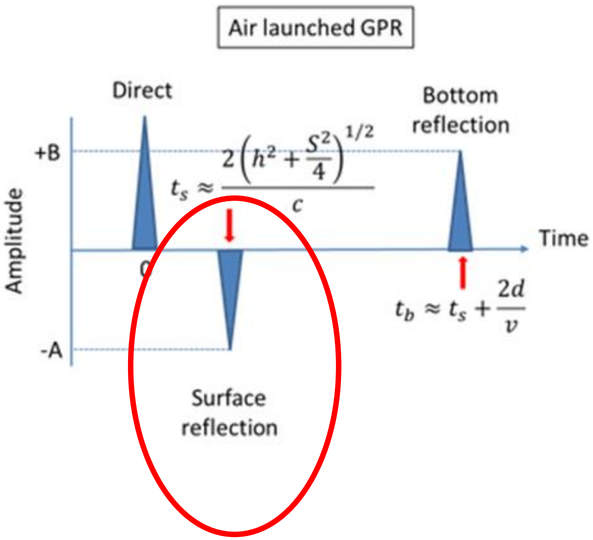
GPR Solutions – 3 elements

- Instrumentation
- Electrical structure model
- Translation to application need

PDP based on Surface Reflection





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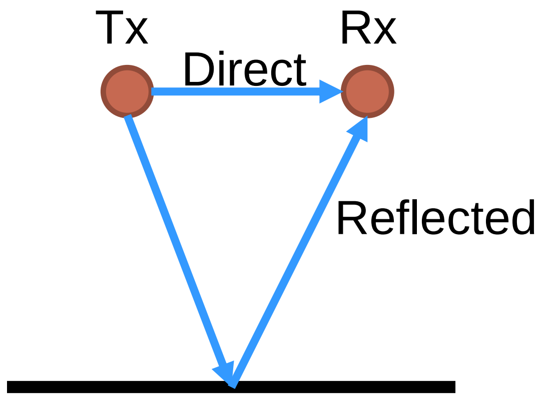
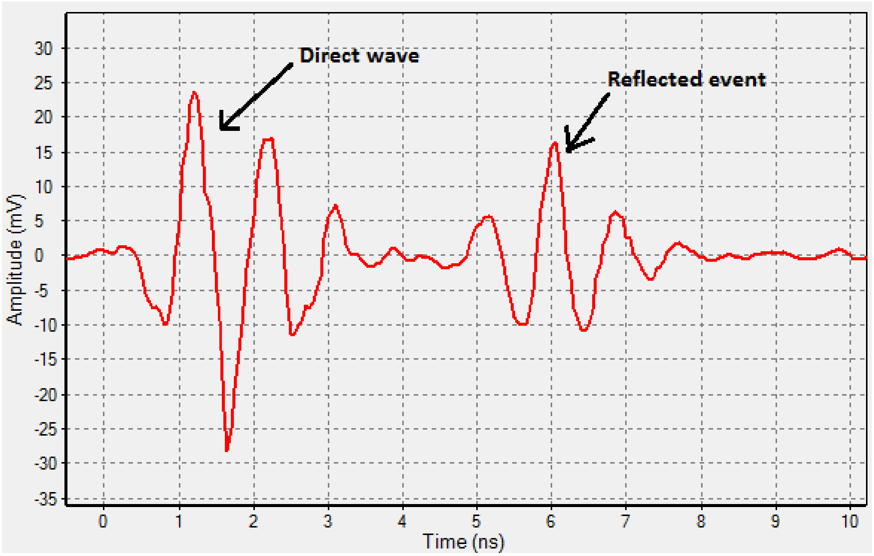
Role of Instrumentation

