
Standard Practice for

**Asphalt Surface Dielectric
Profiling System using Ground
Penetrating Radar**

AASHTO Designation: PP 98-19¹

**Technical Subcommittee: 5c, Quality Assurance
and Environmental**

Release: Group 1 (April)



**American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001**

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1. SCOPE

- 1.1. This standard specifies the equipment and software requirements for a dielectric profiling system (DPS). Calibration and verification procedures are also detailed.
 - 1.2. A DPS uses ground penetrating radar (GPR) technology to continuously measure asphalt compaction quality up to highway speeds. The DPS system reports the asphalt surface dielectric constant which is strongly correlated to asphalt air void content (FHWA/TX-92/1233-1). As the dielectric constant increases, air void content decreases.
 - 1.3. A DPS may be a single- or multi-channel system and may be cart or vehicle-mounted.
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2. REFERENCED STANDARDS

- 2.1. *AASHTO Standards:*
 - [M 146](#), Terms Relating to Subgrade, Soil–Aggregate, and Fill Materials
 - [R 37](#), Application of Ground Penetrating Radar (GPR) to Highways
 - [PP 80](#), Continuous Thermal Profile of Asphalt Mixture Construction
 - [PP 81](#), Intelligent Compaction Technology for Embankment and Asphalt Pavement Applications
- 2.2. *ASTM Standards:*
 - [D150](#), Standard Test Methods for AC Loss Characteristics and Permittivity (Dielectric Constant) of Solid Electrical Insulation
 - [D2520](#), Standard Test Methods for Complex Permittivity (Dielectric Constant) of Solid Electrical Insulating Materials at Microwave Frequencies and Temperatures to 1650°C
 - [D4748](#), Standard Test Method for Determining the Thickness of Bound Pavement Layers Using Short-Pulse Radar
 - [D6087](#), Standard Test Method for Evaluating Asphalt-Covered Concrete Bridge Decks Using Ground Penetrating Radar
 - [D6429](#), Standard Guide for Selecting Surface Geophysical Methods
 - [D6432](#), Standard Guide for Using the Surface Ground Penetrating Radar Method for Subsurface Investigation

- 2.3. *Federal Highway Administration:*
- FHWA/TX-92/1233-1, Implementation of the Texas Ground Penetrating Radar System, Texas Transportation Institute with the Federal Highway Administration, 1992
 - S2-R06C-RR-1, Sebesta, S., T. Saarenketo, and T. Scullion. Using Infrared and High-Speed Ground Penetrating Radar for Uniformity Measurements on New HMA Layers. SHRP 2 Project R06(C) Final Report, SHRP 2, Washington, DC

3. SUMMARY OF METHOD

- 3.1. This specification describes the hardware and software requirements and calibration procedures for a DPS.

4. TERMINOLOGY

- 4.1. Definitions shall be in accordance with the terms and symbols given in terminologies and definitions from [R 37](#), [PP 80](#), [PP 81](#), and [ASTM D6432](#).

- 4.2. *Definitions Specific to This Standard:*

- 4.2.1. *dielectric constant*—The measured dielectric property of the finished asphalt pavement surface. The surface dielectric constant is calculated using Equation 1 (S2-R06C-RR-1):

$$e_r = \frac{\left[1 + \left(\frac{A_0}{A_i} \right) \right]^2}{\left[1 - \left(\frac{A_0}{A_i} \right) \right]} \quad (1)$$

where:

e_r = dielectric constant,

A_0 = amplitude of the reflection at the air/asphalt interface

A_i = initial antenna amplitude. (May be measured with a metal plate calibration.)

- 4.2.2. *dielectric profile*—The surface dielectric readings and associated stationing, offset, GNSS coordinates, and time stamps.

- 4.2.3. *dielectric profiling system (DPS)*—The specific arrangement of the GPR equipment used to measure the dielectric constant including the GPR antennas, radar control unit, and suitable data storage, calculation, and display devices.

- 4.2.4. *heat map plot*—A graphic display of data using color scales. These plots may display raw values or employ varying degrees of smoothing (adapted from [PP 81](#)).

