

## Subsurface Utility Locating Skills Enhancement Training Guide

### COURSE PURPOSE

This course strengthens the knowledge, judgment, and field skills needed to investigate, locate, mark The location of pipes, cables, wires, structures of many types and anomalies beyond the surface that we see. This training course explores how underground utility networks are arranged, the materials and construction methods used, and how system design, grounding, bonding, branches, joints, repairs, and other field conditions affect whether a facility can be detected.

The course explains the capabilities and limitations of electromagnetic pipe-and-cable locators, sondes, detectable rods, electronic markers, ground-penetrating radar, acoustic locating methods, mapping technologies, and safe physical exposure. Participants learn how applied current creates a detectable signal field, how transmitters and receivers provide different information, and how frequency, circuit conditions, depth, nearby conductors, and field distortion affect the response.

Locating is presented as a systematic investigation rather than simply operating an instrument. Participants learn to combine the locate request, utility records, visible structures, surface evidence, system knowledge, transmitter indications, receiver responses, estimated current, depth estimates, Peak and Null observations, and other available evidence. They then use that information to develop a locating plan, select an appropriate method, create the best controlled signal, search, trace, pinpoint, evaluate, mark, document, and communicate the results.

The course emphasizes that a receiver detects and measures a signal field; it does not see or independently identify the buried facility. A surface mark represents the locator's best supported estimate of the facility's position based on the available evidence. The facility's actual position, depth, size, material, and condition are confirmed only when it is safely exposed and directly observed.

The overall purpose is to help participants make safer, more consistent, and better-supported locating decisions while recognizing uncertainty, equipment limitations, and conditions that require additional investigation or physical verification.

### What Participants Will Work Toward

- Recognize the purpose and general arrangement of underground utility networks, from higher-voltage and higher-pressure systems to lower-voltage and lower-pressure distribution systems.
- Compare common near-surface locating technologies and select methods with an awareness of their advantages and limitations.
- Explain the applied science of electromagnetic locating in practical, easy-to-understand terms.
- Apply detectable current with a transmitter, detect the resulting signal field with a receiver, and evaluate whether the response is trustworthy.
- Use safe, repeatable fundamental steps before marking one facility at a time.

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**The National Utility and Pipeline Infrastructure** Modern civilization depends on a vast network of infrastructure systems that operate quietly beneath our cities, roads, and communities. Most people rarely see these systems, yet they support nearly every aspect of daily life. Beneath the surface lies an interconnected set of underground networks that deliver energy, water, electricity, and information to homes, businesses, hospitals, and industries. These systems form the unseen framework that allows modern society to function.

Collectively, these networks account for millions of miles of buried infrastructure that stretch beneath streets, neighborhoods, industrial corridors, and transportation rights-of-way throughout the United States.

## **Common Engineering Principles**

- Upstream production & Treatment
- Midstream Bulk Supply Transmission (High Voltage/High Pressure/High Capacity)
- Distribution (Lower Voltage and Pressure )

Despite serving different functions, these infrastructure systems are built upon similar engineering principles. Most begin at a source or production point, pass through treatment or processing facilities, traverse major transmission networks, and finally branch into smaller distribution systems that reach end users. For example, water is sourced from rivers, reservoirs, or aquifers, treated, and then moved through transmission pipelines into local distribution networks. Similarly, oil and natural gas are extracted, processed, transmitted, and distributed. Electrical power is generated at stations, carried through high-voltage transmission lines, and distributed via substations. Telecommunications rely on backbone networks and major hubs before branching into local service networks that reach homes and businesses.

## **Energy Production and Gathering Systems**



Oil and natural gas infrastructure starts with the extraction of resources from underground reservoirs through wells. These resources are then transported via flowlines and gathering pipelines that connect individual wells to central processing facilities. Gathering systems typically include wellhead flowlines, gathering pipelines, separation facilities, gas processing plants, and storage facilities.

Flowlines move raw oil, natural gas, and associated liquids from wells to gathering systems. Gathering pipelines then transport these products to treatment plants, processing facilities, storage terminals, or transmission pipelines. Steel pipe is most commonly used for these pipelines due to its strength and ability to withstand pressure and temperature changes. In environments where corrosion is a concern, materials like

fiberglass reinforced pipe or polyethylene pipe may be used.



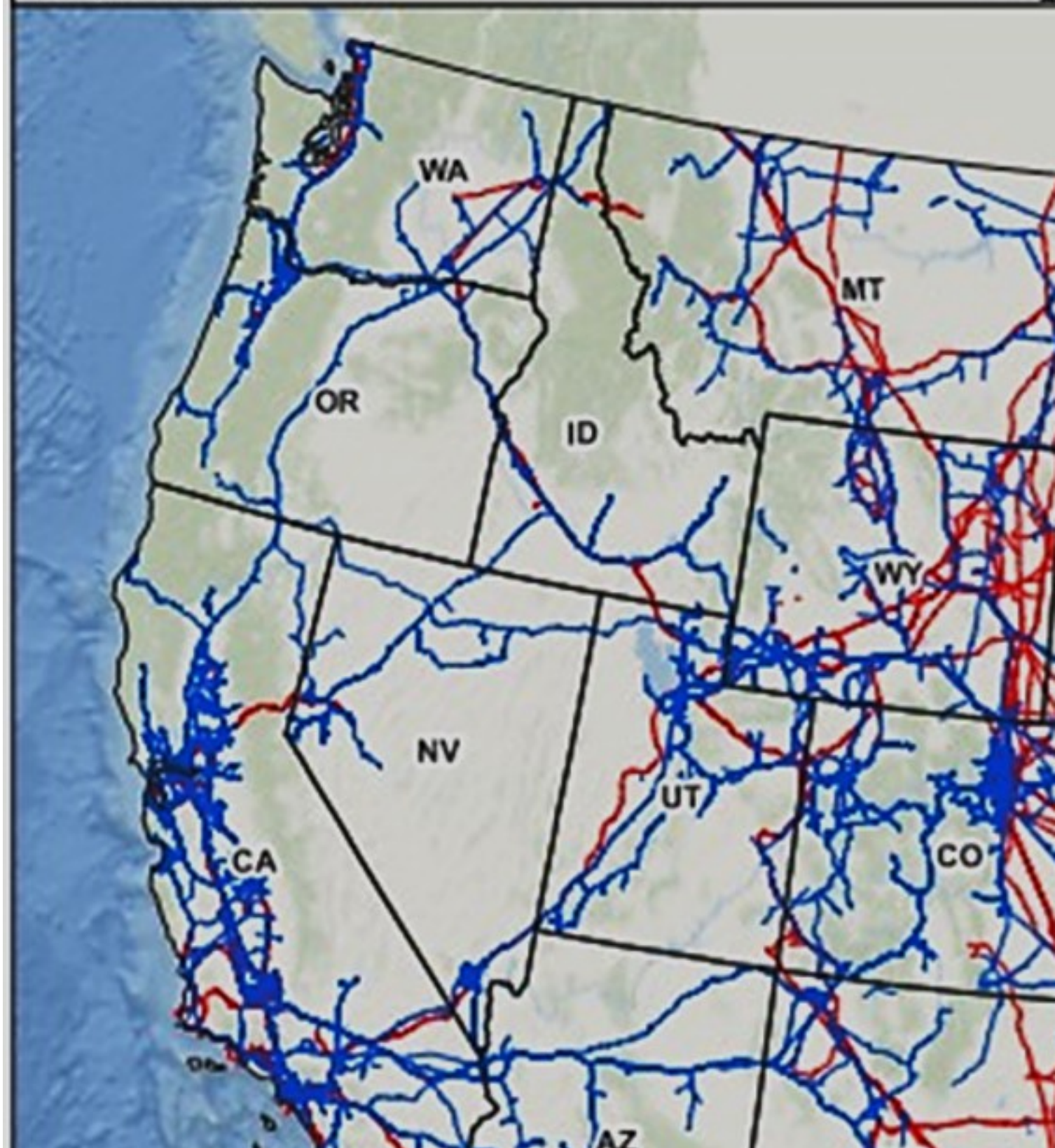
Electrical and communication cabling are often installed alongside production equipment to operate pumps, control valves, instrumentation, and monitoring systems across these fields. Once processed, oil and natural gas enter l

## **Transmission Pipelines**



U.S. Department of Transportation  
Pipeline and Hazardous Materials  
Safety Administration

# Gas Transmission Pip



**Transmission pipelines** are the backbone of the energy transportation network. They move large volumes of crude oil, natural gas, and refined petroleum over long distances, linking producing regions, refineries, storage terminals, industrial centers, and major markets.

Constructed from coated carbon steel pipe, these pipelines operate at high pressures and are installed along dedicated rights-of-way, often spanning hundreds or thousands of miles. Supporting infrastructure includes compressor stations for natural gas, pump stations for liquids, valve stations, metering facilities, and storage terminals. These surface facilities often indicate the presence of underground pipelines.

## **Natural Gas Distribution Systems**

After passing through transmission pipelines, natural gas enters local distribution systems that deliver gas to homes, businesses, and industrial facilities. These systems operate within cities and towns, consisting of pipeline networks that branch throughout neighborhoods and commercial areas.

Distribution systems typically start at city gate stations where gas moves from transmission



pipelines into local networks. Here, gas pressure is reduced and flow is measured before entering municipal systems. Distribution mains transport gas through communities, branching beneath streets and roadways. Service lines connect these mains to individual buildings and meters. Surface access points in these systems commonly include regulator stations, valve boxes, service shutoff valves, gas meters, and pressure control cabinets.



Pipeline materials vary by pressure level and system age. Transmission pipelines are typically steel for strength and high-pressure operation.



Distribution systems use steel, polyethylene plastic, and, in older systems, cast or wrought iron. Polyethylene plastic is widely used in modern systems for its flexibility, corrosion resistance, and ease of installation. As plastic pipes do not conduct electricity, tracer wire is typically installed to allow for future location of the system.



## Public Works Systems

Public works departments operate vast underground piping networks that provide drinking water, collect wastewater, and manage storm drainage. In the United States, public works infrastructure includes roughly 2.2 million miles of drinking water pipelines, 800,000 miles of sanitary sewers, and 3.5 million miles of storm drainage systems—about 6.5 million miles of buried public infrastructure in total.



Like energy systems, these networks have both transmission and distribution components. Large transmission pipelines move water from sources to treatment plants and municipal systems; distribution systems deliver treated water to homes and businesses. Wastewater systems transport sewage to treatment plants, while storm drainage systems collect rainwater runoff and convey it to streams, rivers, or detention facilities.

Surface access structures include fire hydrants, valve boxes, manholes, catch basins, and storm inlets.

## Pipe Materials and Joint Styles



Public water, wastewater, and storm drainage systems are constructed from various materials, reflecting the era, standards, and operating conditions at the time of installation. For line locators, the key distinction is whether the pipe is conductive or non-conductive, and whether a conductive path exists for electromagnetic locating signals. Understanding pipe materials and joint styles helps locators choose the most effective locating method and improves their ability to identify infrastructure in the field.

In North America water mains are approximately 28% cast iron, 28% ductile iron, 22% PVC, 13% asbestos-cement, and smaller amounts of steel, HDPE, and concrete cylinder pipe. Cast iron and ductile iron together make up about half of the installed water mains, explaining why metallic water pipes are common in older systems.

Modern water systems often use PVC and HDPE for their advantages: light weight, corrosion resistance, smooth interiors, lower installation cost, and compatibility with trenchless construction methods. Ductile iron remains in use for high-pressure, large-diameter pipelines, or where strength is essential, resulting in modern systems containing both old metallic and new plastic pipes.

Much underground water infrastructure was installed during earlier periods of growth, with legacy materials like cast iron, ductile iron, asbestos-cement, vitrified clay, and concrete pipes still in use. Many were installed before tracer wire became standard, making them difficult to locate using electromagnetic signals.

Pipe materials fall into two groups for locating: conductive (steel, ductile iron, cast iron) and non-conductive (PVC, HDPE, asbestos-cement, clay, concrete). Conductive materials

can carry locating signals when electrical continuity exists; non-conductive materials require tracer wire or other conductive elements to be detected electromagnetically.

Locators often encounter a range of materials. Water systems may include cast iron, ductile iron, PVC, HDPE, steel, and asbestos-cement. Sewer systems may use vitrified clay, PVC, concrete, ductile iron, or HDPE. Storm drainage systems often have reinforced concrete, HDPE, PVC, or corrugated metal pipes.

Joint styles offer clues about pipe material and installation era. Bell-and-spigot joints are common in cast iron, ductile iron, clay, and some concrete pipes. Older installations often used lead and oakum seals; modern systems use rubber gaskets. Push-on gasket joints are typical in ductile iron and PVC pipes, while mechanical joints are used with ductile iron fittings and valves. Sleeve couplings are seen with asbestos-cement or pipeline repairs, and HDPE uses fusion-welded joints, creating a continuous pipeline without mechanical joints.

Welded steel pipe and fusion-welded HDPE with tracer wire provide the most continuous conductive pathways for locating. Gasketed, mechanical, or corroded joints may add resistance that interrupts the locate circuit, weakening the electromagnetic field.

Modern installations usually include tracer wire with non-conductive pipes, installed attached, alongside, or above the pipe in the trench. The wire allows for the application of an electromagnetic locating signal.

Older non-metallic pipelines were often installed without tracer wire or locating aids. In such cases, the pipeline cannot carry a locating signal, so locators use alternative methods such as inserting a sonde, ground penetrating radar, identifying surface features, or reviewing system records. Knowledge of materials and installation practices informs the choice of locating method.

## **Electrical Power Cable Systems**

The electrical power grid also follows a transmission and distribution model. Electricity is generated at power plants, transmitted via high-voltage lines to substations, and distributed locally to homes and businesses.

In urban areas, much of the electrical distribution is underground, using copper or aluminum conductors, insulated cables, conduit networks, transformers, and switching equipment.

Surface access includes pad-mounted transformers, switch cabinets, underground vaults, utility poles, electric meters, and service panels.

Electrical systems rely on grounding and bonding for stability and safety. Grounding occurs at equipment transitions, exposed metallic equipment, transformers, cable transitions, fuses, meters, and service panels. These systems provide a common reference and safely dissipate energy into the earth.

For locators, grounding and bonding are important because electrical systems offer multiple paths for locating signals. Ground rods, bonded or concentric neutrals, metallic sheaths, and interconnected grounding can influence how a locate signal behaves. The signal may return through grounding conductors, neutral systems, or other bonded metallic structures, making interpretation more complex than on a continuous steel

pipeline. Nonetheless, underground electrical conductors and metallic components usually provide a very good path for electromagnetic locating when proper connection methods are used.

