FAULT FINDING SOLUTIONS

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Table of Figures

GOOD CABLE INSULATION

When voltage is impressed across any insulation system, some current leaks into, through, and around the insulation. When testing with dc high-voltage, capacitive charging current, insulation absorption current, insulation leakage current, and by-pass current are all present to some degree. For the purposes of this document on cable fault locating, only leakage current through the insulation will be considered.

For shielded cable, insulation is used to limit current leakage between the phase conductor and ground or between two conductors of differing potential. As long as the leakage current does not exceed a specific design limit, the cable is judged good and is able to deliver electrical energy to a load efficiently.

Cable insulation may be considered good when leakage current is negligible but since there is no perfect insulator even good insulation allows some small amount of leakage current measured in microamperes. See Figure 1.

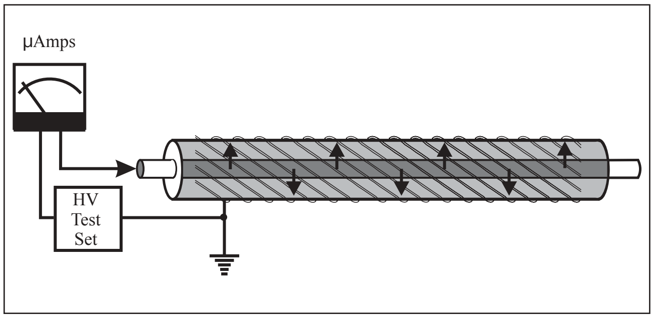


Figure 1: Good insulation

The electrical equivalent circuit of a good run of cable is shown in Figure 2. If the insulation were perfect, the parallel resistance R_P would not exist and the insulation would appear as strictly capacitance. Since no insulation is perfect, the parallel or insulation resistance exists. This is the resistance measured during a test using a Megger® Insulation Tester. Current flowing through this resistance is measured when performing a dc hipot test as shown in Figure 1. The combined inductance (L), series resistance (R_S), capacitance (C) and parallel resistance (R_P) as shown in Figure 2 is defined as the characteristic impedance (Z_0) of the cable.

WHEN CABLE INSULATION IS BAD

When the magnitude of the leakage current exceeds the design limit, the cable will no longer deliver energy efficiently. See Figure 3.

Why A Cable Becomes Bad

All insulation deteriorates naturally with age, especially when exposed to elevated temperature due to high loading and even when it is not physically damaged. In this case, there is a distributed flow of leakage current during a test or while energized. Many substances such as water, oil and chemicals can contaminate and shorten the life of insulation and cause serious problems. Cross-linked polyethylene (XLPE) insulation is subject to a condition termed treeing. It has been found that the presence of moisture containing contaminants, irregular surfaces or protrusions into the insulation plus electrical stress provides the proper environment for inception and growth of these trees within the polyethylene material. Testing indicates that the ac breakdown strength of these treed cables is dramatically reduced. Damage caused by lightning, fire, or overheating may require replacement of the cable to restore service.

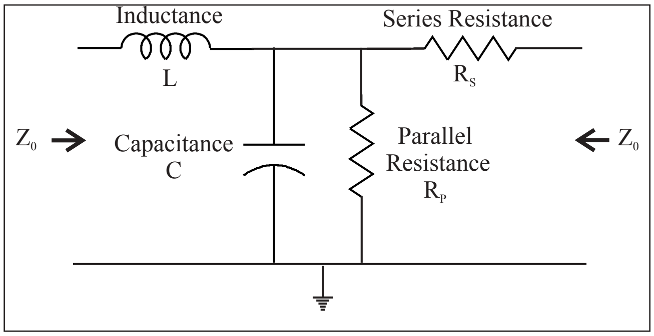


Figure 2: Equivalent circuit of good cable

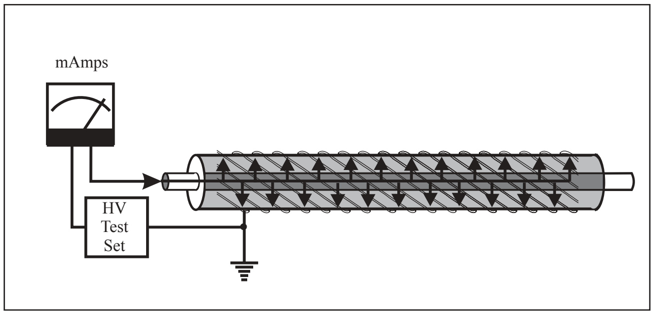


Figure 3: Bad insulation

CABLE FAULTS DESCRIBED

When at some local point in a cable, insulation has deteriorated to a degree that a breakdown occurs allowing a surge of current to ground, the cable is referred to as a faulted cable and the position of maximum leakage may be considered a catastrophic insulation failure. See Figure 4. At this location the insulation or parallel resistance has been drastically reduced and a spark gap has developed. See Figure 5.