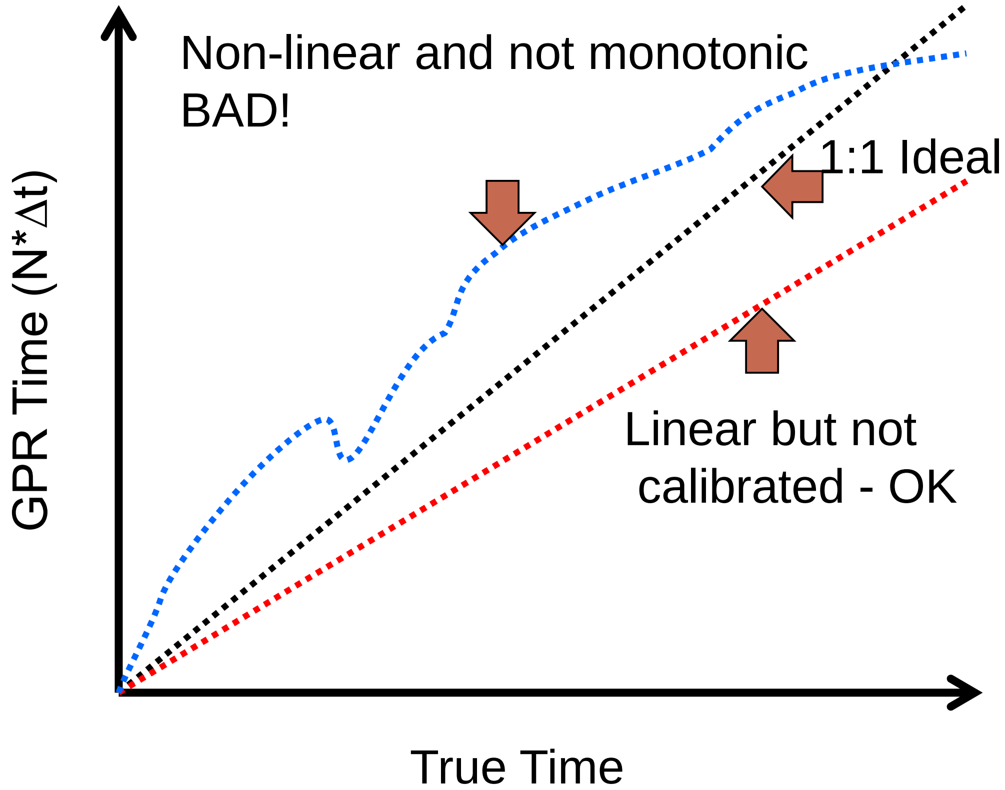
- The instrumentation is focused on data acquisition
- Must acquire calibrated signal.
- Must acquire data with time and amplitude fidelity

Raw data example





Time-base



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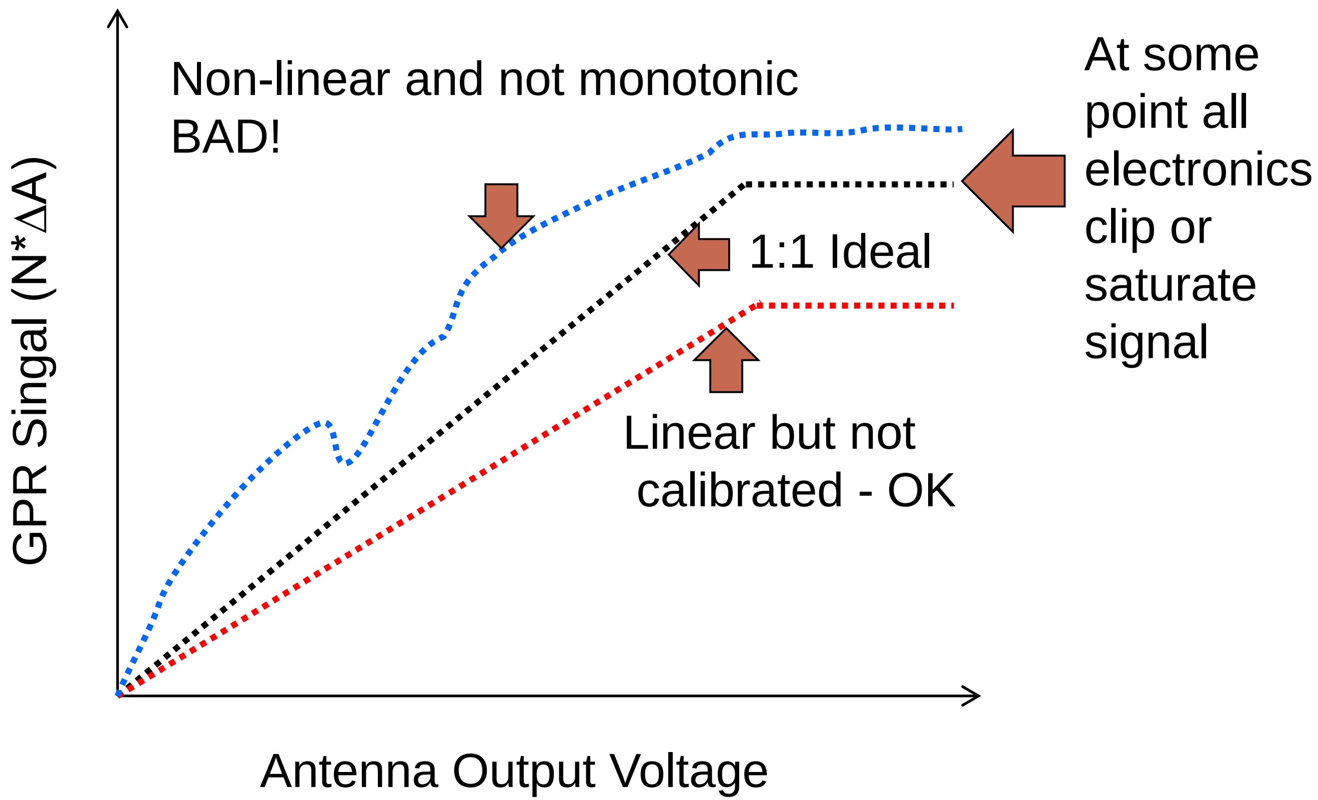
Amplitude Fidelity