## **Telecommunications Networks**

Telecommunications infrastructure also uses a transmission and distribution model. Long-distance backbone networks connect major cities and hubs, while local networks deliver services to end users.

This infrastructure includes fiber optic cables, coaxial cable systems, and legacy copper cables. Access points include handholes, splice vaults, pedestals, fiber cabinets, and manholes.

Legacy copper cables and coaxial shields are conductive and can be located electromagnetically. Fiber optic cable is non-conductive unless metallic armor, shielding, or tracer elements are present, making system records, tracer systems, and surface features important for locating.

Telecommunications grounding and bonding also affect locating. Metallic shields, bond wires, cabinets, and grounding can create multiple conductive paths, so signals may not stay on the intended cable if bonded paths are interconnected. Understanding the layout and connection points improves accuracy.

## **Private Utility Systems**

Private underground utilities are utility systems that exist beyond the ownership or service responsibility of a public utility. In most cases, the point of ownership changes at a meter, service disconnect, property line, or another defined demarcation point established by the utility provider. Private utilities extend from that point into a residential, commercial, industrial, or institutional property. These private systems and associated equipment are typically owned and maintained by the property owner and are typically not marked by public utility operators when an 811 excavation notification is submitted.

These systems often include electrical distribution, natural gas piping, water and irrigation systems, sanitary sewer laterals, storm drainage, telecommunications, site lighting, fire protection systems, and a variety of privately installed process or facility-specific utilities. From a buried propane pipe to an electric dog fence, private utilities can be located beneath utility easements.

Private utilities are installed for the same reasons as public utilities: to deliver essential services where they are needed. The difference is ownership, not function. A private electrical feeder carries electricity just as a public distribution cable does. A private water service delivers water in the same manner as a municipal water main. Once these facilities are buried, they become part of the underground infrastructure serving that property and may remain in service for decades. As buildings are expanded, remodeled, or repurposed, additional private utilities are often added while older systems are abandoned in place, creating layers of active and inactive infrastructure beneath a single property.

Unlike public utility systems, private utilities are frequently absent from one-call locating requests because they are generally outside the responsibility of public utility owners.

Property owners may have construction drawings, as-built records, or maintenance documentation, but the accuracy and availability of those records can vary considerably. Many private utilities have been modified over many years by different contractors, and documentation is not always updated to reflect those changes. For this reason, excavating on private property often requires additional planning, investigation, and the use of qualified private utility locating services. Understanding where public ownership ends and private ownership begins is essential for safe excavation

## Abandoned Pipes, Cables and Conduits



**Abandoned underground utilities** are a normal consequence of how infrastructure evolves over time. As communities grow, utilities are expanded, upgraded, relocated, or replaced to meet increasing demand, improve reliability, or accommodate new construction. Water mains are upsized, gas distribution systems are modernized, electrical and telecommunications networks are rebuilt, and industrial facilities change ownership or cease operation. In many cases, the original pipe, cable, or conduit is disconnected from service and left in the ground because removing it would be significantly more expensive, disruptive, or hazardous than abandoning it in place. As a result, every generation of construction leaves behind portions of previous underground infrastructure.

An abandoned utility is simply a pipe, cable, conduit, or other underground facility that is no longer intended to provide service but remains buried. Although it no longer performs its original function, it continues to occupy physical space beneath the surface. Depending on its material, it may still be detectable with electromagnetic locating equipment, visible on historical records, or encountered during excavation. In many corridors, abandoned facilities exist alongside active infrastructure, creating multiple generations of utilities within the same right-of-way. This accumulation is especially common in older urban areas where decades of construction have repeatedly reused the same underground corridors. The presence of abandoned utilities is not, by itself, a problem. The challenge is that many of these facilities were never accurately documented when they were taken out of service, and some have been forgotten entirely. As records become outdated and experienced personnel retire, knowledge of these abandoned facilities is gradually lost. Future excavators and utility locators may encounter pipes or cables that have no identifiable owner, are absent from current maps, and cannot be readily classified as active or abandoned. This uncertainty increases excavation risk, delays construction, and reduces confidence in the accuracy of underground infrastructure records. Continuous

documentation of abandoned facilities when they are exposed offers an opportunity to improve those records for the benefit of every future excavation.

## Beneath Our Communities

Together, energy pipelines, natural gas systems, public water infrastructure, electrical power cables, and telecommunications networks form the hidden framework that supports modern communities. These systems span approximately 30 million miles beneath our public and private properties and easements.

Although each utility system serves a unique purpose, they share common patterns in production, transmission, distribution. Surface access, grounding, and material limitations impact how they can be located. Understanding these aspects is essential for anyone working around underground infrastructure.

Accurate locating and protection of these systems is crucial for maintaining safe, reliable utility services. Modern locators must not only operate equipment correctly, but also understand the engineering and construction characteristics of the infrastructure they are locating.

## Implications for Line Locators

For line locators, the key distinction is whether a system can carry an electromagnetic locating signal. Conductive systems include steel, ductile iron, and cast iron pipelines, copper communication cables, coaxial shields, electrical conductors, tracer wires, and metallic bond paths. Non-conductive systems include plastic water and gas pipes, clay, concrete, asbestos-cement pipes, and fiber optic cable without metallic components.

Non-conductive infrastructure is often installed with tracer wire or metallic detection elements. However, many older systems predate this practice, requiring locators to use indirect evidence, supplemental technologies, records, or selective exposure to identify these networks.

### 01 Beneath the Surface

*Underground systems, ownership, materials, and visible evidence*

## Exploring Underground Infrastructure Systems

What the Networks Show and What Line Locators Need to Know

Modern communities rely on large underground networks that deliver energy, water, wastewater service, electricity, and communications. Millions of miles of buried pipes, cables, conduits, and related structures extend beneath streets, neighborhoods, industrial corridors, and transportation rights-of-way across the United States.

Although each system serves a different purpose, most follow a similar arrangement. **A product or service begins at a source, moves through treatment or processing, enters a higher-capacity transmission network, and then branches into distribution and service systems that reach individual users.** Recognizing that arrangement helps the locator anticipate what may be present, where it may run, and which surface features may provide useful evidence.

## Energy Production and Gathering Systems

Oil and natural gas infrastructure begins at wells that bring resources from underground reservoirs to the surface. From the well, flow-lines move raw oil, natural gas, and associated liquids from individual wells into gathering

systems. Gathering pipelines then transport those products toward separation facilities, processing plants, storage sites, or transmission pipelines.

Production and gathering systems may include wellheads, flowlines, gathering pipelines, separators, processing equipment, valves, tanks, and storage facilities. Steel pipe is common because of its strength and ability to withstand pressure and temperature changes. Fiberglass-reinforced pipe and polyethylene may also be used where corrosion resistance or operating conditions favor a nonmetallic material. Electrical power and communications cables may be installed alongside production equipment to operate pumps, valves, instruments, and monitoring systems.

For the locator, the important question is not simply whether a pipeline exists. The material, joint style, electrical continuity, grounding, bonding, and availability of a tracer wire or other conductive element determine whether an electromagnetic locating signal can travel along the intended route.

## Transmission Pipelines

Transmission pipelines form the backbone of the energy transportation network. They move large volumes of crude oil, natural gas, and refined petroleum products between producing regions, processing facilities, refineries, storage terminals, industrial centers, and major markets.

These pipelines are commonly constructed from coated carbon steel, operate at higher pressures, and follow dedicated rights-of-way that may extend for hundreds or thousands of miles. Compressor stations support natural gas transmission, while pump stations support liquid pipelines. Valve stations, metering facilities, storage terminals, line markers, and maintained rights-of-way can provide surface evidence of the underground route.

Welded steel normally provides an excellent conductive path because the pipe sections form a nearly continuous metallic circuit with low resistance at the joints. Even so, coating condition, insulating fittings, cathodic-protection components, bonds, casings, branches, and connections to other structures can affect where locating current travels. The locator must follow and evaluate the response rather than assume that a strong signal remains only on the intended pipeline.

## Natural Gas Distribution Systems

After natural gas moves through a transmission pipeline, it enters a local distribution system that serves homes, businesses, and industrial customers. The transition commonly occurs at a city gate or similar station where pressure is reduced, flow is measured, and gas enters the local network. Distribution mains branch through communities, and service lines connect those mains to individual buildings and customer meters.

Surface evidence may include regulator stations, pressure-control cabinets, valve boxes, service shutoff valves, meter sets, risers, and warning markers. These features help establish a working picture of the system, but they do not prove the exact underground route between visible points.

### Natural Gas Pipe Materials

Gas-system materials vary with pressure, system age, installation practice, and local standards. Transmission pipelines are normally steel. Distribution systems may include steel, polyethylene, cast iron, or older wrought iron. Polyethylene is widely used because it is flexible and corrosion resistant, but it is nonconductive. A properly installed and accessible tracer wire or another traceable component is therefore needed for ordinary electromagnetic line locating.

## Public Works Piping Systems

Public works agencies operate extensive networks that deliver drinking water, collect wastewater, and manage stormwater. The supplied industry overview identifies approximately 2.2 million miles of drinking-water pipelines, about 800,000 miles of sanitary sewer pipelines, and roughly 3.5 million miles of storm-drainage systems across the United States. Together, these systems represent **about 6.5 million miles of buried public infrastructure**.

Water systems begin at rivers, reservoirs, wells, or other sources. Raw water moves toward treatment, and large transmission mains carry treated water into storage and local distribution systems. Distribution mains branch through communities and connect to services that supply individual customers. Wastewater systems collect flow from buildings and carry it toward treatment facilities. Storm systems collect runoff through inlets and catch basins and convey it through pipes, channels, detention structures, and outfalls.

Common surface evidence includes hydrants, valve boxes, meter boxes, manholes, cleanouts, lift stations, catch basins, storm inlets, headwalls, and outfalls. Each feature provides a clue. The locator must still evaluate records, expected system geometry, pipe material, depth, access, and field conditions before deciding how the underground route may continue.

## Pipe Materials and Joint Styles

Public water, wastewater, and storm systems contain many generations of construction. Materials may include cast iron, ductile iron, steel, PVC, HDPE, asbestos-cement, vitrified clay, reinforced concrete, concrete cylinder

pipe, and corrugated metal. The material often reflects the installation era, engineering standards, product carried, pressure, soil conditions, and repair history.

The supplied North American water-main overview estimates that cast iron and ductile iron each account for about 28 percent of installed water main, PVC about 22 percent, and asbestos-cement about 13 percent, with smaller shares of steel, HDPE, and concrete cylinder pipe. Cast iron and ductile iron together therefore represent roughly half of the installed water-main infrastructure described in that overview.

### **Conductive and Nonconductive Materials**

Steel, ductile iron, cast iron, copper, aluminum, and other metals are conductive, but a conductive material is not automatically a continuous locating path. Coatings, corrosion, repairs, insulating fittings, and joint construction can interrupt or redirect current. PVC, HDPE, asbestos-cement, clay, fiberglass, and ordinary concrete pipe do not provide a continuous metallic path for conventional electromagnetic line locating. These systems require a usable tracer wire, detectable component, sonde, acoustic method, radar response, reliable records, or physical exposure, depending on the facility and site.

### **Joint Styles and Electrical Continuity**

Welded steel pipe normally provides the most continuous conductive route. Bell-and-spigot joints are common in cast iron, ductile iron, clay, and some concrete systems. Older metallic installations may use lead and oakum, while modern push-on joints commonly use elastomeric gaskets. Mechanical joints use a bolted gland and gasket. Sleeve couplings may be found on asbestos-cement pipe and at repairs. HDPE sections may be heat-fused into a continuous pipe, but the fused plastic remains electrically nonconductive.

Gaskets, mechanical connections, corrosion, replacement sections, and repairs can add resistance or break electrical continuity. A metallic pipe can therefore produce a weak or interrupted electromagnetic response even though the pipe itself is conductive. The locator must distinguish pipe material from the condition of the complete locatable circuit.

## **Electrical Power Cable Systems**

The electric power grid also follows a transmission-and-distribution arrangement. Power is produced by generation facilities, moved over long distances through high-voltage transmission lines, and delivered to substations. From the substation, primary distribution circuits carry power toward local transformers. Transformers reduce voltage for secondary conductors and services that supply homes, businesses, and other loads.

Underground electrical systems may include copper or aluminum conductors, insulated cable, metallic neutrals or shields, conduit, duct banks, vaults, transformers, switches, and protective equipment. Surface evidence includes pad-mounted transformers, switch cabinets, risers, utility poles, underground vaults, pull boxes, meters, and service panels.

### **Grounding and Bonding**

Electrical systems use grounding and bonding for safety, fault-current paths, voltage control, and equipment performance. Grounding and bonding may be present at overhead-to-underground transitions, transformers, switches, protective devices, meter sets, service panels, and exposed metallic equipment. These connections can give locating current additional paths. They may help complete a circuit, but they can also allow current to divide onto other bonded conductors.

## **Telecommunications Networks**

Telecommunications networks use long-distance backbone routes and local distribution systems to move voice, data, and video services. Underground facilities may include fiber-optic cables, coaxial cables, legacy copper communication cables, innerduct, conduit, duct banks, handholes, splice vaults, pedestals, cabinets, and communication manholes.

Copper conductors, coaxial shields, metallic armor, messengers, and installed tracer wires may provide a conductive path for electromagnetic locating. Glass or plastic optical fiber is nonconductive. A fiber route without a usable metallic component cannot be traced merely because data is moving through the cable. Records, visible structures, electronic markers, radar, safe access to a traceable element, and physical exposure may all become important.

## **What This Means for the Line Locator**

The most important first distinction is whether the system provides a usable conductive path. Welded steel pipelines, continuous cable conductors, cable shields, neutrals, and sound tracer wires often carry locate current well. Gasketed iron pipe, corroded connections, insulating fittings, broken tracer wires, and poorly grounded conductors may limit the distance and reliability of the response. Plastic, clay, concrete, fiberglass, and unarmored fiber-optic facilities require another traceable element or another appropriate locating method.

System layout also matters. Transmission lines, distribution mains, services, branches, grounds, bonds, crossings, and shared structures can divide or redirect current. The receiver guides the locator to a signal response;

the locator interprets that response using records, surface evidence, system knowledge, repeated measurements, and verification.