Occasionally a series fault shown in Figure 6 can develop due to a blown open phase conductor caused by high fault current, a dig-in or a failed splice.

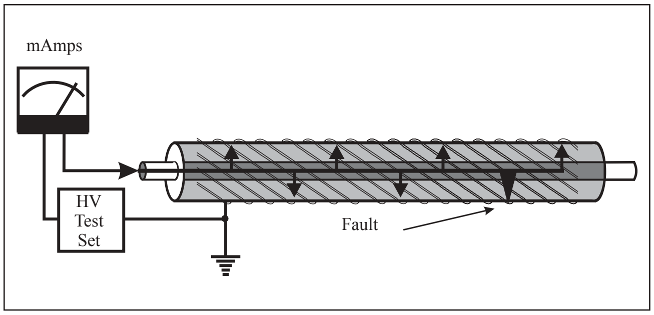


Figure 4: Ground or shunt fault on the cable

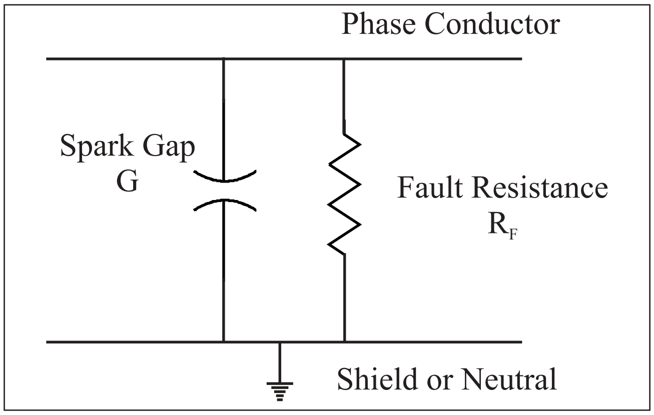


Figure 5: Fault region simplified diagram

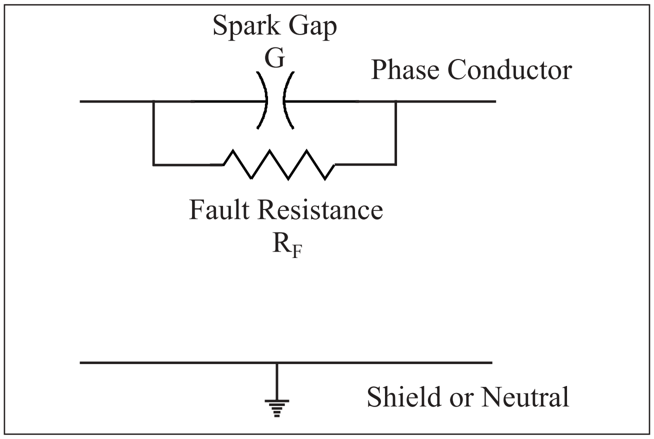


Figure 6: Open or series fault on the cable

LOCATE FAULTS IN BURIED PRIMARY CABLE

After all clearances have been obtained and the cable has been isolated in preparation for cable fault locating, it is strongly recommended that a fixed plan of attack be followed for locating the fault. As in diagnosing any complex problem, following a set step-by-step procedure will help in arriving at the solution or, in this case, pinpointing the fault efficiently.

At the very start, it is a good idea to gather as much information as possible about the cable under test. Information that will help in the fault locating process is:

- Cable type — is it lead covered, concentric neutral (bare or jacketed), tape shield?
- Insulation type — is it XLPE, EPR, Paper?
- Conductor and size — is it CU, AL, stranded, solid, 2/0, 350 MCM?
- Length of the run — how long is it?
- Splices — are there splices, are the locations known?
- T-taps or wye splices — are there any taps, are the locations known, how long are branches?

After obtaining the cable description the acronym "TALL" can help you remember the procedure for finding cable faults in buried cable.

TEST ANALYZE LOCALIZE
LOCATE

TEST THE CABLE

Fault Resistance and Loop Test

Although most faults occur between phase and ground, series opens also occur such as a blown open splice or a dig-in. Phase-to-phase faults can also occur on multi- phase runs. Helpful information can be gathered with a Megger® Insulation Tester that has both megohm and an ohm (continuity) range.

