



## How GPR Works — and Why Scan Direction Matters

The GPR system sends a short electromagnetic (EM) pulse into the ground through the antenna. That pulse travels through soil, pavement, or concrete until it encounters a change in material.

When the pulse reaches a boundary between materials with different electrical properties (dielectric constants), part of the energy reflects back to the antenna.

The GPR system measures the time it takes for the reflected energy to return, which is used to estimate distance to subsurface features.

## Why Perpendicular Crossings Are Critical



GPR does not create an image of a utility the way a camera creates a photograph. Instead, it records a **series of reflections over time** as the antenna moves across the ground.

Each trace is a vertical snapshot directly beneath the antenna.

As the cart moves forward, those snapshots are stacked side-by-side to form a profile.

This means **GPR only builds recognizable targets when the antenna crosses a feature**, not when it follows alongside it.

## What Happens When You Cross a Utility Perpendicular

When the cart crosses a pipe, conduit, or cable at a **90-degree angle**, several things happen:

- The antenna approaches the utility, shortening the travel path of the radar wave
- The reflection grows stronger as the antenna nears the target
- The shortest path occurs when the antenna is directly over the utility
- As the cart moves past the utility, the travel path lengthens again

This changing travel time creates the classic **hyperbola shape** seen in GPR data.

That pipe itself **signature** moving



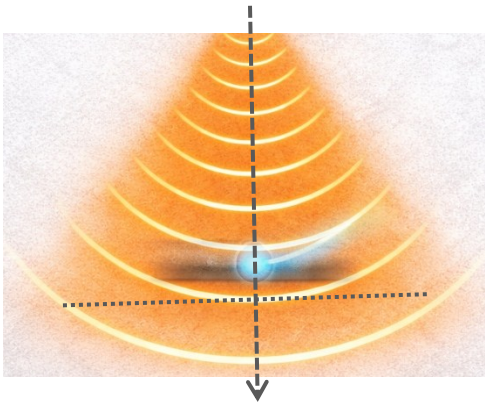
The clearer the confidence the operator has in:

- Target location
- Centerline position

hyperbola is not the — it is a **mathematical** created by the antenna across the target.

and more symmetrical hyperbola, the more

- Relative depth consistency



### **What Happens When You Scan Parallel to a Utility**

When the cart moves **parallel** to a utility:

- The antenna remains nearly the same distance from the target
- The reflection strength and travel time change very little
- No clear hyperbola forms
- The target may appear as a faint, smeared, or intermittent response — or disappear entirely

In this situation, the GPR system has no changing geometry to work with, making interpretation unreliable.

This is one of the most common reasons utilities are missed or misidentified during GPR surveys.

### **Big Picture Training Point**

**GPR needs motion across the target to create meaning.**

Perpendicular crossings give the radar system the changing distances it needs to convert reflections into recognizable patterns.

This is why best practice GPR surveys use:

- Multiple passes
- Different directions
- Grid or cross-line scanning patterns

A single pass in one direction is rarely sufficient.

### **Field Reality Reminder**

GPR is not a “push and see” tool.

The quality of the data — and the safety decisions that follow — depend heavily on:

- Scan direction
- Cart control
- Consistent speed
- Repeatable crossing geometry

Understanding **why perpendicular crossings matter** turns GPR from a gadget into a reliable investigation tool.

### Dielectric Constant (GPR Context)

**The dielectric constant is the property of a material that controls how fast radar energy travels through it and how much of that energy is reflected when it meets another material.**

#### How common materials compare

- **Sand (dry)** Low dielectric constant, Radar energy travels **fast**
  - Good penetration, clear targets
- **Soil (mixed / loamy)**  
Moderate dielectric constant  
Radar energy travels **slower than sand**  
Penetration and clarity depend on moisture
- **Clay** High dielectric constant  
Radar energy travels **slowly** and is strongly absorbed  
Poor penetration, weaker or smeared reflections
- **Silicone (rubber / sealants)**  
Relatively low to moderate dielectric constant  
Radar energy passes through easily  
Often produces little reflection unless contrasted with another material

Material	Soil Cal
Air	300
Ice	160
Dry Soil	140
Dry Rock	120
Soil	100
Wet Rock	100
Concrete	100
Pavement	100
Wet Soil	65
Water	33

#### Dielectric Contrast and GPR Reflection Strength

The **dielectric constant** is the property of a material that controls how fast radar energy travels through it.

However, **what actually creates a visible GPR reflection is the difference in dielectric constant between two materials**, not the dielectric value of one material by itself.

GPR reflections become stronger as the dielectric difference between materials increases, which is why a clay pipe buried in clay soil often produces little or no detectable response.