A ground mark remains an educated estimate of the top dead center of an assumed-to-be-round signal field. It does not prove the exact position, depth, size, material, identity, or operating status of the buried facility. We do not locate the facility itself until it has been safely exposed and observed.

| SYSTEM                     | COMMON TRACEABLE PATH                                          | LOCATING CONSIDERATIONS                                                                                       |
|----------------------------|----------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------|
| Energy transmission        | Welded steel pipeline                                          | Bonds, insulating fittings, casings, branches, and cathodic-protection components can redirect current.       |
| Gas distribution           | Steel main or service; tracer wire with polyethylene           | Plastic is nonconductive; older iron joints, repairs and damaged tracer wire can interrupt continuity.        |
| Water wastewater and storm | Continuous metal pipe or installed tracer wire                 | Gasketed joints, mixed materials, nonmetallic pipe and limited access often restrict electromagnetic tracing. |
| Electric power             | Conductors, neutrals, shields, and bonded metallic components  | Grounds and bonds can divide current onto other conductors and structures.                                    |
| Telecommunications         | Copper pairs, coaxial shield, armor, messenger, or tracer wire | Optical fiber is nonconductive; shared duct and bonded components can complicate route interpretation.        |

## 02 Locating Technologies

*What each method measures, where it helps, and where it can mislead*

- **Electromagnetic pipe and cable locators:** Apply or detect a selected frequency on a conductive path. Common application methods include direct connection, clamp induction, and broadcast induction.
- **Sondes and detectable devices:** Provide a traceable signal from inside a nonmetallic pipe, duct, drain, conduit, or drilling assembly.
- **Ferromagnetic locators:** Respond to changes in the Earth's magnetic field caused by iron and steel objects such as property pins, valve covers, and selected buried components.
- **Ground-penetrating radar and scanning systems:** Transmit electromagnetic energy into a material and display reflections from contrasts below the surface; interpretation and site conditions strongly affect results.
- **Vacuum excavation and safe exposure:** Provide physical verification of a facility's actual position, depth, size, material, and condition before critical excavation decisions.

## Exploring Locating Technologies

### *Advantages Limitations and Appropriate Applications*

Above the surface, people use electromagnetic and acoustic waves for navigation and ranging. Our eyes detect visible light, a narrow portion of the electromagnetic spectrum, and use direction, apparent size, motion, focus, and the slightly different view from each eye to judge position and distance. Our ears detect acoustic waves and compare differences in arrival time and intensity to estimate the direction and distance of a sound source.

Electronic locating technologies extend those same general ideas beyond the visible surface. Sensors detect energy associated with something underground, while the instrument converts the response into information that can guide the operator and help estimate position or distance. Electromagnetic pipe and cable locators operate at frequencies far below visible light. Ground penetrating radar uses higher radio frequencies but remains far below visible light. Acoustic pipe locators use mechanical vibration that can travel through a pipe, the material inside it, or the surrounding environment. The technology detects the energy; the operator interprets what that response can reasonably represent.

## Technology Comparison

| Technology                  | Best Application and Principal Limitation                                                                     |
|-----------------------------|---------------------------------------------------------------------------------------------------------------|
| EM pipe and cable locator   | A transmitter establishes or identifies a signal source and a receiver detects the resulting signal field.    |
| Direct clamp and broadcast  | Three active transmitter application methods that provide different levels of target control and selectivity. |
| Passive signals             | Detects electromagnetic signals already present on conductive facilities without using the transmitter.       |
| GPS and GIS integration     | Records the geographic position and related information associated with an interpreted receiver response.     |
| Sonde signal beacon         | Locates a moving point source inside a nonconductive pipe duct conduit sewer or tool.                         |
| Detectable rod or fish tape | Creates a temporary traceable conductive path inside a nonconductive facility that provides safe access.      |
| EM and RFID markers         | Identifies an installed underground reference point but does not trace the route between markers.             |
| Ground penetrating radar    | Detects reflected electromagnetic energy from subsurface changes when conditions are suitable.                |
| Acoustic pipe locating      | Detects mechanical vibration traveling from pipe to surface or from surface to the pipe.                      |

## EM Pipe and Cable Locators Signal Transmitter and Signal Receiver

An electromagnetic pipe and cable locator normally includes two major components. The signal transmitter establishes an alternating electrical signal on or near a conductive path. Current associated with that path creates a changing signal field around the conductor. The signal receiver detects the field and guides the operator toward its apparent center. The receiver does not see the pipe or cable and does not independently identify the utility; it responds to the field created by current traveling through the electrical circuit.

### *Illustration of a signal field around a conductor.*

This technology is well suited to metallic piping with usable electrical continuity, cable conductors, metallic shields, neutrals, and tracer wires. Welded steel normally provides a continuous path, while mechanical and gasketed joints in ductile or cast iron may resist current. Plastic pipe requires a usable tracer wire or another conductive component. The principal advantage is the ability to trace a conductive route continuously. The principal limitation is that the receiver follows current, which can divide at branches, follow bonds, transfer to nearby conductors, or leave the intended path.

## Basic EM Transmitter Application Methods and Principles

Active electromagnetic locating intentionally establishes alternating current associated with a conductive target. Direct connection, clamp induction, and broadcast induction use different ways to create that current. Each method requires a usable electrical path and provides a different level of control over which conductors carry the signal. These are application principles rather than operating instructions.

### **Direct Connection**

Direct connection places one transmitter lead on an accessible conductive part of the target while the other lead completes the circuit through a temporary ground stake or another approved return path. It usually provides the greatest control because the transmitter is electrically connected to the intended conductor. Its limitations include the need for safe access, a complete circuit, and the possibility that current will divide through bonds, branches, grounds, or other connected conductors.

## Clamp Induction

Clamp induction uses a signal clamp placed around an accessible conductor. The changing magnetic field produced by the clamp induces current on the conductor without requiring a bare-metal connection. The method is useful when direct electrical contact is unavailable or undesirable, but the conductor still needs a complete path beyond the clamp. Current may also travel through connected shields, neutrals, bonds, or other conductors.

## Broadcast Induction

Broadcast induction places the transmitter above the ground and uses its internal antenna to induce current on conductive paths within the transmitter field. It is useful when no connection point is available. It offers the least target selectivity because more than one nearby conductor may receive the signal, and the receiver can also respond directly to the transmitter field when used too close to the transmitter.

## Passive Signals

Passive locating uses electromagnetic signals already present on conductive facilities instead of a signal intentionally established by the transmitter. Power modes may detect 50- or 60-hertz energy and related harmonics. Cathodic-protection current on some steel systems may produce detectable 120-hertz components, and radio modes may detect broadcast energy coupled onto long conductors. Passive modes are useful for searching an area, but the source and identity of a detected signal may be uncertain. A passive response is evidence to investigate, not automatic confirmation of a particular utility.

## Map GPS Points and Other GIS Information with Signal Receivers

Some signal receivers can be paired with GNSS, RTK, mobile mapping, or GIS systems. The receiver supplies an interpreted underground position and may also supply estimated depth, signal information, time, and utility attributes. The positioning system records the geographic location of its own antenna or measured point. Combining the information can preserve a detected route, but precise coordinates do not correct an incorrect locating interpretation. Detection and geographic positioning remain separate measurements.

## Detectable Sonde Signal Beacons

A sonde is a small transmitter that creates a localized signal beacon. It may be pushed through a pipe on a flexible rod, carried by an inspection camera, incorporated into a drilling head, or moved through another suitable facility. A compatible receiver estimates the sonde's position and depth from the surface. Because the signal comes from the sonde, the pipe itself does not have to be conductive.

The receiver locates the beacon rather than the pipe wall or a continuous line signal. Successive sonde positions can help establish a route, but the relationship between the sonde and the facility centerline depends on where the sonde sits inside the pipe. Access, bends, depth, orientation, obstructions, receiver compatibility, and nearby interference affect the response.

## Rodding with a Detectable Rod or Fish Tape

A detectable rod, conductive fish tape, or similar device can be inserted into a nonconductive pipe or conduit and connected to an electromagnetic transmitter. Current on the inserted conductor creates a line-type signal field that can be traced from the surface. The method temporarily provides a detectable conductive path; it does not make the facility itself conductive.

The response represents the position of the inserted device. Access, bends, blockages, diameter changes, friction, insertion distance, and the position of the rod inside the pipe limit what can be concluded. A sonde, rod, or fish tape must never be inserted into an active hazardous-product line or a system that is not designed and approved for internal access.

## EM Markers and RFID

Electronic markers are detectable references installed near valves, fittings, service connections, splices, crossings, changes in direction, and other important underground points. Passive markers return a recognizable response when energized by compatible locating equipment. RFID-enabled markers can also return an identifier or stored information when read by a compatible system.

A marker identifies its installed position. It does not trace the facility between markers and does not prove that it remains correctly associated with the intended feature. Performance depends on marker type, compatible equipment, installation depth, orientation where applicable, surrounding material, and the accuracy of the original placement.

## Ground Penetrating Radar

Ground penetrating radar transmits electromagnetic pulses into the ground and records energy reflected by changes in subsurface electrical properties. Pipes, cables, voids, pavement layers, soil boundaries, disturbed trenches, reinforcement, and moisture changes may produce responses. GPR does not require current on the target and can investigate conductive or nonconductive materials when soil and surface conditions are suitable.

A radar response identifies a change below the surface; it does not identify the object as a particular utility. Depth is estimated from radar travel time and an assumed or calibrated propagation velocity. Conductive soil,

reinforcement, surface clutter, standing water, access, target orientation, depth, and material contrast can limit the result. The absence of a recognizable response does not establish that an area is clear.

## **Acoustic Wave Generation and Detection for Buried Nonconductive Pipes**

Acoustic and mechanical locating uses vibration rather than locating current. Mechanical energy must travel through matter, including a pipe, the material inside it, the soil, pavement, or another connected structure. These methods can provide evidence of nonconductive piping that cannot carry a conventional electromagnetic locating signal. Pipe material, joints, fittings, water, soil, distance, source coupling, sensor contact, and background noise all affect the response.

### **Vibrate the Pipe and Listen at the Surface**

A controlled vibration source is attached or coupled to an accessible part of the pipe. The vibration travels along the pipe and transfers energy into the surrounding material. A sensor moved across the surface listens for or measures the response. A repeatable pattern can help indicate a route, but joints, alternate paths, pavement, nearby structures, and changing surface contact can shift or weaken the response.

### **Vibrate the Surface and Listen at the Pipe**

The source and sensor can also be reversed. A controlled vibration is introduced at the surface while a sensor at an accessible pipe, valve, meter, or other connection listens for the energy that reaches the facility. This arrangement can help test whether a suspected surface position is mechanically connected to the pipe. The response depends on soil and pavement conditions, distance, pipe access, background vibration, and the quality of contact at both ends.

No locating technology works under every condition, and no instrument response automatically identifies the object that caused it. Each method provides a different form of evidence. The useful conclusion must remain within the physical limits of the technology that produced the response.

### **From Detection to Observation**

## **PHYSICAL EXPOSURE — THE POINT WHERE ESTIMATION BECOMES OBSERVATION**

Electronic line locating, GPR, acoustic detection, magnetic locating, drawings, measurements, and surface evidence can progressively narrow uncertainty. Physical exposure changes the investigation because the underground facility can finally be directly observed at the exposed location. The exposed point provides physical evidence that can be compared with the marks, maps, electronic response, estimated depth, and other information collected before excavation.

Vacuum excavation technologies are among the safer methods available for exposing underground facilities when used under appropriate procedures. Depending on the equipment, pressurized water or air can be used for soil displacement while vacuum removes loosened material. Appropriate hand tools can also be used for exposure when conditions and procedures allow. The purpose is not to promote one machine or one excavation medium; it is to safely reveal the facility so its actual location can be observed.

## **DOCUMENT WHAT BECOMES VISIBLE**

Exposure creates an opportunity to improve the underground record instead of allowing the information to disappear when the excavation is closed. Once visible, the facility can be identified and its actual horizontal position, depth, material, diameter, configuration, tracer system, casing, fittings, crossings, and other relevant characteristics can be documented.

- Photograph the exposed facility with recognizable references and enough context to understand where the photograph was taken.
- Record measurements from clearly identified permanent or recoverable reference points.
- Capture coordinates when appropriate and document the method used to obtain them.
- Record discrepancies between the observed facility and existing maps, records, locate marks, or expected route.
- Install or document detectable references, tracer systems, or electronic markers when procedures permit and future detection would benefit.
- Return verified information to the record system so the next investigation begins with better evidence.

## **EQUIPMENT CARE IS PART OF MEASUREMENT RELIABILITY**

Locating equipment should be inspected before it is depended upon. Batteries, housings, displays, connectors, cables, clamps, sensors, sondes, GPR components, and accessories are all part of the measurement system. Equipment that turns on should not automatically be assumed to be functioning normally. A damaged accessory can create misleading information that appears to be an underground problem.

## **DIRECT CONNECTION LEADS AND CLIPS**

Direct Connection leads are repeatedly stretched, coiled, connected, and disconnected. Common failure points are at or near the clips and near the connection plug or molded junction where the connection wires come together. Repeated flexing can break a conductor internally even when the exterior insulation still appears usable. An intermittent lead can temporarily make or break continuity as it moves, causing transmitter current to change unexpectedly.

- Inspect clips for corrosion, damaged jaws, weak springs, loose connections, and contaminated contact surfaces.

- If transmitter current is low, unstable, or changes as the leads move, check the leads, clips, plugs, and connection points before assuming the problem is underground.
- Keep equipment clean and secure during transportation. Follow manufacturer requirements for batteries, environmental ratings, calibration, inspection, and service.
- Protect instruments from rain, moisture, mud, damaged connectors, and improper storage. Wet equipment should be inspected, cleaned, and dried as appropriate before storage.

### 03 Applied Science

#### *Current, circuits, induction, receiver antennas, and frequency*

*A practical explanation of the physics behind the locate—not a collection of memorized button sequences.*

A signal transmitter and receiver operate through a connected series of electrical and electromagnetic events. The electrical portion begins inside the transmitter and continues through the connected circuit. The electromagnetic portion begins when alternating current produces a changing signal field around a conductor. Understanding the process in this order explains what the equipment is producing, what the receiver is detecting, and why site conditions affect the locate.

## Electrical Charge and Current

Matter contains positively charged protons and negatively charged electrons. In conductive materials, some electrons can move through the material more freely than they can in an insulating material. Metals such as copper, aluminum, and steel are conductive because their atomic structure permits this movement.

Electrical current is the organized movement of electric charge through a conductive path. In a metallic pipe, cable, or wire, the moving charges are electrons. The electrons are already present in the conductor. The transmitter does not fill the conductor with new electrons. It creates an electrical pressure that causes the available electrons to move.

The individual electrons move only a very short distance during each alternating cycle. The usable effect is transferred along the conductor because neighboring charges respond throughout the connected path. This is similar to pushing one ball against the end of a tightly packed row of balls. The first ball does not travel to the opposite end, but the force is transferred through the row.