Make a series of measurements as follows:

- At end A, connect the instrument between the faulted conductor and ground as shown in Figure 7. Using an insulation resistance range, measure and record this resistance reading.
- At end A, connect the instrument between each of the other phase conductors, if any, and ground and record the insulation resistance readings.
- After connecting a short between the phase and neutral at end B (Figure 8), do a loop test for continuity at end A using the ohms or continuity range on the instrument. If a reading of greater than 10 ohms is obtained when the cable has a concentric neutral, test the conductor and neutral independently by using a nearby good cable as a return path. This will help to determine whether it is the conductor or neutral that is the problem. A reading in the hundreds of ohms is a good indication of corroded neutral if working on a bare concentric-type cable. If no nearby good cable is available, use a long insulated conductor to complete the loop from end B. If a reading of infinity is measured either the phase conductor or the neutral is completely open between end A and end B which could be caused by a dig-in or a fault that has blown open the phase conductor.
- Repeat all tests from end B and record all readings.

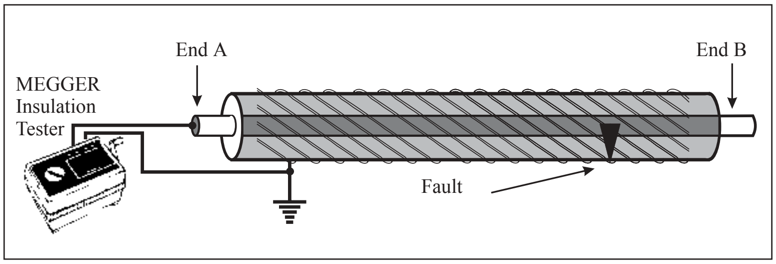


Figure 7: Test for insulation (fault) resistance using a Megger® insulation tester

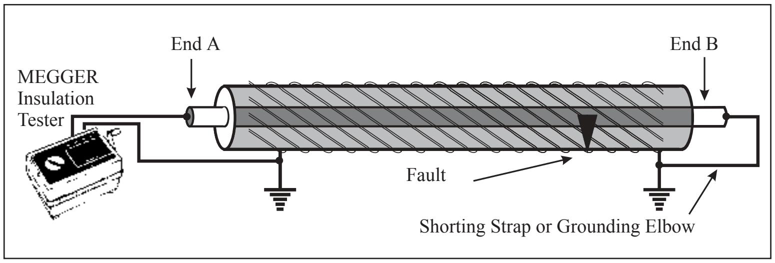


Figure 8: Loop test for continuity using a Megger® insulation tester

TDR Tests

Refer to Section IV for details on the use of the Time Domain Reflectometer.

- At end A, connect a TDR or DART® Cable Analyzer (use the TDR mode) between the faulted conductor and neutral or shield as shown in Figure 9. Look for an upward reflection from the open end of the cable and measure the length to the open using the cursors.
- After connecting a short between phase and neutral at end B (Figure 10), look for the downward indication of a short circuit at the cable end on the TDR. If the TDR shows an alternating open and short when alternately removing and applying the ground at the end of the cable, the phase and shield are continuous to the cable end. If the short does not appear on the TDR and a high resistance was read during the loop test, either the phase or shield is open at some point before the cable end.
- If a downward reflection is observed on the TDR and the fault resistance measured less than 200 Ω in the test, the fault has been found. If a downward reflection is observed on the TDR and the fault resistance measured greater than 200 Ω in the test, there is likely a T-tap or wye splice at that location.

DC Hipot Test

After a surge generator is connected to the cable under test, do a quick dc proof test to be sure the cable is faulted and will not hold voltage. Make a note of the kilovolt measurement when the fault breaks down. This will be an indicator of what voltage will be required when surging in order break down the fault when doing prelocation or pinpointing. If there are transformers connected to the cable under test, a proof test will always indicate a failure due to the low resistance path to ground through the transformer primary winding. A dc proof test in this case is not a valid test.

ANALYZE THE DATA

Fault Resistance and Loop Test

If the insulation resistance of the faulted conductor is less than 50 Ω or more than one MΩ, the fault will be relatively easy to prelocate but may be difficult to pinpoint. For values between 50 Ω and 1 MΩ, the fault may be more difficult to locate. Some reasons for the difficulty with these faults is the possible presence of oil or water in the faulted cavity or the presence of multiple faults.

