Designation: D6432 – 19

Standard Guide for Using the Surface Ground Penetrating Radar Method for Subsurface Investigation[1]

This standard is issued under the fixed designation D6432; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 *Purpose and Application:*

1.1.1 This guide covers the equipment, field procedures, and interpretation methods for the assessment of subsurface materials using the Ground Penetrating Radar (GPR) Method. GPR is most often employed as a technique that uses high-frequency electromagnetic (EM) waves (from 10 to 7000 MHz) to acquire subsurface information. GPR detects changes in EM properties (dielectric permittivity, conductivity, and magnetic permeability), that in a geologic setting, are a function of soil and rock material, water content, and bulk density. Data are normally acquired using antennas placed on the ground surface or in boreholes. The transmitting antenna radiates EM waves that propagate in the subsurface and reflect from boundaries at which there are EM property contrasts. The receiving GPR antenna records the reflected waves over a selectable time range. The depths to the reflecting interfaces are calculated from the arrival times in the GPR data if the EM propagation velocity in the subsurface can be estimated or measured.

1.1.2 GPR measurements as described in this guide are used in geologic, engineering, hydrologic, and environmental applications. The GPR method is used to map geologic conditions that include depth to bedrock, depth to the water table (Wright et al (**1**)[2]), depth and thickness of soil strata on land and under fresh water bodies (Beres and Haeni (**2**)), and the location of subsurface cavities and fractures in bedrock (Ulriksen (**3**) and Imse and Levine (**4**)). Other applications include the location of objects such as pipes, drums, tanks, cables, and boulders, mapping landfill and trench boundaries (Benson et al (**5**)), mapping contaminants (Cosgrave et al (**6**); Brewster and Annan (**7**); Daniels et al (**8**)), conducting archaeological (Vaughan (**9**)) and forensic investigations (Davenport et al (**10**)), inspection of brick, masonry, and concrete structures, roads and railroad trackbed studies (Ulriksen (**3**)), and highway bridge scour studies (Placzek and Haeni (**11**)). Additional applications and case studies can be found in the various *Proceedings of the International Conferences on Ground Penetrating Radar* (Lucius et al (**12**); Hannien and Autio, (**13**), Redman, (**14**); Sato, (**15**); Plumb (**16**)), various *Proceedings of the Symposium on the Application of Geophysics to Engineering and Environmental Problems* (Environmental and Engineering Geophysical Society, 1988–2019), and The Ground Penetrating Radar Workshop (Pilon (**17**)), EPA (**18**), Daniels (**19**), and Jol (**20**) provide overviews of the GPR method.

1.2 *Limitations:*

1.2.1 This guide provides an overview of the GPR method. It does not address details of the theory, field procedures, or interpretation of the data. References are included for that purpose and are considered an essential part of this guide. It is recommended that the user of the GPR method be familiar with the relevant material within this guide and the references cited in the text and with Guides D420, D5730, D5753, D6429, and D6235.

1.2.2 This guide is limited to the commonly used approach to GPR measurements from the ground surface. The method can be adapted for a number of special uses on ice (Haeni et al (**21**); Wright et al (**22**)), within or between boreholes (Lane et al (**23**); Lane et al (**24**)), on water (Haeni (**25**)), and airborne (Arcone et al (**25**)) applications. A discussion of these other adaptations of GPR measurements is not included in this guide.

1.2.3 The approaches suggested in this guide for using GPR are the most commonly used, widely accepted, and proven; however, other approaches or modifications to using GPR that are technically sound may be substituted if technically justified and documented.

1.3 *Units*—The values stated in SI units are to be regarded as standard. The values given in parentheses are provided for information only and are not considered standard. Reporting of test results in units other than SI shall not be regarded as nonconformance with this standard.

1.4 *This guide offers an organized collection of information or a series of options and does not recommend a specific course of action. This document cannot replace education or experience and should be used in conjunction with professional judgment. Not all aspects of this guide may be applicable in all*

---

[1] This guide is under the jurisdiction of ASTM CommitteeD18 on Soil and Rock and is the direct responsibility of Subcommittee D18.01 on Surface and Subsurface Characterization.

Current edition approved Nov. 15, 2019. Published December 2019. Originally approved in 1999. Last previous edition approved in 2011 as D6432 – 11. DOI: 10.1520/D6432-19.