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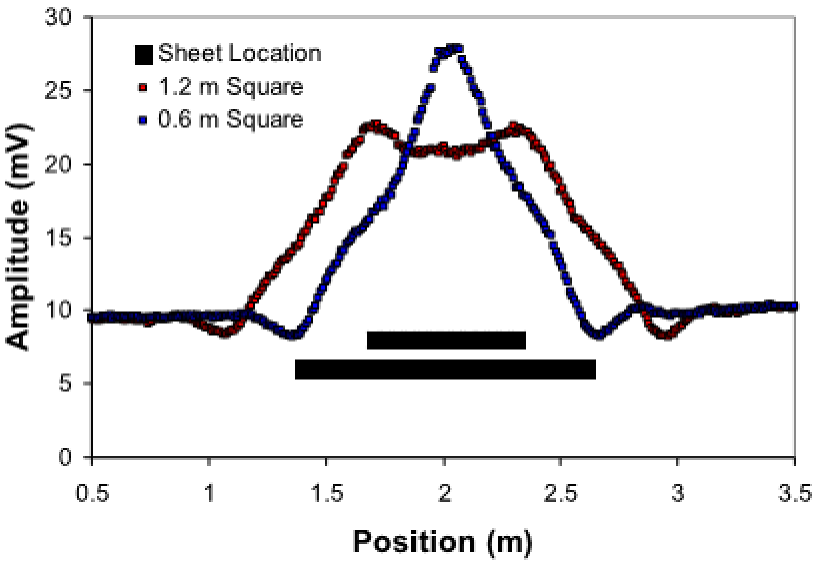
Calibration & Validation



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Instrument summary

- Should produce calibrated data
- Should not need in-field calibration
- Should have in-field performance assessment protocol
- Should be simple to use
- Must enable user to focus on the problem to be solved

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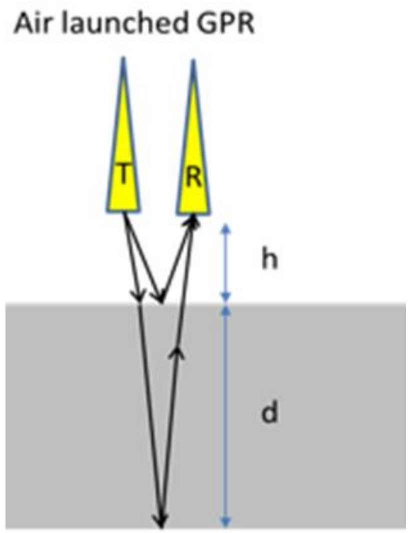
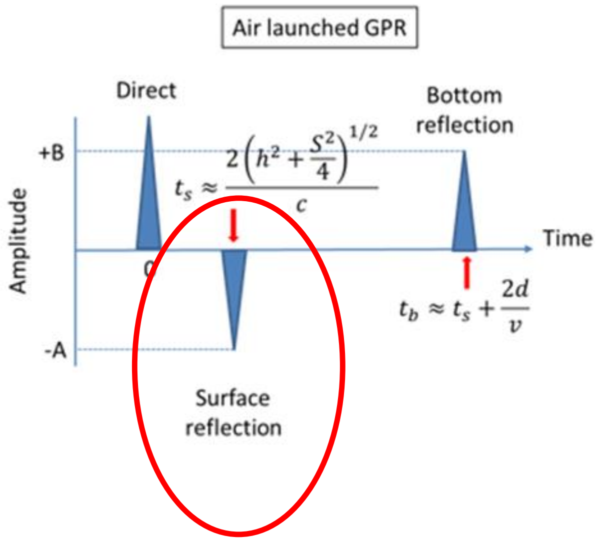
Role of "Model"