Current is sometimes described as traveling only along the surface of a conductor. That description is incomplete. Alternating current can occupy the conductor's cross-section, although increasing frequency causes more current to become concentrated toward the outer portion. This behavior is called skin effect. Its practical influence depends on frequency, conductor size, material, and construction.

## Voltage Places Charge in Motion

Voltage is the electrical pressure or difference in electrical potential between two points. Current can move when a conductive path connects points having different electrical potentials.

During direct connection, the transmitter establishes an alternating voltage difference between its two output terminals. One lead connects to the intended conductor, and the other connects to a temporary ground stake or another approved return connection. This voltage difference places charge into alternating motion throughout the completed circuit. Voltage is the pressure attempting to move the charge. Current is the resulting movement. Resistance and impedance oppose that movement. These quantities are related, but they are not interchangeable.

## Alternating Current and Frequency

A line-locating transmitter is an alternating-current signal source. It repeatedly reverses electrical polarity, causing charge within the circuit to move back and forth. The current moves in one direction during one half of the cycle and reverses during the other half.

One complete movement in one direction and back again is one cycle. Frequency describes the number of complete cycles occurring each second. One cycle per second equals one hertz, written as 1 Hz. A frequency of 512 Hz completes 512 cycles each second. A frequency of 33 kHz completes 33,000 cycles each second.

The current passes through zero as it changes direction. It then increases in the opposite direction, decreases, and passes through zero again. This repeating electrical vibration creates a changing signal field around the conductor at the same frequency.

The transmitter and receiver must be set to matching frequencies. The receiver is designed to recognize a field changing at the selected rate. It does not respond because it recognizes the buried pipe or cable. It responds because it detects energy at the expected frequency.

## The Complete Locatable Circuit

Current requires a complete circuit. During direct connection, the circuit normally includes the transmitter, connection leads, connection point, intended conductive pipe, cable, or tracer wire, grounding points and distributed contact with the earth, the earth-return path, and the temporary ground stake.

Current leaves the transmitter through one lead, enters the connected conductor, travels along the conductive system, transfers into the earth, and returns through the soil to the temporary ground stake. It then passes through

the second lead and returns to the transmitter. The current moving along the connected conductor is the applied current. Current returning through the earth is return current. These are not separate electrical supplies. They are portions of the same completed circuit.

Current does not take only one path of least resistance. It divides among every available conductive path. More current travels through paths having lower opposition, while less current travels through paths having greater opposition. If the target is connected to other pipes, cables, grounding systems, or structures, some applied current may divide onto those paths.

## **Conductivity and Continuity**

Conductivity describes how readily a material permits current to move. Copper and aluminum are highly conductive. Steel is conductive but offers greater resistance than copper or aluminum of comparable dimensions. Ductile iron and cast iron are conductive, but mechanical joints, gaskets, corrosion, and repairs can interrupt or restrict electrical continuity.

Plastic, fiberglass, clay, concrete, and similar materials are poor electrical conductors. A nonmetallic pipe normally requires a properly installed tracer wire, detectable tape, sonde, or another locating method. A tracer wire must have usable continuity and an effective return path before it can carry enough alternating current to create a detectable signal field.

Continuity means that the circuit provides an unbroken conductive path. A closed circuit permits current to travel out from the transmitter and return. An open circuit contains a break that restricts or stops current. Broken tracer wires, insulated joints, disconnected bonding wires, corrosion, loose clips, and poor connection points can create open or high-impedance conditions.

A circuit does not have to be perfect before some current can move. Alternating current may transfer through capacitance across small gaps or between nearby conductors. This is more likely at higher frequencies. However, the transferred current may be weak or may appear on a conductor other than the intended target.

## **The Earth as Part of the Circuit**

The earth is a conductor, but its conductivity changes with location and conditions. Moisture, dissolved minerals, soil type, compaction, temperature, and the contact area of the temporary ground stake all affect the earth-return path.

Moist soil containing dissolved minerals usually conducts better than dry sand, gravel, frozen soil, or highly resistive material. Improving ground-stake contact can reduce circuit opposition and allow the transmitter to produce more usable current. Placement also matters. The temporary ground stake should be positioned away from the target and other buried conductors whenever practical so that return current is not encouraged to travel through an unwanted utility.

The return current spreads through a volume of earth rather than following a narrow, visible line. If another grounded conductor provides an easier return route, some current may enter that conductor and create a detectable signal field around it.

## **Current Voltage Resistance and Impedance**

Ohm's law describes the relationship among voltage, current, and resistance in a basic electrical circuit. Increasing voltage can increase current when resistance remains unchanged. Increasing resistance reduces current when voltage remains unchanged.

A locating circuit uses alternating current, so its total opposition is more accurately called impedance. Impedance includes ordinary resistance along with effects caused by capacitance and inductance. The transmitter evaluates the connected circuit and adjusts its output in an attempt to drive usable current.

A transmitter current reading indicates what the transmitter measures at the connection point. It does not prove that the same amount of current remains on the target at every location. Current can leave the conductor, divide at branches, transfer to other conductors, or weaken as distance from the transmitter increases.

Increasing transmitter power may increase circuit voltage and current, producing a stronger field. However, additional power cannot repair broken continuity or force all current to remain on the intended path. More power can also strengthen current on unwanted conductors if the circuit allows the signal to divide.

## **From Electricity to Electromagnetic Induction**

Moving electrical charge produces a magnetic field around the conductor. When the current is alternating, the direction and strength of that field continually change. This changing field is the signal field detected during an active locate.

Direct connection places current onto the conductor through physical contact. Clamp induction uses a changing magnetic field to induce current onto a conductor passing through the clamp. Broadcast induction produces a field in the surrounding area, which can induce current onto one or more buried conductors.

The process can also operate in the opposite direction. A changing magnetic field passing through a conductor can induce alternating voltage and current in that conductor. This is electromagnetic induction. Alternating current creates a changing signal field, and a changing signal field can create alternating current in another conductor.

The receiver uses this same principle. The changing signal field passes through coils inside the instrument and induces small electrical responses. The receiver processes those responses to display signal strength, directional information, Peak or Null response, estimated depth, and, on many models, an estimated current measurement.

## Transfers and Transforms in the Form of Waves

**An electric guitar pickup** is essentially a wave sensor that converts the mechanical vibrations of the guitar strings into magnetic vibrations causing an electrical signal/signal. The pickup is a type of transducer that uses electromagnetic induction to generate an alternating current (AC) signal, which can then be amplified and processed back to sound by running the electrical vibrations to a coil of copper wire surrounding a stationary magnet un attached to a paper cup, comma commonly known speaker.

Basic Components of a Pickup

1. Pickup Magnet(s) – Typically, pickups have a permanent magnet made of materials like Alnico or ceramic. The magnet creates a static magnetic field around the strings.
2. Wire Coil loops – A thin wire (usually copper) is wound around the magnet thousands of times, forming an inductor.
3. Steel Guitar Strings (Ferromagnetic Material) – The strings must be made of a material that can be influenced by a magnetic field, such as steel or nickel.

How It Works

1. When a guitar string vibrates within the pickup's magnetic field, it disrupts the field by changing the magnetic flux.
2. This changing flux induces an alternating current in the coil (based on Faraday's Law of Electromagnetic Induction).
3. The alternating current (AC) signal corresponds to the frequency and amplitude of the vibrating string.
4. The signal is then sent to an amplifier, which increases its strength before it's output through a speaker.

## How the Receiver Uses Its Antennas

The receiving elements inside a pipe and cable locator are coils, often described as antennas. A changing signal field passing through a coil induces a small voltage in the coil. The amount of response depends on field strength, frequency, the coil's orientation, and its distance from the conductor. Receiver designs vary by manufacturer. A traditional receiver commonly contains two horizontal Peak antennas and one vertical Null antenna, while newer instruments may use additional screened or multi-axis coils. A displayed locate mode may combine several coils through digital processing rather than use only one physical antenna.

### Lower Horizontal Peak Antenna

The lower horizontal antenna is the primary pinpointing antenna in Peak mode. The word horizontal describes its sensing axis, not simply the way the coil appears inside the housing. When the receiver is held vertically and its antenna is oriented across the route of the conductor, the changing field produces its strongest usable response as the antenna passes over the apparent center of an undistorted field.

The lower antenna is placed close to the ground so it receives the strongest available field. As the receiver approaches the apparent center, the displayed response rises to a maximum. After the receiver crosses the center, the response decreases. The Peak is not a view of the pipe. It is the location where the selected antenna and processing mode measure the greatest field response. A deeper conductor produces a broader Peak because the field changes more gradually across the surface.

### Upper Horizontal Peak Antenna

The upper horizontal antenna has the same general sensing orientation as the lower Peak antenna but is mounted a known distance higher in the receiver. It measures the same signal field from a greater distance. The lower antenna normally receives a stronger response than the upper antenna because it is closer to the field source.

The receiver compares the responses from the upper and lower antennas to estimate the distance to the apparent center of the field. This is similar to depth perception: two measurements taken from known positions provide information that one measurement alone cannot provide. The calculation assumes that the receiver is correctly oriented above a single conductor and that the signal field is reasonably circular. Distortion, multiple conductors carrying the frequency, nearby metal, bends, tees, laterals, and crossings can produce an incorrect depth. Receiver current measurements also use field strength and apparent depth to estimate current on the conductor; they are not direct measurements of current flowing through a connected meter.

### Vertical Null Antenna

The Null antenna has a vertical sensing axis and responds to a different component of the signal field. On an ideal circular field, the vertical component changes direction as the receiver crosses the conductor and passes through a minimum directly above the field center. The display therefore falls toward a Null at the apparent center and increases on either side. Direction arrows may reverse as the receiver crosses this point.

A Null response can appear sharper than a Peak response, but that sharpness does not make it more reliable in a distorted field. The Null position is easily pulled away from the conductor by current on nearby conductors or by an uneven field. When Peak and Null do not agree, the separation is evidence of distortion. Pinpoint and mark from the

Peak response, then use the disagreement as a warning that the apparent center and electronic depth may be displaced.

### Directional and Multi Axis Antenna Arrays

Some receivers contain additional coils or paired three-axis antenna sets. These instruments measure more than one component of the field and use the comparison to operate left-right guidance arrows, a directional compass, broad search modes, distortion indicators, or three-dimensional field displays. The exact number and arrangement of coils are manufacturer-specific.

Guidance information helps the locator approach and follow the signal path, but the final center should still be established with the Peak response. A broad Peak or search mode may use one antenna or combine coils to increase sensitivity over a wider area. This can help find a weak or deep response, but the wider response is less precise for final pinpointing. In sonde mode, the same receiving array is processed differently because a sonde produces a dipole field with a central Peak and two smaller side responses rather than the continuous field pattern produced by current on a long conductor.

### What the Antennas Can and Cannot Establish

The antennas measure the signal field that reaches the receiver. They cannot determine whether that field belongs to the intended pipe, cable, or tracer wire. A strong Peak can be produced by an unwanted conductor carrying more of the applied current. A stable compass can follow the wrong parallel line. Peak and Null agreement improves confidence that the local field is reasonably shaped, but it does not prove utility identity.

The receiver guides; the locator interprets. The ground mark is an educated estimate of the top dead center of an assumed-to-be-round signal field. The trace must still be compared with connection points, records, visible structures, current behavior, reasonable depth, and the expected utility route. Safe exposure provides confirmation.

*Relative frequency ranges used by electromagnetic pipe-and-cable locators and utility-locating GPR. Not to scale.*

## Frequency Choices

Frequency changes how readily the applied current follows the intended conductor, crosses poor continuity through capacitance, transfers to nearby conductors, and weakens with distance. Frequency is not transmitter power. Selecting a higher frequency does not automatically place more current on the intended utility, and a stronger receiver display does not prove that the response belongs to the target.

The most controlled approach is to use the lowest frequency that produces a stable and traceable response. Begin with a very low or low-to-mid frequency when direct connection, conductor continuity, and the earth return are good. Increase frequency when the lower choice will not produce usable current, when a clamp requires it, or when broadcast induction is necessary. Each increase trades some selectivity and distance for easier coupling.

| Frequency band | Typical range | Advantages and common uses                                                                                                                                                                                     | Limitations                                                                                                                                                                                                                                 |
|----------------|---------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Very low       | 256 to 640 Hz | Best control on long, continuous, well-bonded metallic paths. Travels farther and is least likely to couple onto nearby conductors. Useful for direct connection and supported current-direction applications. | Requires good continuity and an effective return path. Often weak across insulated joints, corroded connections, or broken tracer wires. Normally unsuitable for broadcast induction and may fall within bands affected by power harmonics. |
| Low to mid     | 1 to 10 kHz   | Good general-purpose balance of distance, selectivity, and coupling. Effective for direct connection and supported clamp methods. Often works well on continuous cables, coated steel, and bonded systems.     | May not transfer adequately across resistant joints or onto small, poorly grounded conductors. Some clamps and broadcast transmitters require a higher available frequency.                                                                 |
| High           | 20 to 44 kHz  | Couples readily through clamps and broadcast induction. Useful on small-diameter cables, moderately poor continuity, and circuits that do not accept a lower                                                   | Transfers more easily to parallel utilities, grounds, fences, and other conductors. Usually loses strength over a shorter distance and increases the risk of tracing an                                                                     |

| Frequency band   | Typical range                 | Advantages and common uses                                                                                                                                                                                                       | Limitations                                                                                                                                                                                                                                                                                                |
|------------------|-------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                  |                               | frequency well. Common for initial searches.                                                                                                                                                                                     | unintended path.                                                                                                                                                                                                                                                                                           |
| <b>Very high</b> | Above 45 kHz to about 480 kHz | Useful for difficult short targets, very small conductors, high-impedance circuits, dry soil, and induction where lower choices will not establish a usable response. Examples include 65, 83, 131, and 200 kHz where supported. | Produces the greatest unwanted coupling and normally attenuates fastest. It can energize several nearby conductors and create a strong but misleading response. Many transmitters reduce available output above 45 kHz, often to about 1 watt; the equipment rating and regulatory region must be checked. |

The ranges in the table are practical teaching categories rather than universal equipment settings. Available frequencies, clamp performance, transmitter power, and regulatory limits vary by model and region. The locator must know which frequencies the specific transmitter can deliver through direct connection, clamp, and broadcast induction.

Frequency should be judged by what happens along the trace. After changing frequency, repeat the sweep and compare route, Peak position, Null agreement, receiver-estimated current, signal strength, and depth behavior. If a higher frequency produces several responses, abrupt route changes, or growing Peak and Null disagreement, the added coupling may have reduced confidence rather than improved the locate. Use the lowest effective frequency, maintain control of the locatable circuit, and pinpoint before painting.

