Ground Penetrating Radar (GPR)

**Applications**

GPR is used to map geologic conditions that include depth to bedrock, depth to the water table, depth and thickness of soil and sediment strata on land and under fresh water bodies, and the location of subsurface cavities and fractures in bedrock. Other applications include the location of objects such as pipes, drums, tanks, cables, and boulders, mapping landfill and trench boundaries, mapping contaminants, and conducting archeological investigations.

**Speed of EM Wave**

\[
c = \sqrt{\frac{\mu}{\varepsilon}} = \sqrt{\frac{\mu_0}{\varepsilon_0}} \sqrt{\frac{\mu_r}{\varepsilon_r}} = c \sqrt{\frac{\mu_r}{\varepsilon_r}} \propto \sqrt{\frac{1}{\varepsilon_r}}
\]

<table>
<thead>
<tr>
<th>Material</th>
<th>Relative Permittivity, $\varepsilon_r$</th>
<th>Pulse Velocities, m/ns</th>
<th>Conductivity, mS/m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air</td>
<td>1</td>
<td>0.3</td>
<td>0</td>
</tr>
<tr>
<td>Fresh water</td>
<td>81</td>
<td>0.033</td>
<td>0.10-30</td>
</tr>
<tr>
<td>Sand (dry)</td>
<td>4-6</td>
<td>0.15-0.12</td>
<td>0.0001-1</td>
</tr>
<tr>
<td>Sand (saturated)</td>
<td>25</td>
<td>0.0055</td>
<td>0.1-1</td>
</tr>
<tr>
<td>Silt (saturated)</td>
<td>10</td>
<td>0.095</td>
<td>1-10</td>
</tr>
<tr>
<td>Clay (saturated)</td>
<td>8-12</td>
<td>0.106-0.087</td>
<td>100-1000</td>
</tr>
<tr>
<td>Granite (dry)</td>
<td>5</td>
<td>0.134</td>
<td>0.00001</td>
</tr>
<tr>
<td>Concrete</td>
<td>5-10</td>
<td>0.134-0.095</td>
<td></td>
</tr>
<tr>
<td>Asphalt</td>
<td>3-5</td>
<td>0.173-0.134</td>
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</tr>
</tbody>
</table>
Attenuation and Penetration

\[ |E_r| = |E_0 e^{-\alpha x}| \]

\(E_r\) and \(E_0\) are the received and transmitted magnitude of the Electric field of the EM pulse, \(x\) is the propagation distance, and \(\alpha\) is the attenuation in nepers/m.

**Example.** For dry sand the attenuation is about 0.5 nepers/m. Thus, after one meter the magnitude of the EM field has fallen to \(e^{-0.5 \times 1} = 0.61\). In other words, after one meter the amplitude is \(20\log(0.6) = 4.34\) dB.

Lowering frequency improves depth of exploration because attenuation primarily increases with frequency. As frequency decreases, however, two other fundamental aspects of the GPR measurement come into play. First, reducing frequency results in a loss of resolution. Second, if frequency is too low, electromagnetic fields no longer travel as waves but diffuse which is the realm of inductive EM or eddy current measurements.
Time-Bandwidth, Spatial Resolution

$$|X(f)| = \tau |\text{sinc}(f\tau)|$$

Bandwidth $\sim 1/\tau$
Sample Measurements
Sample GPR Systems

<table>
<thead>
<tr>
<th>400 MHz</th>
<th>40 MHz</th>
</tr>
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<tbody>
<tr>
<td>500 MHz</td>
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</table>

**SPECIFICATIONS:**
- **Transmit center frequency** ............... 500MHz
- **Average radiated power** .................. 16mW
- **Receiver type** ......................... Equivalent time sampling
- **Input noise** ............................. <10uV RMS
- **Dynamic Range input** ................... 120db
- **Dynamic Range digitized** ............... 96db
- **Digital resolution** ..................... 16 bits
- **Antenna type** ........................... Proprietary tapered
  - impedance travelling wave
- **Antenna impedance** ..................... 50 ohms
- **Antenna VSWR** ........................... <1.6:1
- **System weight** ......................... 12.5kg

**Websites**

http://fate.clu-in.org/GPR_main.html
http://www.du.edu/~lconyer/what_is_gpr.htm