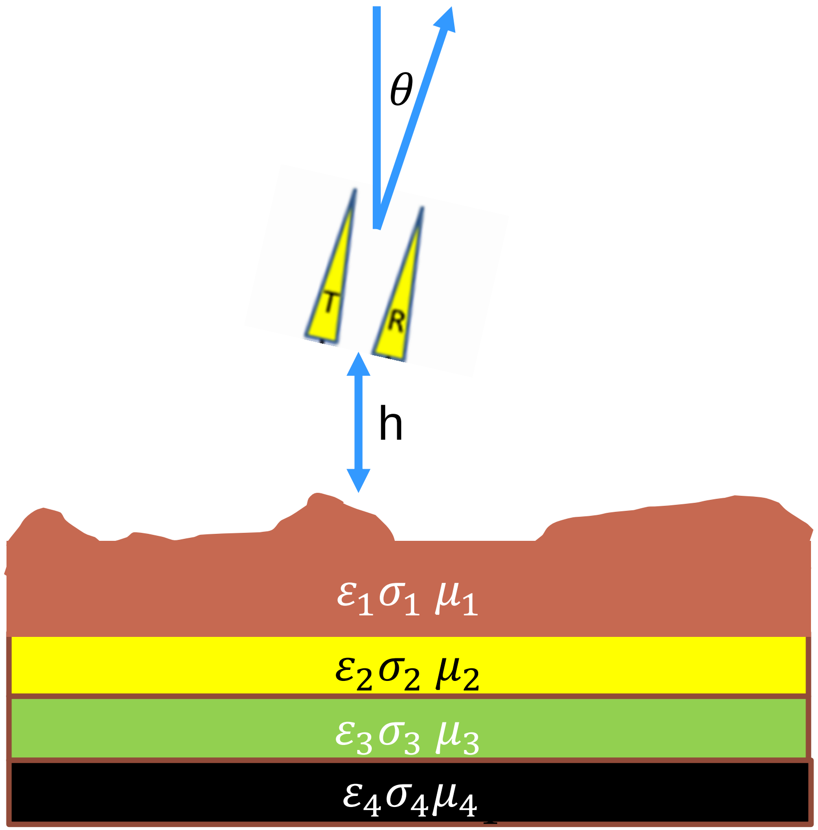
- GPR signals must be transformed to model
- Model best representation of the structure that explains the GPR data
- Contains geometrical and physical property parameters

PDP based on Surface Reflection





Surface reflection model



Parameters:

- Surface roughness
- Vertical layering
- Horizontal changes
- Electrical properties
  - Permittivity
  - Conductivity
  - Permeability
- System
  - Height
  - T-R separation
  - Orientation

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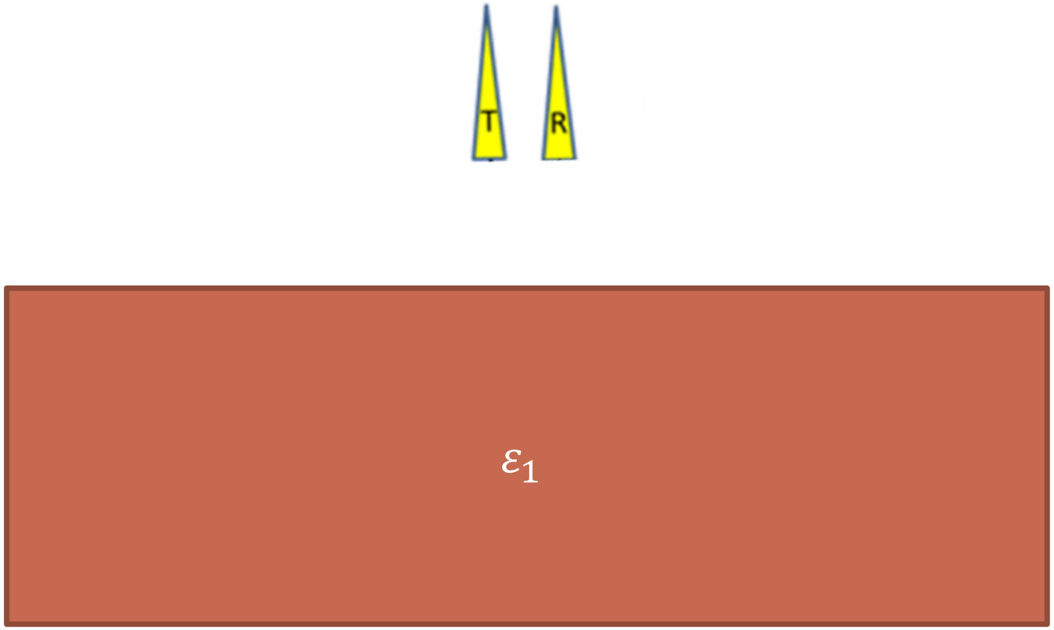
Most simple model