[2] The boldface numbers in parentheses refer to the list of references at the end of this standard.

*A Summary of Changes section appears at the end of this standard *circumstances. This ASTM standard is not intended to represent or replace the standard of care by which the adequacy of a given professional service must be judged, nor should this document be applied without consideration of a project's many unique aspects. The word "Standard" in the title of this document means only that the document has been approved through the ASTM consensus process.*

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.5.1 *It is the responsibility of the user of this standard to follow any precautions in the equipment manufacturer's recommendations and to establish appropriate health and safety practices.*

1.5.2 *If this standard is used at sites with hazardous materials, operations, or equipment, it is the responsibility of the user of this standard to establish appropriate safety and health practices and to determine the applicability of any regulations prior to use.*

1.6 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[3]

D420 Guide for Site Characterization for Engineering Design and Construction Purposes

D653 Terminology Relating to Soil, Rock, and Contained Fluids

D3740 Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction

D5730 Guide for Site Characterization for Environmental Purposes With Emphasis on Soil, Rock, the Vadose Zone and Groundwater (Withdrawn 2013)[4]

D5753 Guide for Planning and Conducting Geotechnical Borehole Geophysical Logging

D6235 Practice for Expedited Site Characterization of Vadose Zone and Groundwater Contamination at Hazardous Waste Contaminated Sites

D6429 Guide for Selecting Surface Geophysical Methods

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of common technical terms used in this standard, refer to Terminology D653.

3.1.2 The majority of the technical terms used in this guide are defined in Sheriff **(27)**.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *antenna, n*—a transmitting GPR antenna converts an excitation in the form of a voltage pulse or wave train into EM waves. A receiving GPR antenna converts energy contained in EM waves into voltages, which are regarded as GPR data.

3.2.2 *attenuation, n—wave,* (*1*) the loss of EM wave energy due to conduction currents associated with finite conductivity (σ) and the dielectric relaxation (also referred to as polarization loss) associated with the imaginary component of the permittivity (ε''), and magnetic relaxation associated with the imaginary component of magnetic permeability.

(*2*) The term "attenuation" is also sometimes used to refer to the loss in EM wave energy from all possible sources, including conduction currents, dielectric relaxation, scattering, and geometrical spreading.

3.2.3 *bandwidth, n*—The operating frequency range of an antenna that conforms to a specified standard (Balanis **(28)**). For GPR antennas, typically the bandwidth is defined by the upper and lower frequencies radiated from a transmitting GPR antenna that possess power that is 3 dB below the peak power radiated from the antenna at its resonant frequency. Sometimes the ratio of the upper and lower 3-dB frequencies is used to describe an antenna's bandwidth. For example, if the upper and lower 3-dB frequencies of an antenna are 600 and 200 MHz, respectively, the bandwidth of the antenna is said to be 3:1. In GPR system design, the ratio of the difference between the upper frequency minus the lower frequency to the center frequency is commonly used. In the preceding case, one would have a ratio of 400:400 or 1:1.

3.2.4 *bistatic, adj*—the survey method that uses two antennas. One antenna radiates the EM waves and the other antenna receives the reflected waves.

3.2.5 *conductivity, n—electrical*, the ability of a material to support an electrical current (material property that describes the movement of electrons or ions) due to an applied electrical field. The units of conductivity are Siemens/metre (S/m).

3.2.5.1 *Discussion*—Conductivity is defined by Ohm's law for continuous media given by: $J = \sigma E$

where:

σ = conductivity
J = Current density (a vector field)
E = Electric field (a vector field)

The units of conductivity are Siemens/metre (S/m).

3.2.6 *control unit* (C/U), *n*—an electronic instrument that controls GPR data collection. The control unit may also process, display, and store the GPR data.

3.2.7 *coupling, n*—the coupling of a ground penetrating radar antenna to the ground describes the ability of the antenna to get electromagnetic energy into the ground. A poorly coupled antenna is described as being mismatched. A well-coupled antenna has an impedance equal to the impedance of the ground.

3.2.8 *depth of penetration, n*—the maximum depth range a radar signal can penetrate in a given medium, be scattered by

---

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[4] The last approved version of this historical standard is referenced on www.astm.org.

an electrical inhomogeneity, propagate back to the surface, be recorded by a receiver GPR antenna, and yield a voltage greater than the noise levels of the GPR unit.