#### 04 Interpreting Locate Current *Transmitter output, receiver estimates, current division, and field trends*

##### Understanding Transmitter and Receiver Current Indications

Electromagnetic pipe-and-cable locating depends on alternating current traveling through a conductive circuit. The transmitter applies current to a pipe, cable, tracer wire or other conductor. That current produces a signal field around the conductor. The receiver detects the signal field and guides the locator along its path.

Some transmitters display current in milliamps, while others provide a visual or audio response. Receivers may also display a value labeled in milliamps, but the transmitter and receiver are not making the same measurement.

The transmitter shows how the complete connected circuit is responding at the signal source. Depending on the model, it may display current in milliamps or provide a relative visual or audio response. The receiver provides an estimated locate-current reading associated with the signal field at one location along the route. These are different kinds of information and should not be expected to match.

| COMPARISON             | TRANSMITTER INDICATION                                                                       | RECEIVER CURRENT                                                                        |
|------------------------|----------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------|
| What it is             | Measured current or a relative visual or audio response from the complete connected circuit. | Calculated estimate associated with the signal field detected at one location.          |
| Where it applies       | At the signal application point between the transmitter's output leads.                      | At the receiver's position over the detected conductor.                                 |
| What it helps evaluate | Connection quality, circuit impedance, return path, frequency and available output.          | Probable target, current division and changes along the route.                          |
| Useful comparison      | Compare the response before and after changing one circuit condition.                        | Compare receiver readings taken along the same route with consistent technique.         |
| Important limit        | Does not show how current divides or how much remains on the target farther away.            | Is not a direct electrical measurement and can be affected by distorted field geometry. |

**Essential distinction** The transmitter indicates how the complete circuit is responding at the source. The receiver estimates locate current associated with the detected signal field at its position.

##### What the Transmitter Indication Shows

Some transmitters provide a bar, a connection-quality indicator, or an audio response. Audio behavior varies by model. On some units, beeps repeat faster as more current is delivered; on others, a steady tone changes pitch,

and on some models the pitch gets lower as current increases. The Metrotech 810 is an example of a transmitter whose beeps speed up with increased current. Follow the equipment instructions to interpret a specific display or audio response. None of these indications shows how much current remains on the target farther along the route.

A milliamp display reports measured current at the source. A visual bar or audio response generally indicates a relative change in circuit response, not necessarily a calibrated measurement. The way each indication works varies by model.

**Interpret each change according to the specific transmitter. A faster beep pattern or a lower-pitched steady tone may indicate more current on a model designed to signal that way; another model may use a different pattern. Neither response proves that current is staying on the intended target.**

### Compare the Transmitter Indication Before and After a Change

Do not chase a particular current value or audio pattern. Note the transmitter's stable starting display or response, change one circuit condition, and compare again. This comparison is useful only when the other conditions remain the same.

- Note the original value, bar, or audio response.
- Change one condition: connection contact, temporary ground-stake contact, stake position, frequency or output.
- Allow the response to stabilize, compare it with the baseline and then use the receiver to determine where the signal is traveling.

| MORE CURRENT OR FASTER BEEP                                                                                                                      | LESS CURRENT OR SLOWER BEEP                                                                                                                                          |
|--------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Usually means the complete circuit has lower impedance and is accepting current more easily.                                                     | Usually means the complete circuit has higher impedance and is accepting less current.                                                                               |
| May result from cleaner contact, better temporary ground-stake contact, moist soil, good continuity or an effective return path.                 | May result from poor contact, dry or resistive soil, insulated joints, a broken or ungrounded tracer wire, a small high-impedance target or an unsuitable frequency. |
| Caution: bonds, nearby grounds, branches, faults, a nearby ground stake, lead coupling or higher frequency may create additional unwanted paths. | Caution: a modest stable response on an isolated target can be more dependable than a larger response divided among several conductors.                              |

### What the Transmitter Cannot Show

The transmitter cannot show where current goes after it leaves the connection point. If it displays 100 mA, that is the total current delivered into the complete circuit at that moment. Current may continue on the target, divide at a branch, transfer through a bond, follow another conductor, or return through the earth and other available paths. The transmitter does not show how much current remains on the target at the excavation area.

**Field rule Use the transmitter indication to judge how the complete circuit is accepting current. Use the receiver to evaluate the signal along the route. The objective is the best controlled signal on the intended target, not simply the highest number or most pronounced audio response.**

## Frequency Changes the Current Path

Frequency affects circuit impedance and how readily current transfers between conductive structures and the surrounding earth. Lower frequencies generally remain on a well-connected conductor better and are less likely to couple onto nearby utilities. They may have difficulty passing through high-impedance joints or poorly grounded systems.

Higher frequencies may produce more displayed transmitter current because they pass more readily through capacitive paths. They can sometimes continue across resistive joints or short breaks, but they are also more likely to transfer onto adjacent conductors and leak into the surrounding environment.

An increase in transmitter current after selecting a higher frequency does not mean the metallic continuity improved. It may mean that additional capacitive and coupled paths became available, so current must be evaluated together with frequency. Comparing a 512 Hz response directly with a 33 kHz response without considering their different behavior can be misleading.

## What the Receiver Milliamp Reading Means

The receiver is not electrically connected to the buried conductor and cannot directly measure conductor current in the same way as the transmitter. Instead, it detects the signal field produced by the applied alternating current. Its internal coils compare the field at different positions within the receiver. When the receiver is properly aligned over the conductor, it estimates the distance to the center of the signal field and uses the detected field information to calculate an estimated locate-current value.

The exact calculation is manufacturer-specific. In practical terms, the receiver attempts to compensate for the effect of distance between the conductor and receiver. That makes its current display more useful than raw signal strength when comparing conductors at different depths.

**Receiver mA** An estimated locate-current index calculated from the detected signal field and the receiver's estimated distance from the center of that field.

The equipment may label the value as milliamps, but it remains a calculated estimate. Its accuracy depends on the field resembling the expected field around a reasonably straight, isolated conductor.

## Signal Strength and Estimated Current Are Different

Signal strength is the receiver's response to the field at its present location and gain setting. It is influenced by:

- Current on the conductor.
- Distance from the conductor.
- Receiver gain.
- Receiver orientation.
- Field distortion.
- Nearby conductors.
- External interference.

A shallow non-target conductor carrying less current may produce a stronger signal-strength response than a deeper target carrying more current. The deeper target is farther from the receiver, so its field is weaker at the receiver even though it carries more applied current.

The estimated locate-current display attempts to account for this difference in distance. This is why a deeper conductor can show a lower signal-strength response but a higher milliamp reading.

Gain does not place more current on the conductor. Gain changes the sensitivity of the receiver to the field already present. Current measurement is intended to provide information about the signal source, while gain controls how strongly the receiver responds to that signal.

## Using Receiver Current to Identify the Probable Target

When a transmitter is directly connected to one conductor and several nearby lines carry the selected frequency, the conductor with the highest stable estimated current is generally the most likely target.

This occurs because the directly connected conductor initially receives the applied current. Other conductors may receive smaller portions through bonds, common grounding, branches, capacitive coupling or inductive coupling.

The practical interpretation is:

- Highest stable estimated current: probable transmitter-connected target.
- Lower estimated current: possible branch, bonded conductor, coupled conductor or return path.
- Similar current on several conductors: possible common bonding, current division, close parallel alignment or distorted overlapping fields.

The highest reading identifies the probable target, not a confirmed target. The locator should trace the response back toward the connection point and evaluate Peak and Null agreement, field shape, estimated depth, route and known system construction.

## Current Division at Bonds and Branches

Consider a cable shield bonded to several other cable shields at the far end. Before reaching the bond, the original shield may carry most of the applied current. At the bond, current divides among all connected paths.

The amount entering each shield depends on its complete circuit impedance. Important factors include:

- Shield material and cross-sectional area.
- Conductor length.
- Cable construction.
- Grounding at the far end.
- Splices and connections.
- Capacitance to earth.
- Nearby bonded structures.
- Frequency.

The original target may show a higher reading before the bond. Beyond the bond, several cables may carry lower readings. The combined current distributed among those paths comes from the total current that reached the bond.

A receiver reading on one branch does not explain the entire circuit. The locator develops the explanation by comparing readings before and after the branch and on each available route.

## Current Changes Along the Route

Applied current normally decreases with distance because of impedance, capacitance, leakage, branches, bonds and other available paths. Under consistent conditions, that decrease should be gradual.

A sudden change deserves investigation. Possible explanations include:

- A tee or branch.
- A bonded conductor.
- An intentional ground.
- A change in conductor size or material.
- A splice or connection.
- An insulated joint.
- A cable-sheath fault.
- A pipe-coating defect.
- A break or loss of continuity.
- Current transferring onto another conductor.
- A distorted field causing an incorrect depth or current calculation.

The receiver current display is most useful as a pattern. One isolated reading provides limited information. A sequence of readings shows whether the current remains stable, decreases gradually, divides or changes abruptly.

## Taking Dependable Receiver Current Readings

1. Pinpoint the conductor before taking the reading.
2. Confirm the Peak position and compare it with Null.
3. Hold the receiver vertically with its blade aligned correctly over the conductor.
4. Keep the receiver at ground level and use the same technique at every point.
5. Allow the depth and current values to stabilize.
6. Take readings away from large metal objects, vehicles and obvious sources of distortion.
7. Record or remember the trend rather than relying on one number.
8. Investigate abrupt changes by sweeping horizontally and vertically.
9. Compare the current reading with field shape, signal strength, depth and known system design.
10. Repeat a questionable measurement at another point along the conductor.

If the estimated depth is wrong because the field is distorted, the calculated current can also be wrong. This is why current readings must be used with field-shape inspection rather than treated as independent proof.

## Transmitter and Receiver Current Values Serve Different Purposes

The transmitter and receiver may both display values in milliamps, but the two readings are not expected to match and should not be compared as though they represent the same measurement.

The transmitter measures the total current entering the complete locating circuit at the signal application point. The receiver is located farther along the circuit and calculates an estimated locate-current value from the signal field detected at that location.

As the applied current travels away from the transmitter, circuit impedance, distance, capacitance, grounding connections, branches, bonds, faults and other conductive paths reduce or divide the current remaining on the target. The receiver detects the signal field produced by the current that remains on or has transferred to a conductor at the receiver's location.

The receiver's value is also affected by its calculated distance to the center of the signal field. Distortion that affects the depth calculation can also affect the estimated-current calculation.

The readings therefore have separate meanings:

- Transmitter mA: Measured total current entering the complete connected circuit at the application point.
- Receiver mA: Calculated estimate of the current associated with the signal field detected at the receiver's location.

The transmitter reading should be used to evaluate the circuit at the signal application point. Receiver readings should be compared with other receiver readings taken along the route using the same frequency and consistent measurement technique.

**The useful comparison** Compare receiver current readings collected at different locations along the same conductor. Do not compare the transmitter number with the receiver number as though they measure the same value.

## Current Measurements During Fault Finding

Current measurement can help identify cable-sheath faults and pipe-coating defects. A fault provides a location where current can leave the metallic conductor and enter the earth.

**Current path through a fault** Current travels from the transmitter onto the cable shield, leaves the cable at the fault, passes through the earth to the temporary ground stake and returns to the transmitter.

The fault and temporary ground stake become the two primary earth-contact points of the circuit. Together, they form an alternating-current dipole through the earth. Current enters the earth at one point and returns through the other as the alternating polarity repeatedly reverses.

The transmitter milliamp reading represents the total current traveling through all faults, grounds and available return paths. A low-resistance fault may permit considerable current and produce a high transmitter reading. A high-resistance fault may produce a low reading even when the transmitter increases its voltage.

The transmitter cannot show where the fault is located. The receiver can be used to examine how the estimated current changes along the cable.

## Receiver Current Response Survey

A receiver current-response survey compares receiver current readings taken along the same traced cable. First record the transmitter current at the connection point. This confirms how much current is entering the complete circuit. Then move far enough away to avoid direct transmitter pickup and establish the first stable receiver current reading. That receiver reading—not the transmitter reading—becomes the baseline for the survey.

Trace and mark the cable. Using the same frequency and a consistent receiver position, take estimated receiver current readings directly over the cable at regular intervals. Compare each reading with the receiver baseline and the previous reading. A gradual decrease may be normal. An abrupt decrease narrows the area where the conductor or circuit condition changed.

Illustrative example: The transmitter displays 20 mA at the connection point. The first stable receiver reading, taken 25 feet away, is 16 mA. to power out, but The 16 mA receiver reading becomes the survey baseline and is not expected to match the transmitter reading.

| DISTANCE FROM TRANSMITTER | ESTIMATED RECEIVER CURRENT |
|---------------------------|----------------------------|
| 25 feet (baseline)        | 16 mA                      |
| 50 feet                   | 15 mA                      |
| 75 feet                   | 13.5 mA                    |
| 100 feet                  | 12.2 mA                    |
| 125 feet                  | 5.9 mA                     |
| 150 feet                  | 5.5 mA                     |

The abrupt decrease between 100 and 125 feet narrows the change to that section. Take additional receiver readings at shorter intervals between those two points to narrow the area further.

The change does not prove that a fault exists. A ground, branch, bond, splice or change in construction can produce a similar pattern. System knowledge and field-shape inspection remain necessary.

## Responses Near the Fault and Temporary Ground Stake

A receiver may produce a strong response near the transmitter's temporary ground stake because the return current is concentrated at the stake and travels through the black connection lead. A similar response may occur near the fault where current leaves the cable and enters the earth.

If the receiver is moved between the temporary ground stake and a major fault, the current-related response may be strong near the ground stake, decrease between the two points and increase again near the fault. This creates a valley-shaped response across the complete circuit.

The lowest response will not necessarily occur exactly halfway between the stake and fault. Its location depends on:

- Fault resistance.
- Ground-stake contact resistance.
- Distance and circuit geometry.
- Soil conductivity.
- Cable depth.
- Transmitter-lead position.
- Other grounds and bonds.
- Fields that add to or oppose one another.

A milliamp number displayed near a fault or temporary ground stake should not be interpreted as an accurate line-current measurement. The receiver's calculation assumes a field surrounding a reasonably straight conductor. Near a point where current is spreading through the earth, the field geometry is different.

These off-line readings are best treated as current-related responses or reference indexes. They can help identify a pattern or suspected area, but they do not directly measure current through the soil.

## Limits of a Receiver Current Response Survey

A receiver-only current-response survey can be effective for:

- Tracing the faulted conductor.
- Recognizing a gradual current trend.
- Identifying a section containing major current loss.
- Detecting a strong, low-resistance fault under favorable conditions.
- Identifying areas requiring closer investigation.