Parameters:

- ~~Surface roughness~~
- ~~Vertical layering~~
- ~~Horizontal changes~~
- Electrical properties
    - Only Permittivity
    - ~~Conductivity~~
    - ~~Permeability~~
- ~~System~~
    - ~~Height~~
    - ~~T-R separation~~
    - ~~Orientation~~

Permittivity Estimation

GPR Reflection Coefficient

$$R = -\frac{A_r}{A_m}$$

A_r - instantaneous signal

A_m - reference signal

Fresnel Reflection Coefficient

$$R = \frac{1 - \sqrt{\varepsilon_1}}{1 + \sqrt{\varepsilon_1}}$$

Permittivity

$$\varepsilon_1 = \left(\frac{1 - R}{1 + R}\right)^2$$

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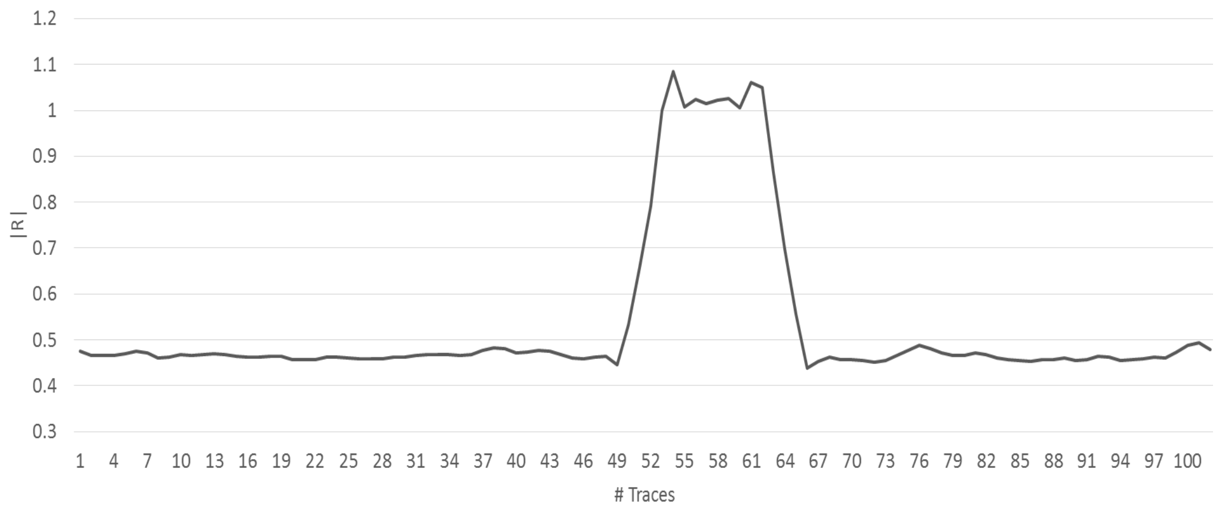
PDP Raw Reflection Coefficient Data