(*1*) In a conductive material (seawater, metallic materials, or mineralogic clay soils), attenuation can be great, and the wave may penetrate only a short distance (less than 1 m). In a resistive material (fresh water, granite, ice, or quartz sand), the depth of penetration can be tens to thousands of metres.

3.2.9 *dielectric permittivity, n*—dielectric permittivity is the property that describes the ability of a material to store electric energy by separating opposite polarity charges in space. It relates ability of a material to be polarized in the electric displacement, D, in response to the application of an electric field, E, through $D=\varepsilon E$. The units of dielectric permittivity, ε, are farads/metre (F/m). Relative dielectric permittivity (previously called the dielectric constant) is the ratio of the permittivity of a material to that of free space, 8.854×10^{-12} F/m. Whenever the dielectric permittivity is greater than that of free space, it must be complex and lossy, with frequency dependence typically described by the Cole-Cole (Cole and Cole (**26**)) relaxation distribution model. Nearly all dielectric relaxation processes are the result of the presence of water or clay minerals (Olhoeft (**27**)).

3.2.10 *dielectric relaxation, n*—generally used to describe EM wave attenuation due to ε" (the imaginary part of the complex permittivity). The term is derived from the empirical relationship developed by describing the frequency-dependent behavior of dielectrics. The classical Debye formulation contains a term referred to as the relaxation time.

3.2.11 *diffusion, n*—the process by which the application of an external force (stimulus) results in a flux or movement of something (response). In electromagnetics, diffusion describes the movement of charges in response to an applied electric field or in response to an applied time-varying magnetic field. Diffusion is the low-frequency, high-loss, limiting behavior of electromagnetic wave propagation and is descriptive of behavior that decays rapidly (exponentially) with distance and time, generally to $1/e$ of the initial amplitude in ½ π of a wavelength.

3.2.12 *dipole antenna*—a linear polarization antenna consisting of two wires fed at the middle by a balanced source (Balanis (**28**)).

3.2.13 *Fresnel zone, n*—the area of a target's surface that contains the portion of the incident wave that arrives at the receive antenna less than ½ of a cycle out-of-phase from earliest arriving reflected energy from the target. There are multiple Fresnel zones that form annular rings around the first Fresnel zone (Sheriff (**29**)).

3.2.14 *loss tangent, n*—There are three loss tangents: electric, magnetic, and electromagnetic. Each loss tangent is the ratio of the imaginary to the real parts or the lossy to the storage parts of the response to the stimulus in the force-flux stimulus-response equations. The electrical loss tangent is the ratio of the imaginary to the real part of the dielectric permittivity plus the electrical conductivity divided by radian frequency times the real part of the permittivity. It represents the cotangent of the phase between E and J (electric and current density). The magnetic loss tangent is the ratio of the imaginary to the real part of the complex magnetic permeability. It represents the cotangent of the phase angle between H and B (magnetic field and magnetic induction). The electromagnetic loss tangent is the ratio of the real to the imaginary parts of the complex propagation constant, and it represents the cotangent of the phase angle between E and H.

3.2.15 *magnetic permeability (μ), n*—the property that describes the ability of a material to store magnetic energy by realignment of electron spin and motion. It relates ability of a material to be magnetized (magnetic polarization) in the magnetic induction, B, in response to the application of a magnetic field H, through $B=\mu H$. The units of magnetic permeability, μ, are Henry/metre. Relative magnetic permeability is the ratio of the permeability of a material to that of free space, $4\pi \times 10^{-7}$ H/m. It is commonly assumed that magnetic properties are those of free space. Whenever the magnetic permeability is greater than that of free space, it must be complex and lossy, with frequency dependence typically described by the Cole-Cole (Cole and Cole (**26**)) relaxation model. Nearly all magnetic properties are the result of the presence of iron in a variety of mineralogical forms (Olhoeft (**27**)). In some of the literature, magnetic susceptibility is used with a variety of units and normalizations (Hunt et al (**30**)).

3.2.16 *megahertz* (MHz), *n*—a unit of frequency. One megahertz equals 10^6 Hz.

3.2.17 *monostatic, adj*—(*1*) a survey method that utilizes a single antenna acting as both the transmitter and receiver of EM waves. (*2*) Two antennas, one transmitting and one receiving, that are separated by a small distance relative to the depth of interest are sometimes referred to as operating in "monostatic mode."