5. HARDWARE REQUIREMENTS

- 5.1. *Dielectric Profiler System Overview:*

- 5.1.1. *The DPS consists of the following components (Figure 1):*

- 5.1.1.1. *Vehicle or Cart:*

- 5.1.1.1.1. Antenna boom,

- 5.1.1.1.2. Distance measuring instrument (DMI), and
- 5.1.1.1.3. Global positioning system (GPS) (strongly recommended);
- 5.1.1.2. *Single or multi-channel air coupled GPR system (see ASTM D4748):*
 - 5.1.1.2.1. Radar antenna/s, and
 - 5.1.1.2.2. Control unit;
- 5.1.1.3. Computer or tablet with software; and
- 5.1.1.4. Metal plate and validation block.

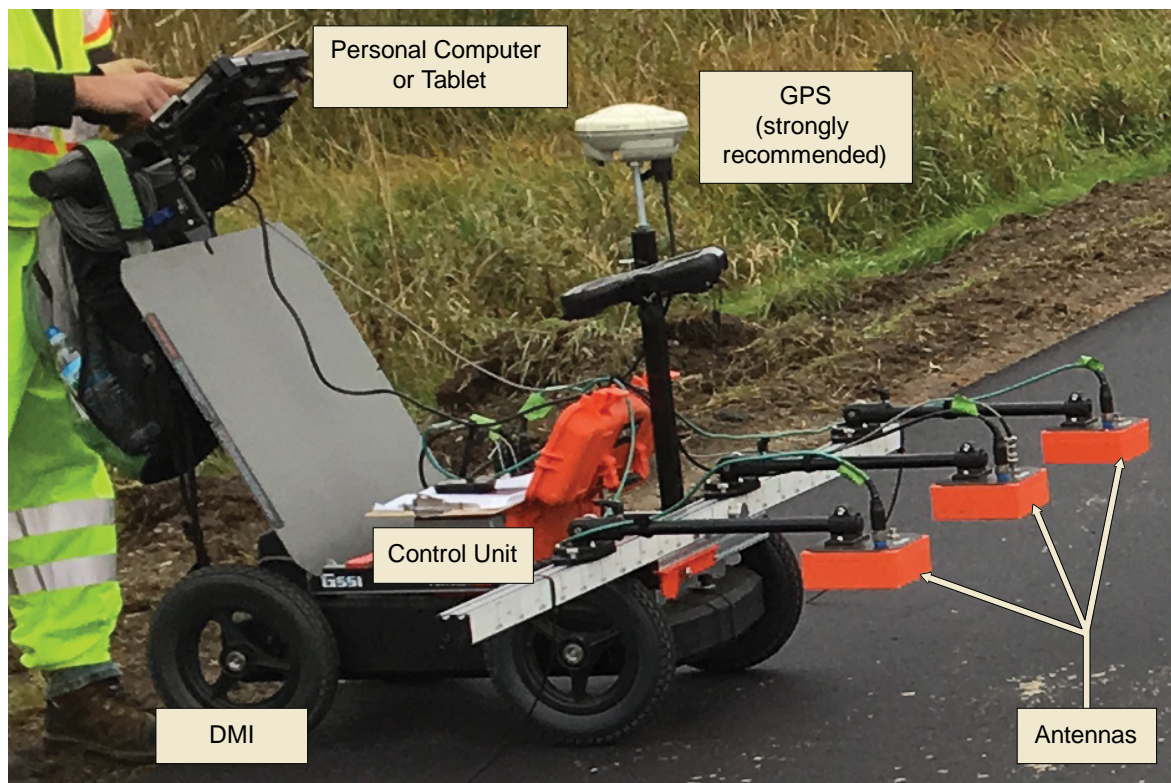


Figure 1—Basic Equipment for DPS

- 5.1.2. The DPS shall measure the dielectric constant of the asphalt surface based on the GPR surface reflection. The system shall be capable of recording this data at both fixed distance intervals (distance mode) and at fixed time intervals (time mode).
- 5.2. *Vehicle or Cart:*
 - 5.2.1. A vehicle or cart shall be provided to carry the GPR system, computer, metal plate, antenna boom, and be equipped with a DMI and GPS receiver.
 - 5.2.2. *Antenna Boom*—Non-metallic boom to maintain the antenna/s at a fixed vertical height and at least 18 in. away from any large metal body such as the vehicle frame. Processing algorithms should account for vertical movement from the vehicle suspension. When vehicle mounted, the system shall be structurally capable of traveling up to 50 mph with tolerable antenna movement.