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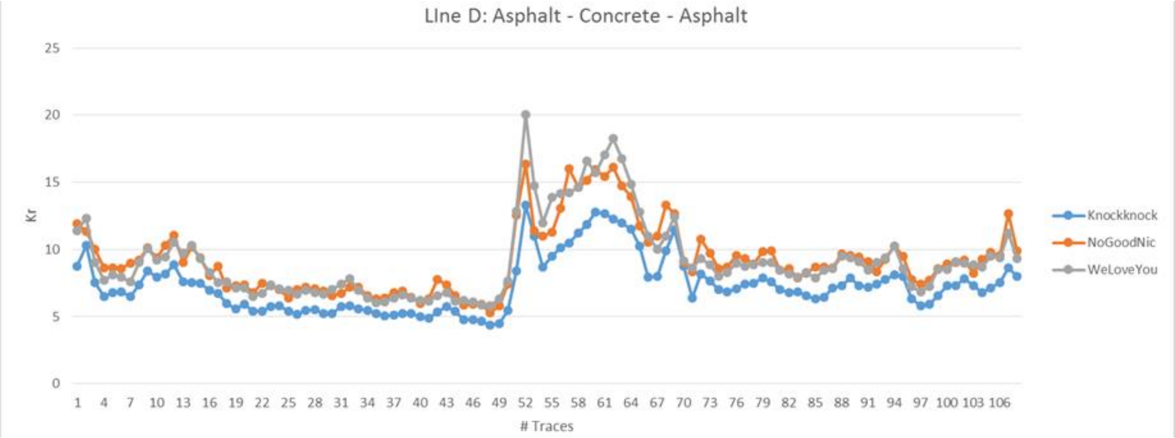
Effective Permittivity



Model Summary

- Model can be very complex or simple
- Need for complexity?
- Must understand when is the model practical
- What level of complexity is really present?
- Can we handle the complexity?

Translation to application

- Goal is to estimate pavement density or void content
- Research has demonstrated that permittivity and density correlated
- Must not confuse instrument problems with model in this discussion

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Definitions Density or Void

- Density –%MRD = G_{mb} x100/ G_{mm}
- $V_a(\%) = \left(1 - \frac{G_{mb}}{G_{mm}}\right) * 100$
- Void – void % =

- Note to add clarification of terms

- Translate permittivity to density

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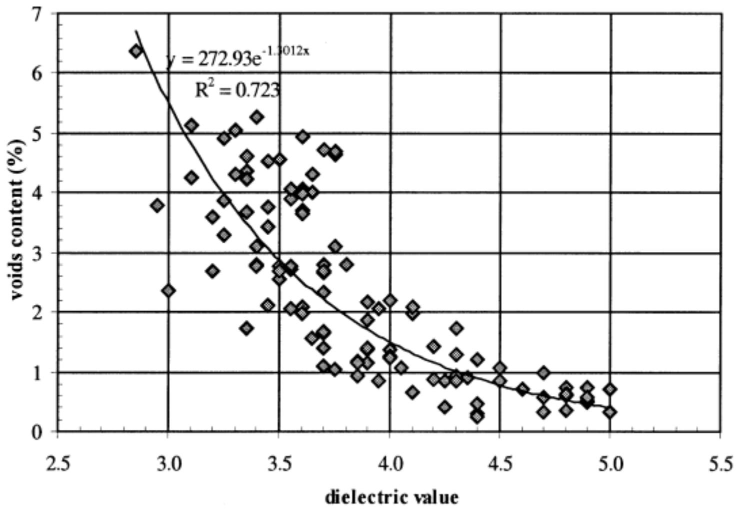
Empirical

Measure core sample and permittivity and develop relationship



$$V_a(\%) = a * e^{-b * k_r}$$

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Mixing Relationship

$$G_{mb} = \frac{\frac{\varepsilon_{AC}-\varepsilon_b}{3\varepsilon_{AC}-2.3\varepsilon_b} - \frac{1-\varepsilon_b}{1-2.3\varepsilon_b+2\varepsilon_{AC}}}{\left(\frac{\varepsilon_s-\varepsilon_b}{\varepsilon_s-2.3\varepsilon_b+2\varepsilon_{AC}}\right)\left(\frac{1-P_b}{G_{se}}\right)-\left(\frac{1-\varepsilon_b}{1-2.3\varepsilon_b+2\varepsilon_{AC}}\right)\left(\frac{1}{G_{mm}}\right)} \quad (10)$$

where,

ε_{AC}: pavement dielectric permittivity (k) – input from GPR measurements

G_{mb}: bulk specific gravity of asphalt mixture which is equal to density (ρ) of the material in g/cm^3

ε_s: dielectric constant of the aggregate (~6-8 for limestone, ~4-7 for granite)

ε_b: dielectric permittivity of the binder

P_b: asphalt binder weight content

G_{mm}: maximum specific gravity of the asphalt mixture (no air)

G_{se}: effective specific gravity of aggregate

Qadi-Lahouar-Leng (ALL) model tuned Bottcher model - Leng et al 2011

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Permittivity to Density

- Concept well understood
- Research confirms efficacy
- K to ρ is a distinct step
- Do not mix system calibration and model simplifications with K to ρ relationship
- Must keep the aspects separate.