3.2.18 *nanosecond* (ns), *n*—a unit of time. One nanosecond equals 10^{-9} s; one billionth of a second.

3.2.19 *polarization, n*—(*1*) the storage of electrical or magnetic energy by the application of electric or magnetic fields to matter. (*2*) The orientation of the direction of the vector electromagnetic field is described by the polarization vector. Most GPR antennas are linearly polarized, though some are circularly polarized (Balanis (**28**)).

3.2.20 *propagation, n*—when sufficient energy storage is available compared to energy dissipation (loss) processes in a material, electromagnetic waves may propagate instead of exponential rapid decay (diffusion). Propagation is characterized by a decay in amplitude from the source to $1/e$ in several wavelengths, a distance called the skin depth or attenuation length.

3.2.21 *receiver, n*—the electronics that are connected to the antenna that is excited by EM waves and converts the EM energy into voltages.

3.2.22 *relative permittivity , n—(relative dielectric permittivity; sometimes called Dielectric constant),* property of an electrical insulating material equal to the ratio of the capacitance of a capacitor filled with a given material to the capacitance of the identical capacitor filled with air. Earth materials are classified generally as conductors, semiconductors, and insulators (dielectrics). The relative permittivity is the ratio of the dielectric permittivity of a material to the permittivity of free space (or vacuum). The permittivity of free space is 8.85×10^{-12} F/m but the relative permittivity of free space is 1 (dimensionless ratio).

3.2.23 *scan, n*—the recording of EM energy over a selected time range for a fixed antenna position. Also referred to as a "trace."

3.2.24 *scattering, n—EM*, the general term that describes the change in direction of electromagnetic wave propagation that occurs at a change in material properties over a short distance compared to a wavelength for an interval comparable to or greater than a wavelength. Scattering includes reflection (reverse change in direction), refraction (forward change in direction), and diffraction (caused by rapid changes that are small compared to a wavelength in both occurrence and interval).

3.2.25 *time gain, n*—also known as range gain control or time varying gain. It is the amplification applied to a trace as a function of time.

3.2.26 *transmit pulse, n*—the voltage impulse that excites the transmitting antenna.

3.2.27 *transmitter electronics*—the electronics that, after receiving a trigger pulse from the control unit, send the transmit signal to the transmitting antenna.

3.2.28 *travel time, n*—the time required for the radar signal to travel from the transmitting antenna to a target or receiving antenna.

3.2.29 *two-way travel time, n*—the time required for the radar signal to travel from the transmitting antenna to a scatterer and return to the receiving antenna.

4. Summary of Guide

4.1 *Summary of the Method*—The GPR equipment utilized for the measurement of subsurface conditions normally consists of a transmitter and receiver antenna, a radar control unit, and suitable data storage and display devices (Fig. 1).

4.1.1 A circuit within the radar control unit generates a train of trigger pulses or synthesizes a train of waves that are sent to the transmitter and receiver electronics. The transmitter electronics produce output pulses or waves that are radiated into the ground from the transmitting antenna.

4.1.2 The receiving antenna detects the EM waves that are reflected from interfaces at which the EM properties of the material(s) change. These signals are sent to the control unit for amplification. As the antenna(s) are moved along a survey line, a series of scans is collected and positioned side by side to form a profile of the subsurface (Fig. 2).

4.1.3 Because the in situ properties of soil, rock, and water vary greatly, and the radar penetration depth is dependent upon these properties, the depth of penetration can range from less than 1 m to greater than 30 m. In certain conditions such as in thick polar ice or salt deposits, penetration depth can be as great as 500 m.

4.2 *Complementary Data*—Geologic data obtained from other complementary surface geophysical methods (Guide D6429), borehole geophysical methods (Guide D5753), and