The position of the antenna(s) should be adjustable to allow for collection at agency specific lateral positions within the pavement lane.

- 5.2.3. *Distance Measuring Instrument (DMI)*—The vehicle or cart should be instrumented with a DMI with a minimum operational tolerance of 1 ft/mi.
- 5.2.4. *Global Positioning System (GPS)*—The vehicle or cart should be instrumented with a GPS with a minimum operational tolerance of ±15 ft and allow for input of an external GPS string.
- 5.3. *Air-Coupled GPR:*
 - 5.3.1. Single or multi-channel air-coupled GPR system with an operational frequency of between 1 and 3 GHz shall be used. All antennas shall have the same frequency.
 - 5.3.2. *Operating Requirements*—The GPR system shall pass the operating requirements in Table 1. These are based on the metal plate reflection tests recommended by the Texas A&M Transportation Institute with the Federal Highway Administration, FHWA/TX-92/1233-1 for general purpose GPR. Each of these measurements shall be determined prior to the first use of the equipment.

Table 1—Operating Requirements Summary Table with Required Limits

Measure Description	Required Limit
Short Term Dielectric Stability (STDS)	Max: 0.06
Drift Dielectric Stability (DDS)	Max: 0.08
Long Term Dielectric Stability (LTDS)	Max: 0.08
Inter-Antenna Dielectric Variation ^a (IADV)	Max: 0.08
Inter-Antenna Amplitude Variation ^a (IAAV)	Max: 5%

^a Multichannel systems only.

- 5.3.3. *Short Term Dielectric Stability (STDS)*—Stability of the measured dielectric constant over a short time period. In time-mode, collect 50 surface dielectric measurements over a validation block at a minimum rate of 15 scans per second. Stacking or moving average techniques may be used if the DPS has the capability of collecting data at a faster rate. Calculate the STDS using Equation 2.

$$STDS = eST_{\max} - eST_{\min} \quad (2)$$

where:

eST_{\max} = maximum recorded dielectric over 50 scans.

eST_{\min} = minimum recorded dielectric over 50 scans.

- 5.3.4. *Drift Dielectric Stability (DDS)*—Stability of the measured dielectric constant over a typical data collection period. In time-mode, collect dielectric measurements over a validation block for 20 min continuously at a minimum rate of 15 scans per second. Stacking or moving average techniques may be used if the DPS has the capability of collecting data at a faster rate. Calculate the LDS using Equation 3.

$$LDS = eL_{\max} - eL_{\min} \quad (3)$$

where:

eL_{\max} = maximum recorded dielectric over 20-min time period.

eL_{\min} = minimum recorded dielectric over 20-min time period.

- 5.3.5. *Long Term Dielectric Stability (LTDS)*—Stability of the DPS between calibrations and over an extended period of time, exceeding the duration of a large paving project. On five separate days spanning 21 days between the first and last measurement, collect 10 data sets spanning at least five

unique days included at least one day with multiple data sets. For each data set, collect 5,000 scans in time-mode over a validation block. Calculate the LTDS using Equation 4.

$$LTDS = eLT_{\max} - eLT_{\min} \quad (4)$$

where:

eLT_{\max} = maximum recorded dielectric over the 10 evaluated data sets.

eLT_{\min} = minimum recorded dielectric over the 10 evaluated data sets.

Note 1—Current testing suggests no impact of testing over a period of time. If this trend continues this performance metric may allow for all 10 data sets to be collected over any duration of time as long as the system is completely turned off between data collection sets.

- 5.3.6. *Inter-Antenna Dielectric Variation (IADV)*—Variation among the dielectric measurements from the different DPS antennas. Applicable to multi-channel DPS systems only. In time-mode, collect 1,000 dielectric measurements with each antenna over a validation block. Calculate the mean dielectric constant of the block for each antenna. Calculate the IADV using Equation 5.

$$IADV = eA_{\max} - eA_{\min} \quad (5)$$

where:

eA_{\max} = maximum mean dielectric among all DPS antennas.

eA_{\min} = minimum mean dielectric among all DPS antennas.