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The PDP Solution

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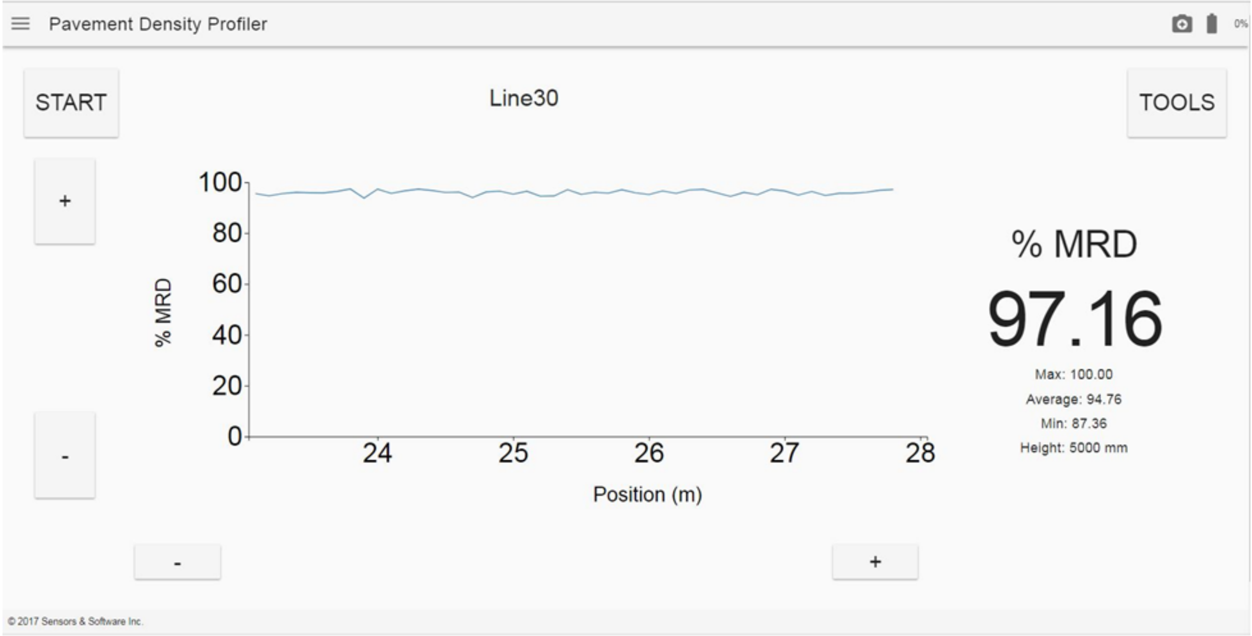
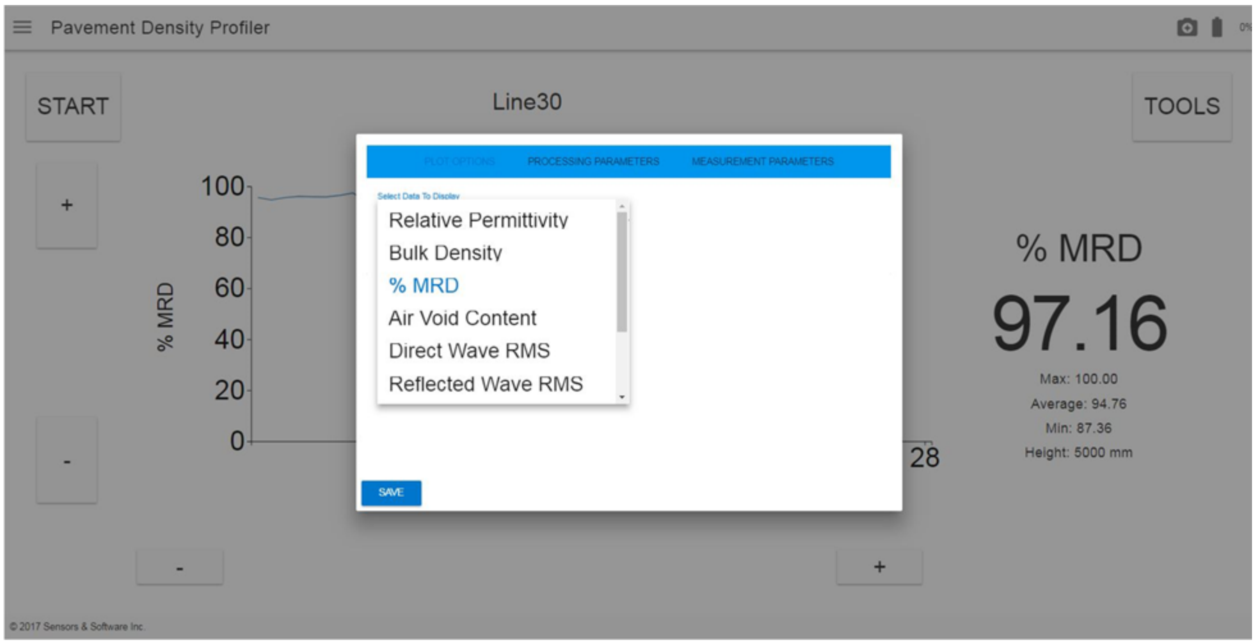
Instrument Design