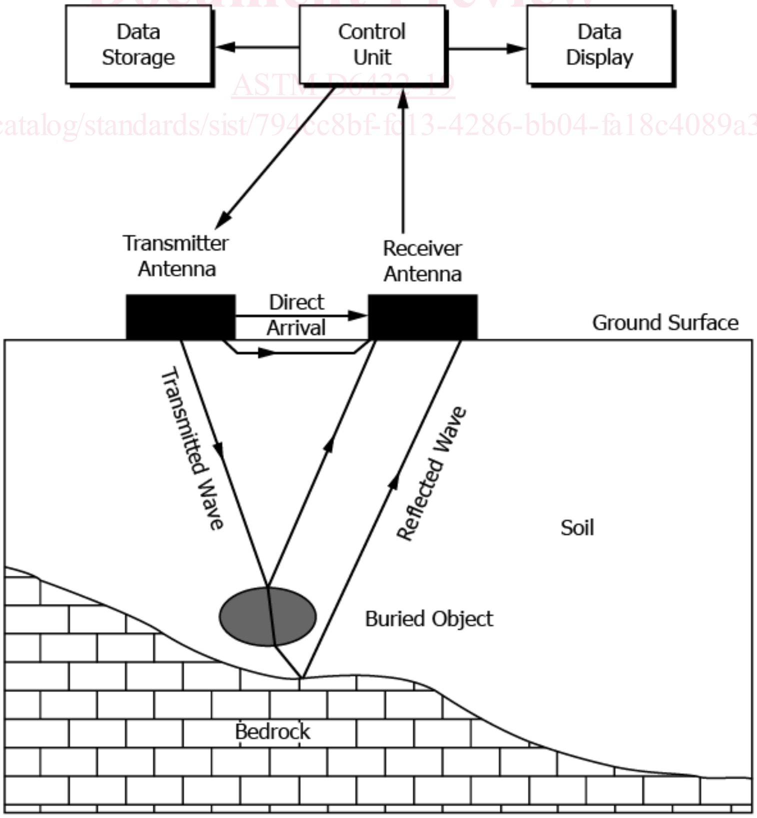

FIG. 1 Schematic Diagram of a Ground-Penetrating Radar System

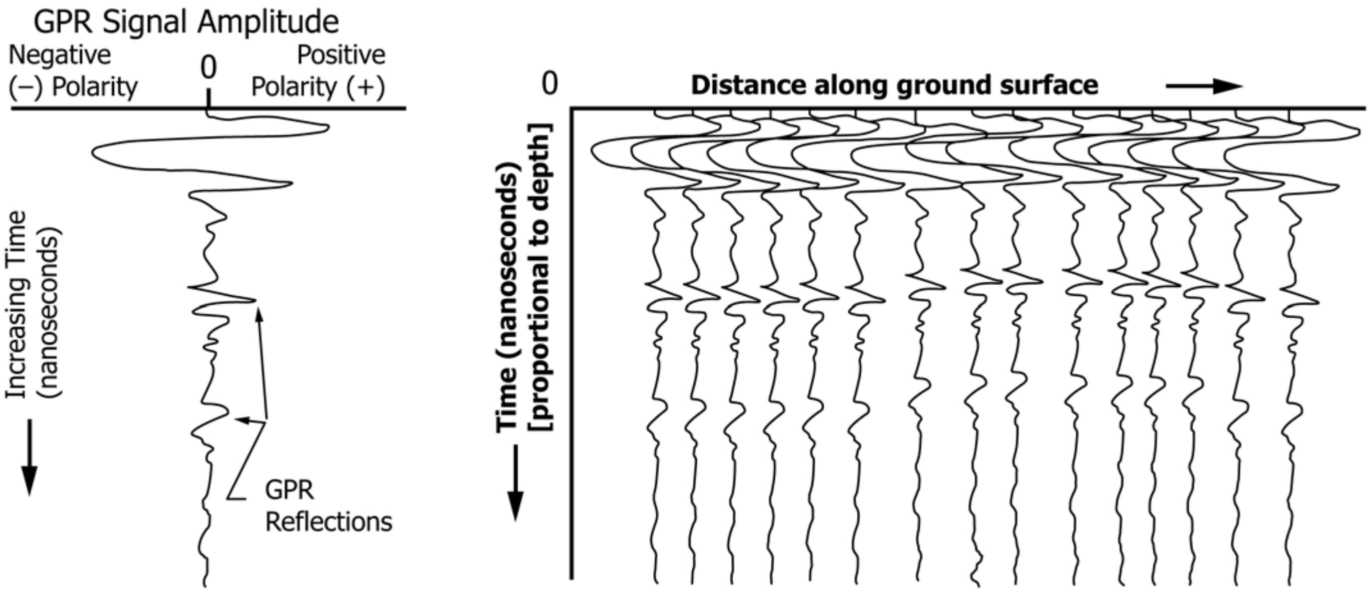

FIG. 2 Schematic Diagram Showing a Typical GPR Trace, and a Series of GPR Traces Collected at Specific Distances to Form a GPR Profile Line or Cross Section

non-geophysical methods may be necessary to help interpret and assess subsurface conditions. The most important complementary data are the location of the antenna and its orientation. The single largest error in any kind of geophysical interpretation, especially radar, is not knowing where the antenna was when the data were taken (for example, location surveying data).