Its limitations include:

- Reduced sensitivity to high-resistance faults.
- Difficulty distinguishing faults from intentional grounds and bonds.
- Difficulty separating multiple faults.
- Current estimates affected by irregular field geometry near a fault or temporary ground stake.
- No dependable directional reversal centered on the fault.
- Ability to narrow a suspected section without proving the exact fault location.

A current-response survey should therefore be used to identify patterns and narrow the search area. It does not by itself prove that a fault exists or establish the exact point where current is leaving the conductor.

## Current Direction Is Different From Current Level

A milliamp value describes magnitude. It does not show whether the detected current is traveling away from or returning toward the transmitter.

Some locating systems provide a separate Current Direction feature. This uses a specialized signal to distinguish current traveling away from the transmitter on the target from coupled current returning toward the transmitter on another conductor.

Current level and Current Direction can support one another:

- Current magnitude helps compare how much current is associated with each response.
- Current Direction helps distinguish outgoing target current from returning or coupled current.
- A standard milliamp display should not be interpreted as a direction indicator unless the equipment is specifically operating in a Current Direction mode.

**No single value controls the locate. Each measurement contributes one part of the explanation.**

## Final Understanding

The milliamp reading at a directly connected transmitter measures the total locating current entering the complete circuit. It indicates how readily that circuit accepts current at the selected frequency and output setting. It does not reveal how the current divides or how much remains on the target farther away.

The milliamp reading on the receiver is a calculated estimate based on the detected signal field and the estimated distance to the center of that field. It helps compare possible target conductors and examine how applied current changes along the route. It is not a direct electrical measurement of conductor current.

**Essential distinction** Transmitter current measures what enters the complete circuit. Receiver current estimates what is detected at a particular location within that circuit.

Used together, these values help the locator understand more than whether a signal is present. They help explain how the locating circuit is performing, where current is traveling, where it divides, where it changes and whether the detected response is likely to represent the intended target.

Current values are evidence. The locator interprets that evidence together with signal-field shape, Peak and Null agreement, gain, estimated depth, system construction, surface features and known connection points before placing a mark.

## EQUIPMENT OPERATION

### 05 Equipment Operation

*Create the signal, acquire the response, trace, verify, and troubleshoot*

#### Transmitter and Receiver Operations

##### Part 1: Applying a Transmitter Signal

The transmitter places alternating current into a locating circuit. Start with the method that gives the best control of the intended conductor. A stronger, stable current often produces a signal that can be followed farther, but a strong signal on the wrong conductor is not a good locate. Check the connection, return path, and receiver response together.

##### Set Up the Transmitter

- Review records, work limits, visible facilities, and the expected route. Identify an approved connection point and a suitable return path.
- Inspect the transmitter, leads, clips, clamp, batteries, and temporary ground stake. Keep leads clear of traffic and walking routes.
- Make the connection before increasing output. Start with a practical low frequency and moderate output. Confirm a usable transmitter indication, then move away to check the receiver response.

##### Choose a Signal Application Method

**Direct connection.** Connect one lead to an approved point on the intended metal pipe, cable component, or tracer wire. Place the temporary ground stake away from the route, generally at a right angle, and connect the return lead. Clean the contact and improve soil contact as needed. This method usually gives the greatest control over the target.

**In-line connection.** Where two approved points on the same conductor are available, connect one lead to each point so the transmitter is in the metallic circuit. Confirm the selected points really belong to the intended conductor.

**Closed-loop connection.** Where an accessible conductor can complete a suitable loop between two points, connect both leads and verify that the loop does not include an unintended path.

**Clamp induction.** Enclose the intended conductor completely with the clamp and latch it. The conductor needs a suitable continuing circuit for useful current to flow. A clamp may also place a signal on other conductors that share a bond or path.

**Broadcast induction.** Use when suitable direct or clamp access is unavailable, or for a controlled search. Align the transmitter with the expected route and begin receiver work far enough away to avoid the direct airborne response. Nearby conductors may also carry the signal.

##### Check the Circuit and Frequency

The transmitter current indicates current entering the entire connected circuit. A higher stable current often creates a stronger signal that can be followed farther, but it does not show which branch carries that current. The receiver's displayed current is a field-based estimate at its position; it is not expected to match the

transmitter number. Trace the line and compare receiver current, field shape, direction, and depth trend to see whether the response remains credible. Lower frequencies often stay on a continuous target more selectively. Higher frequencies can help across poor continuity or short sections but may transfer more readily onto nearby conductors. Choose the frequency that produces the clearest trace of the intended facility, not simply the largest display number. If the response is weak or appears on several lines, improve the contact and return path, try another approved point, or change method before increasing frequency or output.

##### Part 2: Using the Receiver

The receiver senses the signal field; the locator interprets what that field means. It cannot identify a pipe or cable by itself. Keep the receiver upright, at a consistent height, and on the same active frequency as the transmitter. Adjust gain so the response can be followed without saturating the display; gain changes receiver sensitivity, not current on the line.

##### Prepare and Search

- Inspect the receiver, check battery and warnings, select the mode and frequency, and start with moderate sensitivity.
- For direct connection or clamp work, begin roughly 10 feet from the transmitter when practical. For broadcast induction, begin roughly 30 feet away to reduce direct pickup; actual distance depends on equipment and site conditions.
- Sweep slowly across the expected corridor. Continue beyond the first response until the reading rises and falls. Cross back from the opposite direction and repeat until the same field is found reliably.
- Shorten the sweep to shoulder width or less around the response. Glide the receiver across the field at a steady height; do not swing it in an arc. Establish the first repeatable Peak before advancing.

##### Trace and Pinpoint

- From the confirmed Peak, move one or two steps along the expected route and sweep across the field again. Confirm each new point before placing the next mark. Shorten the spacing at bends, branches, crossings, congestion, or changing responses.
- Compare the response on both sides of the Peak and compare Peak with Null where the receiver provides both. Disagreement, an uneven field, an unexpected compass direction, or a sudden change in receiver current or estimated depth calls for investigation.
- Treat displayed depth as an estimate derived from the field, commonly to its center. Nearby conductors and distorted fields can make it wrong. Do not use depth alone to establish the buried facility's position.
- Keep tracing the same repeatable field. If it disappears or moves unexpectedly, return to the last

confirmed point and investigate before marking farther.

### **Evaluate the Response**

A repeatable Peak is only one piece of evidence. Sweep from both sides of the route and look for a similar falloff. Check the directional or compass display if available, and compare the Peak with Null. If these indications point to different horizontal positions, a nearby conductor or altered current path may have changed the signal field. A mark based on one attractive reading could be misleading. Receiver current and estimated depth are useful trends along a trace. Gradual change can be normal; a sudden change near a branch, splice, ground, or crossing deserves a closer look. Compare readings taken with the same frequency, receiver orientation, and method. Signal strength alone is also affected by depth and receiver gain. Let the combined observations guide the next sweep rather than treating any displayed value as proof.

### **Passive Search**

A passive mode detects fields already present, including power or radio-related signals. It can reveal conductors missed during an active search, but absence of a response does not prove the ground is clear, and a response does not identify the facility. Sweep and repeat each indication, compare it with records and surface features, and apply a controlled active signal when suitable to check the interpretation.

### **Where the Trace Becomes Uncertain**

At a tee, service connection, or parallel run, the applied current may divide. Trace each candidate route far enough to understand its direction and compare it with records and visible facilities. At a turn or crossing, make closer, shorter sweeps on both sides. Large metal objects above ground, reinforced concrete, and closely spaced conductors can shift the apparent field center. Move away from the problem area and approach it again from another confirmed point.

If the transmitter reports current but the receiver has no repeatable response, verify the selected frequency, the intended connection, and the return path. Search wider before changing the setup. An unexpected strong response near the temporary ground stake may be current on another conductor in the return circuit. Move

the stake to a more suitable location and check whether the target response improves.

### **Finish the Locate**

Walk the marked route and recheck bends, branches, crossings, and weak sections. Marks should follow confirmed receiver observations and applicable marking requirements. Record and communicate uncertainty or any area that could not be reliably traced. When permitted, confirmed reference marks beyond the excavation area can help re-establish a route if work-area marks are destroyed. Remove the transmitter leads, clamp, and temporary ground stake; restore authorized connections and secure the access points.

### **Part 3: Troubleshooting**

When observations conflict, stop at the last confirmed point. Check one condition at a time and observe whether the change improves the trace.

- Confirm that the receiver and transmitter use the same frequency and that receiver gain is appropriate. Recheck the Peak, Null, direction, current trend, and depth trend.
- Check that both transmitter leads are secure and connected to the intended conductor and return point. Improve metal contact and the temporary ground stake's soil contact.
- Consider a branch, bond, splice, mechanical joint, nearby conductor, or change in material. Trace from another approved point or direction. Increase output or change frequency only after checking the circuit.
- On nonconductive piping, check tracer-wire access and continuity; a broken, ungrounded, or disconnected wire may end the trace. On metallic piping, joints, insulated fittings, plastic repairs, and bonds may interrupt or divide current.
- On cables, shields, concentric neutrals, armor, messenger wires, and common grounds may carry current on several paths. A splice or bond may change the route of the applied signal.
- If direct access is unavailable, a coordinated two-person inductive sweep may help search for conductors. Keep transmitter and receiver spacing and alignment controlled, and verify any candidate route with other evidence.

Do not extend confident marks into an unresolved area. Explain the limitation to the appropriate party and use a suitable verification method when the location must be known more precisely.

## SAFE AND REPEATABLE WORK

### 06 Safe and Repeatable Field Practice *Safety, site investigation, locating decisions, marking, and communication*

Line locating is physically demanding fieldwork performed in environments the locator does not control. Safety begins before equipment operation and continues through site investigation, connection, sweeping, tracing, marking, documentation, and departure.

#### Safety Priorities

- Assess traffic, equipment movement, active excavation, open trenches, surface conditions, weather, electrical hazards, animals, public movement, and access restrictions.
- Make contact with the excavator or site representative before entering an active operating area.
- Maintain awareness while watching the receiver; do not let the display pull attention away from traffic, terrain, or moving equipment.
- Use appropriate PPE, safe body mechanics, hydration, pacing, and stop-work judgment.
- Do not allow ticket urgency or production pressure to make an unsafe condition acceptable.

#### 8 Key Fundamental Steps of the Locate Sequence

|   |                         |                                                                                                           |
|---|-------------------------|-----------------------------------------------------------------------------------------------------------|
| 1 | Stop and assess         | Review the request, work area, hazards, and site activity.                                                |
| 2 | Research and observe    | Use records, visible features, access points, and system knowledge to build an expectation.               |
| 3 | Select a method         | Choose the technology and application method that best fit the facility and site.                         |
| 4 | Create the best signal  | Improve the connection, return path, continuity, frequency, and output before increasing receiver gain.   |
| 5 | Search and trace        | Sweep across the expected route, follow the response, and watch for signal-quality changes.               |
| 6 | Pinpoint and verify     | Compare available modes and measurements; reconcile the result with field evidence.                       |
| 7 | Mark and document       | Mark only after evaluation, follow applicable standards, and record limitations or unresolved conditions. |
| 8 | Communicate and protect | Share relevant findings, preserve safety, and recommend safe exposure when confidence is insufficient.    |

#### Fundamentals of Line Locating and Marking

Line locating is a process of gathering and evaluating evidence to develop the best available surface indication of a buried facility. Records, visible utility features, system knowledge, locating equipment, field observations, and communication all contribute to the result.

An electromagnetic receiver detects a signal field. It does not see the buried facility, create an underground image, or independently determine which conductor is producing the response. The locator must decide whether the detected response reasonably represents the intended facility before placing marks on the ground.

## Step 1. Stop and Assess

Read the locate request and identify the work area before operating the equipment. Confirm the address or location, limits of the proposed excavation, type of work, planned depth, excavation method, equipment being used, bore path, entry and exit points, and any special instructions.

White markings, project drawings, maps, coordinates, written descriptions, and conversations with the excavator may provide additional information. An address identifies a property but may not adequately define the excavation area. Descriptions such as front, rear, both sides, along the roadway, at the intersection, or entire property may require clarification.

Understand what the excavator plans to do and where ground disturbance may occur. A fence installation, trench, bore, grading project, road repair, service replacement, or foundation excavation presents a different work area and different potential conflicts. The locating effort must address the area where the facility could be affected, not merely the nearest point described on the request.

Assess the site for hazards before setting up the equipment. Look for traffic, moving equipment, active excavation, open trenches, overhead electrical conductors, damaged electrical equipment, standing water, unstable lids or access structures, steep or uneven terrain, weather, animals, restricted access, and public activity.

Identify safe locations for parking, walking, connecting the transmitter, placing a temporary ground stake, and operating the receiver. Determine whether traffic control, additional personal protective equipment, another employee, or assistance from the site representative is needed.

The safety assessment continues throughout the locate. Traffic patterns change, construction equipment moves, weather develops, and additional hazards may become visible while walking the site. Stop and reevaluate the work whenever conditions change.

## Step 2. Research and Observe

**Review the Available Records** Review the information available for the work area before relying on the receiver. Sources may include utility maps, design drawings, as-built drawings, GIS information, installation records, service cards, field sketches, repair records, previous locate information, photographs, surveyed positions, documented measurements, and abandoned-facility information.

Determine what each record was created to show. A design drawing represents the planned installation and may not include changes made during construction. An as-built drawing represents what was reported after installation, but its accuracy depends on how the final position was measured and recorded. A GIS line may be based on survey information, documented measurements, digitized drawings, estimated positions, or several sources combined.

Use the map legend and asset details to count expected facilities, branches, and access points. One drawn GIS line may represent several facilities or a shared corridor, and its position may be approximate.

Look for information about:

- Facility type, function, ownership, material, size, and operating status
- Mains, services, laterals, branches, tees, crossings, and connection points
- Valves, meters, hydrants, transformers, pedestals, manholes, handholes, cleanouts, test stations, and tracer-wire access points
- Building entrances, service connections, and utility equipment
- Documented offsets, elevations, bearings, coordinates, and depth information
- Repairs, replacements, reroutes, material changes, and abandoned sections
- Record dates, revisions, missing facilities, conflicting routes, and unclear measurements

Use documented offsets and GIS GPS points to identify specific features and narrow the field search. Check the stated reference point, units, and direction before using an offset. A curb, building corner, monument, valve, or other reference may have moved or been reconstructed; a recorded GPS point for one feature does not establish the route between features.

Recorded depth may also differ from present cover. Grading, paving, erosion, settlement, landscaping, and roadway reconstruction can change the ground surface without changing the facility's position.

Compare the number of facilities expected from the record with those found during the field search. If a mapped line cannot be traced, or an additional response appears, investigate before deciding what to mark. A mapped line may end before reaching a building it serves, and visible features may be missing from the drawing. Record conflicts help identify where more investigation is needed.