- 5.3.7. *Inter-Antenna Amplitude Variation (IAAV)*—Variation among the amplitude measurements from the different DPS antennas when completing metal plate calibration. Applicable to multi-channel DPS systems only. Calculate the median amplitude of the metal plate reflection for each antenna. Calculate the IIDV using Equation 6.

$$IIDV = \frac{aA_{\max} - aA_{\min}}{aA_{\min}} * 100\% \quad (6)$$

where:

aA_{\max} = maximum median amplitude among all DPS antennas on metal plate calibration.

aA_{\min} = minimum median amplitude among all DPS antennas on metal plate calibration

- 5.4. *Validation Block*—A block of plastic insulating material shall be used for performance validation of the GPR antennas. The block shall conform to [ASTM D2520](#) and [ASTM D150](#). The block shall have a known dielectric value between 2 and 15. The minimum block size shall be 24 × 24 in. and 3.5 in. thick.

6. SOFTWARE REQUIREMENTS

6.1. *Data Collection:*

6.1.1. *Metadata*—As a minimum, the software shall store the following metadata:

6.1.1.1. Dielectric value,

6.1.1.2. Project name,

6.1.1.3. Road ID,

6.1.1.4. Travel direction,

6.1.1.5. Lift designation,

- 6.1.1.6. Lane designation,
- 6.1.1.7. Date-time,
- 6.1.1.8. Distance (ft),
- 6.1.1.9. Station (ft),
- 6.1.1.10. Lateral offset (ft),
- 6.1.1.11. Longitude (°),
- 6.1.1.12. Latitude (°),
- 6.1.1.13. Elevation (ft),
- 6.1.1.14. Moving average distance (ft),
- 6.1.1.15. Output interval distance (ft),
- 6.1.1.16. Date, and
- 6.1.1.17. FileName.
- 6.1.2. *Dielectric Data:*
 - 6.1.2.1. *Calibration*—Before every data collection period, the software shall prompt the user to perform an air and metal plate calibration process for each antenna, as described in Sections 7.1 and 7.2. Calibration of the DMI shall also be allowed as described in Section 7.3.
 - 6.1.2.2. *Dielectric*—The software shall calculate the surface dielectric constant from the surface reflection using Equation 1. Recording individual trace data is not necessary.
 - 6.1.2.3. *Air Void Conversion*—The software should provide an empirical conversion from dielectric constant to asphalt air void content using a linear, logarithmic, or power equation.
 - 6.1.2.4. *Distance-Mode*—The software shall be capable of recording dielectric data at fixed distance intervals as small as every 0.5 in. The reported value may be the result of moving average, stacking, and/or oversampling techniques.
 - 6.1.2.5. *Time-Mode*—The software shall be capable of recording dielectric data at fixed time frequency as fast as 15 measurements per second.
 - 6.1.2.6. *Signal Correction*—The software shall account for potential cell tower interference. This may be done through oversampling, stacking, and/or averaging the data. The DPS should also account for any changes to the amplitude of the signals caused by changes in antenna height up to 0.5 in., or temperature of the hardware components expected during normal operation.
- 6.1.3. *Distance*—DMI and GPS measurements shall accompany each dielectric measurement.
- 6.2. *Data Display*—The DPS software shall:
 - 6.2.1. Display the data in real-time.

- 6.2.2. Display the current dielectric values from each antenna, with an appropriate moving average filter. Typically, between 0.5 and 5 ft is reasonable.
- 6.2.3. Provide a plot of dielectric vs. distance/time. The plot shall be a heat map and/or line graph (Figure 2). The scale for the dielectric axis should allow the user to adjust the displayed dielectric range, typically centered close to the mean dielectric with a range of 1.5 from the minimum and maximum displayed values. Minimize changes to the scale as much as possible.