#### Key Principle (this is the part that must be understood)

**The greater the difference in dielectric constant between two materials, the stronger the GPR reflection.**

If the dielectric constants are **similar**, very little energy is reflected — even if an object is physically present.

#### Practical Field Examples

- **Metal pipe in soil**
  - Extremely high dielectric contrast
  - Very strong reflection
  - Easy to detect
- **Plastic or clay pipe in dry sand**
  - Moderate dielectric contrast
  - Detectable reflection
  - Often produces a clear hyperbola
- **Clay pipe buried in clay soil**
  - Very low dielectric contrast
  - Little energy is reflected
  - Pipe may be weak, smeared, or invisible in GPR data

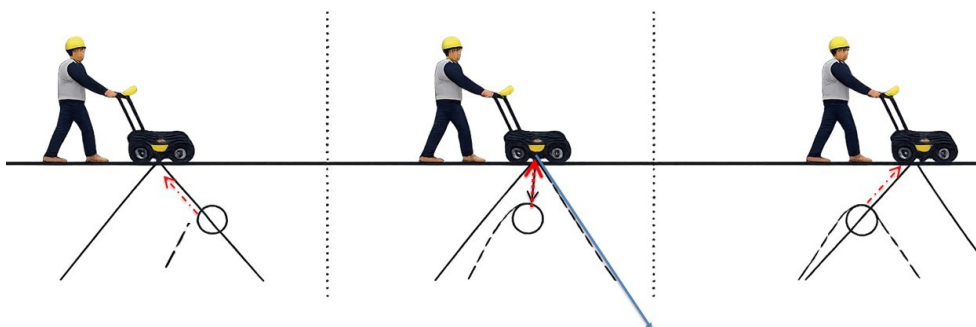
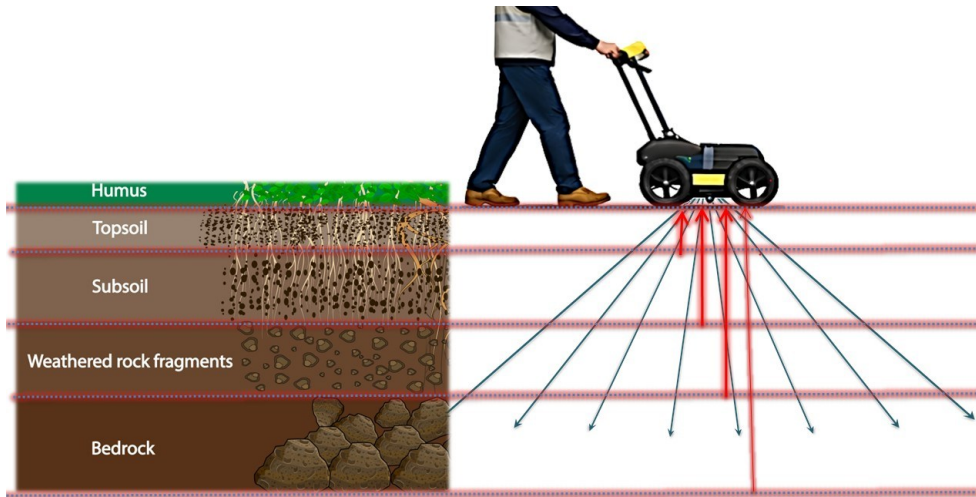
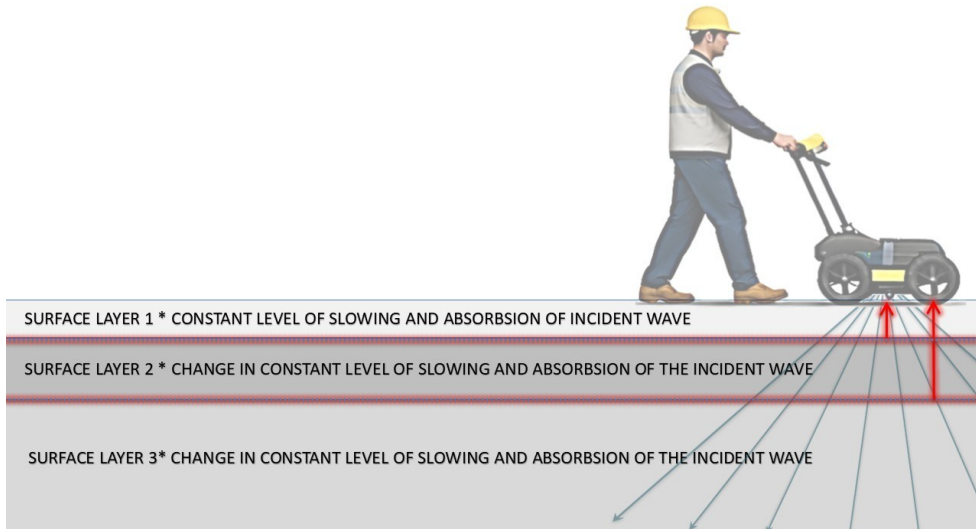
In this case, the radar energy does **not “see” a strong boundary**, because the pipe and surrounding soil behave electrically alike.