## Conduct the Visual Site Investigation

Walk the work area and enough of the surrounding roadway, easement, property, and adjoining area to understand how the site is served. View the site from several directions. A valve, pedestal, transformer, meter, manhole, or building entrance outside the immediate work area may help explain a facility route within it.

Look for visible utility features such as:

- Water meters, valves, hydrants, and service entrances
- Gas meters, risers, valves, test stations, and warning markers
- Electrical meters, transformers, switchgear, cabinets, poles, and conduit risers
- Communication pedestals, cabinets, handholes, manholes, and building entrances
- Sewer manholes, cleanouts, lift-station equipment, and building connections
- Storm drains, catch basins, manholes, culverts, and discharge points
- Irrigation valves, control boxes, backflow devices, and service connections
- Tracer-wire access points, marker posts, identification numbers, utility signs, previous markings, and flags

Visible utility features establish known surface points. A water-valve lid establishes the surface location of the valve structure. A manhole cover establishes the manhole location. A pedestal establishes the location of that communication-system component. These points help develop a possible route, but they do not prove the complete underground path between them.

When a structure is safely accessed by someone trained and authorized to do so, the facility may be directly observed inside. A pipe visible beneath a valve lid, conduits visible inside a manhole, or cables visible inside a handhole establish known facility positions at those specific points.

**Read the Surface** The surface may preserve evidence of earlier utility installation, repair, replacement, or exposure. Linear cracks, depressions, narrow pavement repairs, saw cuts, repaired curbs, trench scars, changes in pavement texture, disturbed soil, and changes in vegetation may follow a previous trench.

Trench backfill is disturbed material. It may settle or respond to traffic, moisture, temperature, and loading differently from the surrounding undisturbed ground. Over time, that difference may create a visible crack, depression, or change in pavement condition along the direction of the trench.

A large square or rectangular pavement patch often indicates that the pavement was cut and excavation occurred beneath it. The work may have involved installing or repairing a main, valve, service lateral, conduit, or another buried facility.

Small round asphalt or concrete patches may indicate previous test holes, including holes made by vacuum excavators to expose a facility. A series of round patches following the same direction may show where a facility was previously exposed at several points.

These surface conditions are clues rather than known facility positions. A pavement patch does not identify which utility was involved. A crack may result from pavement movement unrelated to a utility trench. Their value increases when they align with known utility points, service entrances, records, previous markings, or a logical system route.

Known points anchor the investigation. Surface clues help develop possible routes between them. A water-valve location, linear pavement crack, rectangular repair, and water service entering a building along the same general alignment provide a logical route to investigate. That route remains an expectation until it is supported by a locating response, documented measurement, another known point, or physical observation.

Continue evaluating safety during the visual scan. Open or damaged structures, exposed wiring, traffic exposure, unstable lids, moving equipment, standing water, and restricted access may affect where and how the locating work can be performed.

### Step 3. Develop a Locating Plan

Identify every facility expected within or near the work area, including facilities that may not be the primary subject of the request. Consider electric, communications, gas, water, wastewater, storm drainage, irrigation, lighting, traffic control, fire protection, security, private facilities, abandoned facilities, and unidentified buried systems.

A facility may be expected even when it is absent from the records. A building with electrical service has a supply connection. A hydrant connects to a water main. A light pole normally has a power supply. A storm drain connects to another structure or discharge point. These connections should be considered when developing the search area.

Determine the probable material and construction of each facility. Metallic piping, cable shields, neutrals, and tracer wires may provide conductive paths for active electromagnetic locating. Plastic, concrete, clay, and other nonconductive facilities cannot carry the transmitter's locate current unless they contain or are installed with a conductive locating aid.

Consider whether the expected conductive path is continuous. Welded steel, continuous cable shields, neutrals, and properly connected tracer wires may carry locate current effectively. Mechanical joints, insulating fittings, corrosion, broken tracer wires, ungrounded conductors, and changes from metallic to nonmetallic material may interrupt or weaken the circuit.

Plan the locate around the equipment normally available. Most technicians perform their work with an electromagnetic pipe and cable locator. The plan should identify:

- The most useful transmitter connection point
- The best available signal-application method

- The initial frequency and output
- Where the receiver search will begin
- The expected route and the larger area that must be searched
- Possible branches, tees, crossings, parallel facilities, and shared trenches
- Locations where the signal may weaken, divide, transfer, or become distorted
- Another access point or direction that may help check the result

**Work With the Equipment Available** Direct connection is generally preferred when a safe and suitable connection point is available. It places the transmitter current directly onto the selected conductor and normally provides the greatest control over the signal.

A clamp may be used when the target conductor is accessible but a direct electrical connection is unavailable, inappropriate, or not permitted. Clamp induction works best when the conductor forms a suitable circuit that allows the induced current to travel.

Broadcast induction may be used when neither direct connection nor a clamp is practical. It is less selective because the transmitter may place signal on several nearby conductors. The receiver may follow the conductor carrying the strongest current rather than the intended facility.

GPR may be available to some technicians or for specific projects. It can provide additional subsurface information where soil conditions, moisture, target size, depth, surface access, and surrounding conditions are suitable. GPR does not identify utility ownership or automatically determine that a response represents the facility being investigated. Its results must be interpreted and compared with records, visible features, system knowledge, and electromagnetic locating results.

Some organizations may have access to sondes, inspection cameras, or detectable rodders, but these are not tools that every technician carries. They may be useful when the facility is accessible, the equipment is available, and the work procedure permits their use.

Vacuum excavation is normally performed by the excavator or a vacuum-excavation contractor. The locator places the marks based on the best available evidence. When physical verification is needed, the excavator generally exposes the facility under or near the marks before proceeding with the excavation.

If the facility cannot be located with reasonable confidence using the available equipment, the locator should not place a mark based only on an assumption. The unresolved condition may need to be communicated so the appropriate party can determine whether additional locating assistance, GPR, vacuum excavation, or another verification method is needed.

**Step 4. Create the Best Detectable Signal** When using active electromagnetic equipment, select the most controlled method available for placing locate current on the intended conductor.

### Direct Connection

Direct connection is generally the most selective signal-application method. One transmitter lead is connected to the intended conductor or tracer wire. The other is connected to a temporary ground stake or another appropriate return point.

A direct connection may be made to an accessible pipe, tracer wire, cable shield, neutral, test station, meter connection, or another approved conductive point. Connections should be made only where they are safe, authorized, and appropriate for the facility.

Confirm clean metal-to-metal contact. Paint, corrosion, dirt, loose hardware, and damaged leads may restrict current. Inspect the connection and the leads before increasing frequency or output.

### Clamp Induction

A signal clamp places current on an accessible conductor through induction. The conductor passes through the clamp without requiring a direct metal-to-metal connection.

The clamp must close completely around the conductor. The circuit must also provide a path that allows the induced current to travel. A clamp placed around a conductor that does not form a suitable circuit may produce little or no useful locate current.

**Broadcast Induction** Broadcast induction places the transmitter signal into the ground without a direct electrical connection. It may be useful when no access point is available or during a two-person inductive search.

The transmitter should be positioned and oriented according to the expected facility direction. Because several nearby conductors may receive the signal, broadcast induction requires a broader search and more careful comparison of the detected responses.

**Establish the Locatable Circuit** A complete circuit is required for locate current to flow. With a direct connection and temporary ground stake, current leaves the transmitter, travels along the target conductor, and returns through the earth. The transmitter, conductor, connections, and earth-return path are all parts of the circuit.

Place the temporary ground stake where it can make firm contact with the soil. When practical, extend the ground lead away from the expected target route, generally at a right angle. Avoid placing the stake close to another known utility structure or conductive path.

Dry, rocky, frozen, or sandy soil may provide a poor earth return. Better soil contact, a deeper stake position, or added water may improve the connection when appropriate and permitted.

Review the information provided by the transmitter after connecting. Locate current is one of the most useful indicators that a circuit has been established. Resistance, impedance, voltage, output, or connection-quality information may also be displayed, depending on the equipment.

Evaluate how the circuit information changes after improving the connection, relocating the temporary ground stake, changing frequency, or selecting another connection point. A transmitter showing current confirms that a circuit exists; it does not prove that all of the current is traveling on the intended conductor.

Locate current may divide at branches, follow bonded conductors, transfer onto nearby facilities, or return through another available path. The receiver response must still be compared with the intended facility route.

**Select Frequency and Output** Begin with the lowest practical frequency that produces a usable result. Lower frequencies generally travel farther on a continuous conductor with less attenuation and are less likely to couple onto nearby facilities.

Higher frequencies may help place current on short conductors, higher-resistance systems, poorly connected tracer wires, mechanical joints, or facilities with limited continuity. They also increase the chance of signal coupling and bleed-over onto other conductors.

Use enough transmitter output to create a dependable receiver response. More output does not correct a poor connection or incomplete circuit. Improve the connection, temporary ground-stake contact, access point, or signal-application method before relying on additional output.

Position the transmitter and connection leads so they do not create a trip or traffic hazard. Keep the leads separated from nearby utility structures when practical to reduce unintended coupling.

If the signal appears on several facilities, try a lower frequency, a more selective connection point, a different temporary ground-stake location, reduced output, or another available signal-application method. Then reevaluate the receiver response before continuing.

**Step 5. Search and Trace** Searching and tracing are separate parts of the locating process. Searching identifies detectable responses within the area. Tracing follows a selected response after the locator has evidence that it may represent the intended facility.

Begin at a useful distance from the transmitter. When using direct connection or a clamp, approximately 10 feet may provide a practical starting distance when site conditions allow. When using broadcast induction, begin farther away—often approximately 30 feet—to reduce the receiver's response to the transmitter itself.

Sweep across the expected route instead of walking directly along it. Extend the initial search far enough to identify parallel conductors, crossings, branches, and facilities that do not follow the record.

Maintain the receiver in the correct orientation and use a controlled search pattern. A shoulder-width sweep may be appropriate while following an established response, but the initial search must be wide enough to identify other detectable signals.

Passive power and radio modes may be used as supplemental search tools. Passive power modes detect naturally occurring electrical frequencies that may be present on energized or grounded conductors. Radio modes detect radio-frequency energy that has coupled onto buried conductors. A facility carrying no detectable passive signal will not produce a response, so the absence of a passive response does not establish that the area is clear.

Do not select a response only because it appears near the expected route. Compare it with the transmitter connection, records, visible utility features, known points, service locations, system function, route direction, locate current, and estimated depth.

Once a response is selected, trace it in both directions. Follow it away from the transmitter and then return toward the connection point. Repeatedly sweep across the route rather than walking directly along an assumed centerline.

Watch for:

- Changes in direction
- Branches and tees
- Parallel responses
- Crossings
- Sudden increases or decreases in locate current
- Changes in estimated depth
- Broad, weak, or unstable responses
- Locations where the signal appears to leave the expected route

- Responses that conflict with records or surface evidence
- Continue searching beyond the immediate excavation area when necessary. The route outside the work area may provide the information needed to interpret the portion inside it.

### Step 6. Pinpoint and Evaluate

Pinpoint before painting. Cross the signal path from both directions and identify the apparent top dead center of the detected signal field. Reduce gain as the receiver approaches the strongest response so a broad area of detection is not mistaken for a precise position.

The receiver response is generally interpreted as the top dead center of an assumed-to-be-round signal field surrounding a single conductor. That assumption may not be correct when nearby conductors, branches, bonds, changes in depth, poor circuit conditions, or signal transfer distort the field.

A strong and repeatable response does not guarantee that the signal field is round or correctly centered over the conductor. Distortion can move the apparent field center while still producing a stable receiver response.

### Compare Peak and Null

When available, compare the Peak and Null responses. Agreement between them supports a more symmetrical signal field. Separation between Peak and Null indicates that the field may be distorted.

The Null response is generally affected more by distortion and may move farther from the conductor. The Peak response is normally closer to the actual conductor and should be used for marking when the two responses disagree. The disagreement remains important evidence that the signal field may not be centered over the facility.

### Evaluate Locate Current

Monitor locate current along the route when the receiver provides that information. Consistent current readings can support the conclusion that the receiver is following the same conductive path.

A sudden change in current may indicate a branch, bonded conductor, damaged tracer wire, parallel facility, change in continuity, or current leaving the intended conductor. Current may divide at a tee, causing each branch to carry only part of the current measured before the split.

Locate current should be considered with signal strength, route direction, estimated depth, Peak and Null agreement, visible utility features, and system knowledge. A single current value does not verify the facility.

**Evaluate Estimated Depth** Estimated depth is calculated from the detected signal field. It generally represents the distance to the center of the signal field, not the top of the buried facility.

Take depth readings with the receiver correctly positioned and oriented over the apparent field center. Repeat the measurement at several points. A depth that changes gradually with the terrain or expected installation may support the locate. An abrupt, unstable, or unrealistic depth change requires further investigation.

Distortion, nearby conductors, incorrect receiver position, excessive gain, changes in facility direction, and signal transfer can affect the estimate. A believable depth number is not proof that the correct facility has been located.

### Investigate Questionable Responses

Question responses that do not fit the available evidence. A route that makes an unexplained turn, misses an expected connection, passes through an unlikely obstruction, produces conflicting Peak and Null positions, or changes current and depth unexpectedly should be reevaluated.

Change one condition at a time and observe the result. Reconnect at another available point, relocate the temporary ground stake, change frequency, reduce output, trace from the opposite direction, or use GPR when it is available and appropriate.

If the available equipment and evidence cannot support a dependable mark, the unresolved condition may need to be communicated. The locator should not turn an uncertain response into an apparently confident facility mark.

### Step 7. Mark and Photograph

Place marks after the response has been searched, traced, pinpointed, and evaluated. Follow the applicable marking standards and use the correct color and identification for the facility.

Mark enough points to show the route clearly. Include changes in direction, tees, bends, offsets, service laterals, and other important features. A single isolated mark does not communicate the direction of an underground facility.

Mark spacing should allow the excavator to follow the route without guessing. Congested areas, crossings, distorted signal fields, and changes in direction normally require closer or more detailed markings than a long, straight, clearly defined route.

The marks represent the locator's interpretation of the available evidence and the apparent top dead center of the detected signal field. They do not prove the exact horizontal position, depth, size, material, or condition of the buried facility.

Photograph the completed markings before leaving the site. Include enough of the surrounding work area to show where the marks were placed and the route they represent. Additional views may be useful where the route changes direction, crosses another facility, or enters the proposed excavation area.

## Step 8. Communicate When Needed and Leave the Site Secure

Most completed locates end with the locator marking the site, taking photographs, collecting the equipment, and leaving.