5. Significance and Use

5.1 *Concepts*—This guide summarizes the equipment, field procedures, and data processing methods used to interpret geologic conditions, and to identify and provide locations of geologic anomalies and man-made objects with the GPR method. The GPR uses high-frequency EM waves (from 10 to 3000 MHz) to acquire subsurface information. Energy is propagated downward into the ground from a transmitting antenna and is reflected back to a receiving antenna from subsurface boundaries between media possessing different EM properties. The reflected signals are recorded to produce a scan or trace of radar data. Typically, scans obtained as the antenna(s) are moved over the ground surface are placed side by side to produce a radar profile.

5.1.1 The vertical scale of the radar profile is in units of two-way travel time, the time it takes for an EM wave to travel down to a reflector and back to the surface. The travel time may be converted to depth by relating it to on-site measurements or assumptions about the velocity of the radar waves in the subsurface materials.

5.1.2 Vertical variations in propagation velocity due to changing EM properties of the subsurface can make it difficult to apply a linear time scale to the radar profile (Ulriksen (**31**)).

5.2 *Parameter Being Measured and Representative Values:*

5.2.1 *Two-Way Travel Time and Velocity*—A GPR trace is the record of the amplitude of EM energy that has been reflected from interfaces between materials possessing different EM properties and recorded as a function of two-way travel time. To convert two-way times to depths, it is necessary to estimate or determine the propagation velocity of the EM pulses or waves. The relative permittivity of the material (ε_r) through which the EM pulse or wave propagates mostly determines the propagation velocity of the EM wave. The propagation velocity through the material is approximated using the following relationship (see full formula in Balanis (**32**)):

$$V_m = c/\sqrt{\varepsilon_r} \qquad (1)$$

where:

c = propagation velocity in free space (3.00×10^8m/s),
V_m = propagation velocity through the material, and
ε_r = relative permittivity.

It is assumed that the magnetic permeability is that of free space and the loss tangent is much less than 1.

5.2.1.1 Table 1 lists the relative permittivities (ε_r) and radar propagation velocities for various materials. Relative permittivity values range from 1 for air to 81 for fresh water. For unsaturated earth materials, ε_r ranges from 3 to 15. Note that a small change in the water content of earth materials results in a significant change in the relative permittivity. For water-saturated earth material, ε_r can range from 8 to 30. These values are representative, but may vary considerably with temperature, frequency, density, water content, salinity, and other conditions.

5.2.1.2 If the relative permittivity is unknown, as is normally the case, it may be necessary to estimate velocity or use a reflector of known depth to calculate the velocity. The propagation velocity, V_m, is calculated from the relationship as follows:

$$V_m = (2D)/t \qquad (2)$$

TABLE 1 Approximate Electromagnetic Properties of Various Materials

Material[A]	Relative Permittivity, K	Wave Velocities, m/ns	Conductivity, mS/m
Air	1	0.3	0
Fresh water (f,t)	81	0.033	0.10 - 30
Sea water (f,t,s)	70	0.033	400
Sand (dry) (d)	4-6	0.15-0.12	0.0001 - 1
Sand (saturated) (d,w,f)	25	0.055	0.1 - 1
Silt (saturated) (d,w,f)	10	0.095	1 - 10
Clay (saturated) (d,w,f)	8-12	0.106-0.087	100 - 1000
Dry sandy coastal land (d)	10	0.095	2
Fresh water ice (f,t)	4	0.15	0.1 - 10
Permafrost (f,t,p)	4-8	0.15-0.106	0.01 - 10
Granite (dry)	5	0.134	0.00001
Limestone (dry)	7-9	0.113-0.1	0.000001
Dolomite	6-8	0.122-0.106	
Quartz	4	0.15	
Coal (d,w,f, ash content)	4-5	0.15-0.134	
Concrete (w,f, age)	5-10	0.134-0.095	
Asphalt	3-5	0.173-0.134	
Sea ice (s,f,t)	4-12	0.15-0.087	
PVC, epoxy, polyesters vinyls, rubber (f,t)	3	0.173	

[A]

d = function of density,
w = function of porosity and water content,
f = function of frequency,
t = function of temperature
s = function of salinity, and
p = function of pressure.

where:

D = measured depth to reflecting interface, and
t = two-way travel time of an EM wave.