### **Why This Matters for Locators**

GPR does **not detect objects** — it detects **changes in material properties**.

If there is **no meaningful electrical contrast**, the radar has nothing to reflect from, regardless of:

- Pipe size
- Pipe age
- Pipe material visibility
- Trench Fill

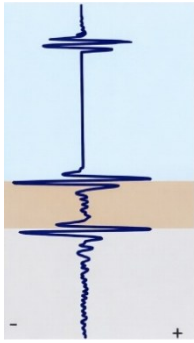


## Why Radar Waves Behave Differently Underground

When we use ground-penetrating radar, what we are really doing is sending electromagnetic energy into the earth and listening for what comes back. To understand why some signals return clearly and others fade away, we have to talk about how radar energy interacts with the ground itself.

### *Soil is not one thing; it is a blend.*

The ground beneath our feet is a mixture of materials—minerals, water, air, and organic matter—all blended together in different proportions. One of the most common elements in that mix is silicon, which forms the backbone of sand, silts, and many soil minerals. Radar waves interact with all of these materials, but how they behave depends on what else is mixed in and how those materials respond electrically.



A radar wave is made of two linked parts: an electric field and a magnetic field. Underground, **the electric field dominates the behavior of the radar wave**. How the ground responds to that electric field determines how fast the wave travels, how much energy is absorbed, and how much returns to the antenna.

Radar waves do not move at one fixed speed underground. Their speed depends on how strongly the surrounding material interacts with the electric field. Some materials interact weakly, allowing energy to pass easily. Others interact strongly, slowing the wave down and absorbing energy.

### **Water plays a major role in this interaction.**

Moisture in the ground allows ions to move, and those ions respond to the electric field. The more water and ions present, the more radar energy is absorbed and dissipated. That does not mean the soil behaves like a metal conductor. Instead, it means the energy is being used up through electrical interaction.

Soils with higher moisture content, finer grain size, tighter compaction, or certain mineral blends tend to absorb radar energy more readily. The wave slows down, penetration decreases, and less energy makes it back to the antenna.

Drier, cleaner, more granular soils—such as sand—interact less with the electric field. In those materials, radar energy moves more easily and travels faster. Penetration improves, and reflections from deeper features are more likely to be detected.

**KEY CONCEPT** Radar reflections do not happen simply because an object is present. They happen because of a **difference in electrical constant area below**.

When a radar wave moves from one material into another such as from a moist, compacted soil into a drier, sandier layer the electric field suddenly sees a different environment. That indifference causes some of the wave's energy to reflect back toward the antenna. This area of indifference and energy reflection causes an loss of the energy strength as the wave continues forward into the new material, often traveling at a different speed when materials change.

That indifference between materials is what creates the reflection.

This is why soil layers appear on a radar record. It is why trench backfill can be visible even when no utility is present. And it is why changes in moisture, compaction, or material type often stand out clearly.

A helpful way to think about this is with light.

A black surface absorbs most of the light that hits it. Very little light reflects back, so it appears dark. A lighter surface reflects more light, making it easier to see.

### **Some soils behave the same way to radar energy.**

Certain soil blends absorb radar energy much like the color black absorbs light. Other soils allow more energy to pass through and reflect back. The radar energy is not blocked—it is absorbed by the material responding to the electric field.

So when penetration is poor or returns are weak, what we are really seeing is strong electrical interaction within the ground.

Nothing about the radar system has changed, only the materials responding to the electric field has changed. Understanding this helps explain why radar performance varies from site to site, why depth estimates depend on soil conditions, and why velocity calibration matters. It also helps separate radar from other locating technologies. Radar does not energize utilities. It does not rely on current flow. It sends energy into the ground and listens for reflections of the wave.

### **Why Trenches May Show Up on GPR**

One of the best real-world examples of this concept is a trench. When a trench is dug, the soil is disturbed, removed, and then put back. Even when it looks the same at the surface, the soil underground is no longer arranged the same way. The compaction changes. Air gaps change. Moisture distribution changes. And those changes alter how the ground responds to the radar's electric field.

As the radar wave travels through undisturbed soil, it moves at a fairly consistent speed. But when it crosses a trench that was dug perpendicular to the radar path, the wave suddenly encounters a zone with different electrical behavior.