Additional communication may be needed when uncertainty, changed work limits, access restrictions, missing facility information, or another unresolved condition could affect the excavator's understanding or use of the markings. Any uncertainty that may affect the excavation should be communicated to the excavator or other appropriate party.

Vacuum excavation is generally the responsibility of the excavator. The excavator may use its own vacuum excavator or hire a contractor to expose the facility under or near the marks when physical verification is needed.

Before leaving, close any lids, covers, cabinets, or access points opened during the locate. Restore any temporary connection changes, disconnect the transmitter leads, retrieve the temporary ground stake, and collect the locating equipment and traffic-control devices.

Perform a final visual check. Confirm that the markings are visible, the required photographs have been taken, no equipment has been left behind, and the site has not been left with an avoidable hazard.

### Fundamental Operating Sequence

**Stop and assess. Research and observe. Develop the locating plan. Create the best detectable signal. Search before tracing. Pinpoint and evaluate before painting. Mark the facility, photograph the site, communicate uncertainty when necessary, and leave the site secure.**

A surface mark represents an educated estimate based on the available evidence. The receiver identifies the apparent center of a detected signal field, not the buried facility itself. The facility is physically known only where it has been safely exposed and directly observed.

## Class and Field Notes

### Key point I want to remember

This image shows a full page of white paper with horizontal blue or grey ruling lines. The lines are evenly spaced and run across the width of the page, typical of notebook paper. There are no margins, text, or other markings on the page.

## TERMS AND DEFINITIONS

A course reference for locating principles, field procedures, and utility networks. Definitions describe general use; equipment instructions and facility records control specific applications.

**811 ticket.** A request routed through a one call center to the appropriate facility operators for a proposed excavation. Ticket terminology and duties vary by jurisdiction.

**Abandoned facility.** A facility no longer used for service. Its operating status cannot be established solely from a receiver response or surface appearance.

**Access point.** A location where a conductor or a designated terminal can be reached for a transmitter connection. An accessible cathodic protection test lead is connected to a metallic structure; it is not automatically a tracer wire.

**Acoustic pipe locating.** A method that sends a sound or vibration into a pipe and listens for the response at the surface. Results depend on pipe, connections, soil, background noise, and operator technique.

**Active locating.** Detecting a signal field produced by alternating current placed on a conductor with a transmitter.

**Alternating current AC.** Electric current that reverses direction repeatedly; its frequency is the number of complete cycles per second.

**Ampere A.** The unit of electric current. One ampere equals one coulomb of charge passing a point each second; it does not describe the speed of electrons.

**Anode.** A metal or impressed current electrode that supplies protective current in a cathodic protection system.

**Asymmetrical response.** A receiver response that falls off differently on opposite sides of an apparent Peak; it may indicate a complicated or distorted field.

**Bleed over.** Informal term for a detectable transmitter signal on an unintended nearby conductor, often caused by a bond, common return path, or capacitive or inductive coupling.

**Capacitance.** The ability of conductors separated by insulating material to store electric charge. Alternating signals can couple through this arrangement without current physically jumping through intact insulation.

**Casing.** A protective outer pipe around a carrier pipe at some crossings; the casing and carrier can be electrically isolated or connected.

**Cathodic protection CP.** A corrosion control method that makes a metallic structure the cathode of an electrochemical system. A CP test station serves monitoring, not a generic tracer wire connection.

**Circuit.** A complete path for electric current from a source and back to that source.

**Clamp.** An accessory placed around an accessible conductor to induce a locating signal. Its use depends on the conductor and equipment instructions.

**Closed loop.** A continuous conductive path that allows current induced by a transmitter clamp to circulate.

**Coaxial cable.** A communications cable with a central conductor, insulation, and an outer conductor or shield. Its metallic components may carry locate current.

**Common ground or bond.** An electrical connection shared by two or more systems. It can provide a route for locating current to travel onto a non target conductor.

**Conductor.** A material that allows electric charge to move. Metal pipes, cables, and suitable tracer wires can carry locate current.

**Conduit or duct.** A protective pathway that contains one or more cables or other facilities; detecting a cable does not establish every duct position or contents.

**Continuity.** An unbroken conductive connection between points. Continuity alone does not establish that the intended line is isolated from others.

**Crossing.** A point where one facility passes above, below, or near another. Nearby conductors can affect electromagnetic field shape.

**Current.** The rate at which electric charge passes a point in a circuit, measured in amperes.

**Current measurement.** A receiver estimate of current at the selected frequency on a detected conductor, calculated from the field and the equipment model. It is not a direct electrical contact measurement and can be affected by distortion.

**Damage.** Harm to a facility or its protective components caused by excavation or other activity; reporting definitions depend on the applicable system.

**Damage investigation.** A structured review of a damage event to identify what happened and the contributing causes.

**Depth estimate.** A receiver calculation based on an assumed field shape and instrument geometry; commonly an estimate to the center of the field or conductor, not the top of a pipe. Confirm by exposure when exact depth is needed.

**Direct connection.** A transmitter method in which one lead connects to an accessible conductor and the return lead connects to a suitable separate return point, commonly a temporary ground stake.

**Direct current DC.** Electric current that flows in one direction, even if its magnitude varies.

**Direct lead.** A transmitter lead that connects to the intended conductor or a suitable access terminal.

**Distortion.** A change in the shape or apparent center of a signal field, often caused by current on nearby conductors or other conductive structures.

**Distribution system.** The portion of a utility network that delivers a product or service from a higher capacity network toward local customers; arrangements differ by utility type.

**Duct bank.** A group of conduits, often encased in concrete, carrying utility cables.

**Easement.** A legal right to use a defined area of property for a stated purpose. An easement boundary does not establish the exact position of a facility.

**Electric distribution.** The portion of an electric system that carries power from substations toward customers through primary, transformers, secondary, and services; arrangements vary.

**Electric transmission.** High voltage lines and associated equipment used to move electric power over longer distances; voltage classifications vary by system.

**Electromagnetic locating.** Using a receiver to detect an alternating signal field associated with current on a conductive facility or tracer wire. The receiver guides the locator; the locator interprets the response.

**Facility or utility.** An underground or aboveground structure used to provide or carry a service or product, including cables, pipes, and associated equipment.

**Facility record or print.** A drawing or record showing known or planned utility features and measurements. Accuracy and completeness must be evaluated in the field.

**Far end ground.** An earth connection at a distant point on a conductor that can provide a return path for locate current.

**Ferromagnetic locator.** An instrument that senses changes in the earth's magnetic field caused by ferrous objects such as iron or steel. It may detect a buried object without an applied locating current but cannot identify it by product.

**Fiber optic cable.** A cable that carries information as light through glass or plastic fibers. A nonmetallic cable requires an associated traceable conductor, detectable marker, suitable records, or another method for electromagnetic locating.

**Flag or whisker.** A physical surface marker used to show an approximate utility route; colors and marking practices follow applicable local rules and conventions.

**Frequency.** The number of complete cycles of an alternating signal each second, measured in hertz.

**Gain or sensitivity.** A receiver adjustment that changes its response to detected field strength; changing gain does not increase current on the buried line.

**Gas distribution main.** A pipeline in a gas distribution system that serves as a common source of supply for service lines.

**Gas gathering line.** A pipeline that carries gas from production toward a processing facility, transmission line, or main; exact regulatory definitions depend on the system.

**Gas service line.** A distribution line serving an individual customer or another arrangement defined by the applicable system and rules.

**Gas transmission line.** A pipeline that transports gas among gathering, processing, storage, large volume customers, and distribution systems; diameter and operating pressure vary.

**Ground lead.** A transmitter lead connected to a suitable return point, often a temporary ground stake placed away from the target route.

**Ground mark.** A surface estimate of the top dead center of an assumed to be round signal field, interpreted by the locator; it does not prove the actual pipe or cable position.

**Ground penetrating radar GPR.** A method that sends radar pulses into the ground and interprets reflections from changes in material properties. It does not by itself identify a detected object as a specific utility; depth estimates depend on soil and settings.

**Ground return.** The part of a locating circuit in which current returns toward the transmitter through earth and other available conductive paths; current can divide among paths.

**Handhole.** An access enclosure that may house cables, splices, or other equipment; contents must be confirmed before making a connection.

**Hertz Hz.** One complete cycle per second.

**Horizontal antenna.** A receiver antenna oriented to provide a Peak response to a suitable signal field. Receiver designs differ.

**Horizontal directional drilling HDD.** A trenchless method that steers a drill head along a planned underground path; some drill heads can be tracked with compatible locating equipment.

**Impedance.** The overall opposition to alternating current, including resistance and frequency dependent effects.

**Induction or broadcast.** A transmitter method that couples a signal into nearby conductors without a direct lead or clamp connection. More than one conductor may receive the signal.

**Innerduct.** A smaller duct installed inside a larger conduit, commonly to route communications cables.

**Interference.** An unwanted external signal that masks or complicates reception of the intended locating frequency.

**Lateral.** A branch from a main route toward a service area or customer; usage varies by utility network.

**Locate current.** Alternating current at the selected locating frequency that travels on a conductor and produces a detectable signal field.

**Locate mark.** A surface indication of an interpreted facility route, subject to applicable marking rules and tolerance requirements.

**Magnetic field.** A field associated with electric current or a magnet. The alternating field around a conductor carrying locate current is detected by an electromagnetic receiver.

**Manhole or vault.** An access structure for underground utility equipment or lines. Entry may require confined space procedures.

**Metallic pipeline.** A pipe made of a conductive metal; coating, joints, bonds, and continuity affect how an applied signal travels.

**Metallic shield.** A conductive layer around a cable that may carry current and affect what an electromagnetic receiver detects.

**Non target conductor.** A conductor that is not the intended line but carries or couples to a detectable signal.

**Nonconductive pipe.** A pipe material that does not provide a continuous metallic path for ordinary electromagnetic line locating, such as many plastics. A tracer wire, sonde, acoustic method, or another suitable method may be needed.

**Null response.** A minimum response obtained in a receiver mode using an appropriate antenna arrangement; its apparent position may shift in a distorted field.

**Offset.** A change from a route to a parallel route through bends; records and surface features may not show the exact geometry.

**Ohm law.** The relationship among voltage, current, and resistance in a simple resistive circuit: current equals voltage divided by resistance.

**Ohm  $\Omega$ .** The unit of electrical resistance or, in alternating current calculations, impedance.

**Open circuit.** A break in a conductive path. Coupling and other return paths can sometimes allow a detectable alternating signal despite a break in the intended conductor.

**Passive locating.** Detecting field energy already present on a conductor without applying a transmitter signal, such as power frequency or some radio signals. A passive response does not identify the conductor by itself.

**Peak response.** A maximum response as the receiver crosses a suitable signal field in Peak mode. A Peak is an apparent field center, subject to distortion.

**Pinpointing.** Sweeping across a field to identify and check its apparent center before placing a mark; pinpoint before painting.

**Potholing or test hole.** A small excavation used to expose and directly observe a facility at a specific point, subject to safe excavation practices.

**Primary electric circuit.** Distribution conductors on the higher voltage side of a distribution transformer; actual arrangements and voltages vary.

**Receiver.** The instrument that senses signal fields and provides indications for the locator to interpret; it does not independently identify a utility.

**Record research.** Reviewing available maps, prints, tickets, and operating information to plan and check a locate. Records may be incomplete or outdated.

**Rectifier.** A device that converts alternating current to direct current, including in some impressed current cathodic protection systems.

**Resistance.** Opposition to electric current, measured in ohms. A locating circuit also has frequency dependent impedance.

**Restore.** Returning access points and the work area to a safe condition after locating, including reconnecting authorized bonds and removing temporary equipment.

**RFID electronic marker.** A buried marker that responds to a compatible marker locator at its designated frequency; it identifies a marker location, not a continuous pipe route by itself.

**Scanning.** Checking the work area for surface evidence and detectable signals before and during a locate.

**Secondary electric circuit.** Distribution conductors on the lower voltage side of a distribution transformer serving customer loads.

**Service line.** A line connecting a distribution facility toward a customer or service point; its precise definition depends on the utility.

**Service riser.** A segment where an underground service comes above ground, often near a meter or equipment connection.

**Signal field.** The detectable alternating magnetic field associated with current on a conductor. Nearby conductors may alter the field shape.

**Signal split.** Division of locate current into more than one conductive path, such as at a tee, bond, or branch.

**Signal strength.** A receiver indication of detected field intensity; it depends on distance, orientation, gain, and field conditions as well as current.

**Soil conductivity.** The ability of soil to conduct electric current; moisture, dissolved salts, and other conditions affect it.

**Sonde.** A small self contained transmitter inserted into a nonconductive pipe, duct, or tool. A compatible receiver can locate the sonde position and estimate its depth.

**Splice.** A connection between conductors or cables; its location and electrical continuity can affect a locate.

**Substation.** A facility with equipment for switching, protection, measurement, or changing voltage within an electric system.

**Symmetrical response.** A similar receiver response on both sides of an apparent Peak. Symmetry can support an interpretation but does not by itself prove the utility position.

**Target line.** The pipe, cable, or tracer wire the locator intends to trace. A detected response must be checked against other evidence before being attributed to that line.

**Tee or branch connection.** A point where a facility divides into two or more routes, often causing locate current to split.

**Temporary ground stake.** A conductive stake placed in soil to provide a transmitter return connection during a locate. Placement and soil contact affect the circuit.

**Test lead.** A wire intentionally connected to a structure or corrosion control component for measurement; its purpose must be identified before use.

**Test station CP.** An accessible enclosure with leads connected to a metallic structure or corrosion control components for CP measurements. It is not a tracer wire access point merely because wires are present.

**Tracer wire.** An installed conductor intended to make an otherwise nonconductive facility traceable. Its presence, continuity, access, and routing must be checked; it is not necessarily a fixed gauge or material.

**Tracing.** Following and repeatedly checking an interpreted signal field along a route.

**Transformer.** A device that transfers alternating electrical energy between windings and can change voltage.

**Transmitter.** The instrument that supplies an alternating locating signal by direct connection, clamp, or induction.

**Vacuum excavator.** Equipment that removes loosened soil using suction to expose a buried facility under an appropriate safe digging procedure.

**Valve box.** An enclosure providing access to a valve operator; the visible box is evidence to investigate and does not alone prove the pipe's route.

**Verification.** Checking a locate with independent observations or methods. Physical exposure provides direct confirmation of a buried facility's position at the exposure point.

**Vertical antenna.** An antenna orientation used for a Null response in some receivers; the actual internal arrangements vary by model.

**Volt V.** The unit of electric potential difference.

**Voltage.** Electric potential difference between two points; it can drive current through a complete circuit.