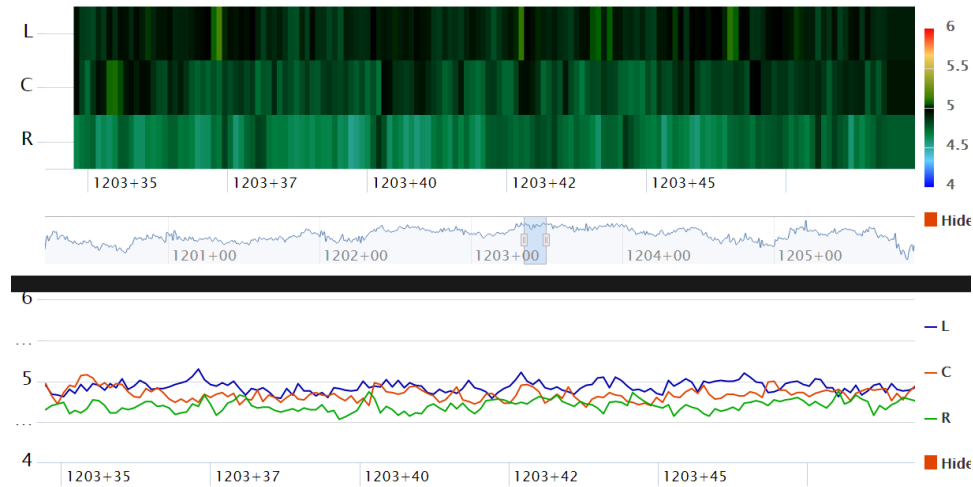


Figure 2—Example Heat Map and Line Graph

- 6.3. *Data Analysis*—The DPS software shall perform the following data analyses onsite:
 - 6.3.1. *Data Filtering by:*
 - 6.3.1.1. Centerline offset,
 - 6.3.1.2. Stationing, and
 - 6.3.1.3. Antenna serial number.
 - 6.3.2. *Summary Statistics (applied to any combination of data filtering):*
 - 6.3.2.1. Average dielectric,
 - 6.3.2.2. Median dielectric,
 - 6.3.2.3. Standard deviation of dielectric,
 - 6.3.2.4. Dielectric value at nth percentile (user-specified percentage),
 - 6.3.2.5. Percent below/within/above limits (user-specified dielectric range), and
 - 6.3.2.6. Joint ratio (mean dielectric along the joint divided by mean dielectric along the center of the mat).
 - 6.3.3. *Summary Visuals (applied to any combination of data filtering):*
 - 6.3.3.1. Plot of dielectric vs. distance. The plot shall be a heat map and/or line graph, and

- 6.3.3.2. Histogram of the data.

7. CALIBRATION

- 7.1. *Air Calibration*—Air calibration is used to subtract the direct coupling and associated noise from the antenna from the recorded signal. Follow the manufacturer recommendations for performing the air calibration. Generally, position the antennas in the air at least 1.5 times the height of the antenna during operation.
- 7.2. *Metal Plate Calibration*—Metal plate calibration is used to measure the antenna amplitude, A_i , in the dielectric constant calculation. Follow the manufacturer's recommendations for performing the air calibration.
- 7.2.1. *Metal Antenna Variation*—If the metal plate calibration amplitude is outside of three standard deviations from the historic mean metal calibration amplitude the equipment should be re calibrated.
- 7.3. *DMI System*—Perform DMI calibration according to the manufactures recommendations. Make sure the DMI is fully functional before beginning each project.
- 7.4. *GNSS*—When analyzing data in conjunction with intelligent compaction and/or IR technology the global positioning calibration requirements from [PP 80](#) or [PP 81](#), or both, shall be followed.

8. PROFILER ACCURACY

- 8.1. *Dielectric Profile Precision*—Currently, no precision information exists for this test method. See performance specifications from Section 5 for guidance.
- 8.2. *Dielectric Profile Bias*—Currently, no bias information exists for this test method.

9. KEYWORDS

- 9.1. Asphalt pavement uniformity; asphalt paving; dielectric profile; dielectric profiling; dielectric segregation; global navigation system; global positioning system; GNSS; GPR; GPS; ground penetrating radar; mat dielectrics; material segregation; surface dielectric measurements; uniformity.

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¹ This provisional standard was first published in 2019.