- Instrument calibrated at factory
- No need for user to adjust GPR
- Model of various complexity embedded
- Empirical or mixing model embedded
- Integrated positioning
- Total wifi control
- Simple to use

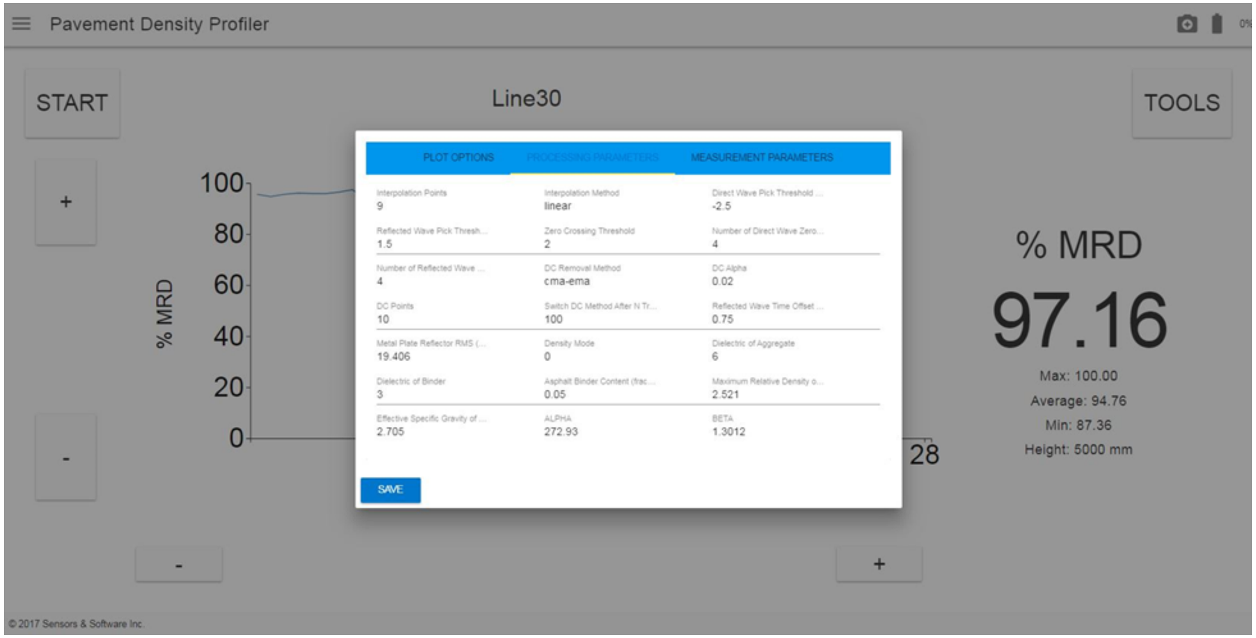
Normal user interface



Select parameter to display



Set permittivy-density parameters



Summary

- Have outlined the core principles
- Current state and needs still poorly defined
- Pre-production instrument works
- Optimization needs more understanding of workflow and use cases

See instrument demo

- Get a hands on look
- See how unit functions
- Give feedback on users needs
- Kick the tires
- Its really easy to use

Thank you for attending!

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