That change causes part of the radar energy to reflect. Not because there's a pipe. Not because there's metal. But because the soil is different.

The radar is seeing a contrast in compaction and electrical response. The wave may slow down slightly, speed up slightly, or lose energy differently within the trench zone. That difference creates a reflection that appears on the screen as a linear disruption or repeated reflection along the trench wall.

This is why trench lines often show up clearly on a radar record, even years after excavation. The ground may look healed at the surface, but electrically, it never fully returns to its original state.

### **Radar doesn't see the trench. Radar sees the change in how energy moves through the soil.**

Once you understand that radar is responding to **differences in how materials interact with the electric field**, the subsurface starts to make a lot more sense.

### Slide 1 — What GPR Is Really Doing

#### On-screen text

- Sending energy into the ground
- Listening for what comes back

#### Slide narration

“Ground-penetrating radar works by sending electromagnetic energy into the ground and listening for what comes back. The system doesn’t see objects directly—it responds to how energy behaves underground.

### Slide 2 — Soil Is Not One Thing

#### On-screen text

- Soil is a mixture
- Minerals, water, air, compaction

#### Slide narration

“Soil is not one uniform material. It’s a mixture of minerals, water, air, and organic matter, blended together in different ways. A large portion of the Earth’s crust is made of silicon-based materials, which form sand, silt, and many soil minerals.”

### Slide 3 — The Electric Field Dominates Underground

#### On-screen text

- Radar = electric + magnetic fields
- Electric field controls behavior

#### Slide narration

“A radar wave has both an electric field and a magnetic field. Underground, the electric field dominates the behavior. How the ground responds to that electric field determines wave speed, energy loss, and reflection strength.”

### Slide 4 - Radar Waves Change Speeds

#### On-screen text

- Speed depends on material
- Not constant underground

**Slide narration** “Radar waves don’t travel at one fixed speed underground. Their speed changes depending on how strongly the surrounding material interacts with the electric field.”

### Slide 5 — Why Some Soils Slow Radar Down

#### On-screen text

- Moisture
- Ions
- Compaction

#### Slide narration

“Water plays a major role. Moisture allows ions to move, and those ions interact with the electric field. Soils with higher moisture, finer grain size, or tighter compaction absorb more radar energy. The wave slows down, penetration drops, and less energy returns.”

### Slide 6 — Why Sand Lets Radar Travel Faster

#### On-screen text

- Lower interaction
- Faster travel
- Better penetration

#### Slide narration

“Cleaner, drier, more granular soils—like sand—interact less with the electric field. Radar energy moves more easily, travels faster, and penetrates deeper.”

### Slide 7 — What Happens at a Material Boundary

#### On-screen text

- Some energy reflects
- Some continues forward
- Speed may change

#### Slide narration

“When radar energy moves from one material into another, three things happen at once. Some energy reflects back to the antenna. Some continues forward. And in the new material, the wave may travel at a different speed.”

### **Slide 8 — Reflection Happens Because of Difference**

#### **On-screen text**

- Reflection = contrast
- Not just objects

#### **Slide narration**

“Radar reflections happen because of differences in electrical response, not just because an object is present. Changes in material type, moisture, or compaction can all create reflections.”

### **Slide 9 — Clay and the Color Black Analogy**

#### **On-screen text**

- Absorbs energy
- Weak return

#### **Slide narration**

“Clay behaves to radar waves the way the color black behaves to light. Black absorbs light instead of reflecting it. Clay absorbs radar energy instead of returning it. Penetration is poor and returns are weaker.”

### **Slide 10 — The Radar Is Not Blocked**

#### **On-screen text**

- Energy is absorbed
- Not stopped

#### **Slide narration**

“The radar signal isn’t being blocked. It’s being absorbed. The ground is using up the energy through interaction with the electric field.”

### **Slide 11 — What You See on the GPR Screen**

#### **On-screen text**

- Soil layers
- Depth depends on velocity

#### **Slide narration**

“This explains why soil layers appear on radar records, why depth calculations depend on soil conditions, and why velocity calibration matters. If velocity is wrong, depth will be wrong.”

### **Slide 12 — Radar vs Locating (Quick Reminder)**

#### **On-screen text**

- Radar: listens for contrast
- Locating: induces current

#### **Slide narration**

“Radar does not energize utilities. It does not rely on current flow. It sends energy into the ground and listens for how materials respond to the electric field.”

### **Slide 13 — Key Takeaway**

#### **On-screen text**

- Electric field interaction matters

#### **Slide narration**

“Radar waves slow down in some soils and speed up in others because different materials interact with the electric field differently. Once you understand that, GPR behavior starts to make sense.”