5.2.1.3 Methods for measuring velocity in the field are found in 6.7.3. Note that measured velocities may only be valid at the location where they are measured under specific soil conditions. If there is lateral variability in soil and rock composition and moisture content, velocity may need to be determined at several locations.

5.2.2 *Attenuation*—The depth of penetration is determined primarily by the attenuation of the radar signal due to the conversion of EM energy to thermal energy through electrical conduction, dielectric relaxation, or magnetic relaxation losses. Conductivity is primarily governed by the water content of the material and the concentration of free ions in solution (salinity). Attenuation also occurs due to scattering of the EM energy in unwanted directions by inhomogeneities in the subsurface. If the scale of inhomogeneity is comparable to the wavelength of EM energy, scattering may be significant (Olhoeft (**33**)). Other factors that affect attenuation include soil type, temperature (Morey (**34**)), and clay mineralogy (Doolittle (**35**)). Environments not conducive to using the radar method include high conductivity soils, sediments saturated with salt water or highly conductive fluids, and metal.

5.3 *Equipment*—The GPR equipment utilized for the measurement of subsurface conditions normally consists of a transmitter and receiver antenna, a radar control unit, and suitable data storage and display devices.

5.3.1 *Radar Control Unit*—The radar control unit synchronizes signals to the transmitting and receiving electronics in the antennas. The synchronizing signals control the transmitter and sampling receiver electronics located in the antenna(s) in order to generate a sampled waveform of the reflected radar waves. These waveforms may be filtered and amplified and are transmitted along with timing signals to the display and recording devices.

5.3.2 Real-time signal processing for improvement of signal-to-noise ratio is available in most GPR systems. When working in areas with cultural noise and in materials causing signal attenuation, time-varying gain is necessary to adjust signal amplitudes for display on monitors or plotting devices. Filters may be used in real time to improve signal quality. The summing of radar signals (stacking) is used to increase effective depth of exploration by improving the signal-to-noise ratio.

5.3.3 *Data Display*—The GPR data are displayed as a continuous profile of individual radar traces (Fig. 2). The horizontal-axis represents horizontal traverse distance and the vertical-axis is two-way travel time (or depth). Data are commonly presented in wiggle trace display, where the intensity of the received wave at an instant in time is proportional to the amplitude of the trace (see Fig. 2), or as a gray scale or color scale display, where the intensity of the received wave at an instant in time is proportional to either the intensity of gray scale (that is, black is high intensity, and white is low intensity; see Fig. 3) or to some color assignment defined according to a specified color-signal amplitude relationship.

5.3.4 *Antennas and Control Cables*—The antennas used to transmit and receive radar signals are generally electric dipoles. A single-dipole antenna can be used to both transmit and receive signals in the monostatic mode. The bi-static mode uses separate antennas for transmitting and receiving. These antennas can be housed in a single enclosure where the distance between the two antennas are fixed, or in separate enclosures where the distance between the two antennas can be varied. The ability to vary the distance between the two antennas is helpful in optimizing the survey design for specific types of target detection.

5.3.4.1 Electromagnetic waves are three-dimensional vector fields where the orientation of the fields is described by the vector direction or polarization of the electrical and magnetic fields. Changing the polarization of a linearly polarized electric dipole antenna can cause maximum or minimum coupling to a scattering object. For example, alignment of the electric field axis (the long length of a dipole antenna) parallel to a pipe or wire will maximize the response of the pipe as a reflector scatterer, while a perpendicular alignment will minimize the pipe response. Typically, two antenna systems use the same orientation and polarization for both antennas, but sometimes the receive antenna will be oriented with its electric field perpendicular (orthogonal) to the transmit antenna, resulting in insensitivity to reflection from horizontal layers and linear features (like pipes) that are aligned to either antenna, but high sensitivity to off-alignment pipes.

5.3.4.2 Antennas are manufactured both with and without shielding (metal or high radar absorption material). Shielding