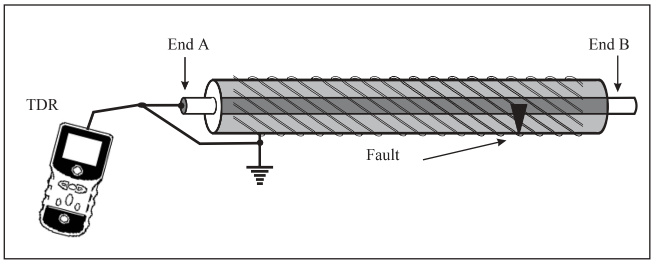


Figure 9: TDR test for cable length

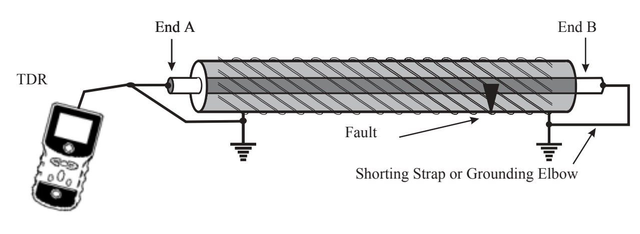


Figure 10: TDR test for continuity

If tests indicate insulation (fault) resistance values less than 10 ohms, it may not be possible to create a flashover at the fault site when surge generator methods are used. This type of fault is often referred to as a bolted fault. A TDR can be used to locate this type of fault.

If a measurement of very low resistance in ohms is made from one end and a high resistance in megohms from the other end, it is likely that the phase conductor or a splice is blown open.

If the loop test indicates a resistance reading in the 10 to 1000 ohm range and particularly if the reading varies during the measurement, there is very likely neutral corrosion on the cable. This could affect success when performing localizing and locating procedures. If the loop test measurement is infinity, indicating an open circuit, either the phase conductor or a splice has blown open or a dig-in has occurred.

TDR Tests

If the TDR tests indicate a shorter than expected cable length with no change of reflections when a short is applied to the cable end there is likely a blown open splice or phase conductor or a dig-in has occurred. If the TDR tests indicate a longer than expected cable run, a thorough route trace may be in order to detect additional cable not indicated on maps.

DC Hipot Test

If the cable holds voltage during the dc hipot test, the cable may be good. If the cable is faulted, burning may be required to reduce the breakdown voltage required when surging or you have connected to the wrong phase.

Cable Route

At this point, it is recommended that the cable route be determined or confirmed by consulting accurate maps or actually tracing the cable route. See Section III. When attempting to localize or locate the cable fault, prelocation measurements and pinpointing techniques must be made over the actual cable path. Being off the route by as little as a few feet may make the locate an extremely difficult and time-consuming process.

LOCALIZE - PRELOCATE THE FAULT

Selection of a localizing technique is based, at least in part, on the character of the fault. Several techniques are fully described in Section VI. They are as follows:

- Sectionalizing
- Bridge — single faults
- TDR/low-voltage radar — faults measuring less than 200 Ω and all opens
- High-voltage radar methods — all faults arc reflection, surge pulse reflection and decay
- Electromagnetic impulse detection — all shorts and some opens

LOCATE - PINPOINT THE FAULT

Locating, often referred to as pinpointing, is necessary before digging up direct buried cable. After the fault has been localized, a surge generator is connected to one end of the faulted cable and then listening in the localized area for the telltale thump from the fault. When the thump is not loud enough to hear, it may be necessary to use a surge detector or an acoustic impulse detector to pinpoint the fault.

Voltage gradient test sets are effective in pinpointing faults on direct-buried secondary cable but the method depends on the fault existing between conductor and earth. When the cable is in conduit, a different method must be used. When a single conductor is contained within a plastic conduit, shorts cannot occur unless water gains access through a crack or other entry point. When a fault develops, leakage current flows from the conductor through the break in insulation, and then follows the water to the break in the conduit to earth. If voltage gradient is used, the location of the crack in the conduit could be found, but the location of the fault in the insulation would remain unknown.

LOCATE FAULTS IN ABOVE GROUND PRIMARY CABLE

Some faults can be found by searching for obvious physical damage to the cable especially if the cable section is short. If necessary, connect a surge generator and walk the cable and listen for the discharge. If the cable is very long it might take a good deal of time to walk the cable while the surge generator is on. To reduce the total time spent and to minimize high-voltage exposure to the cable, use a localizing technique before attempting to pinpoint the fault.

Once the fault is localized, a listening aid is used to zero in on the thump that occurs when the surge generator breaks down the fault. For metal-to-metal (bolted) faults on non-buried cable, an electromagnetic impulse detector may help to pinpoint the fault. The use of electromagnetic impulse detectors is discussed in detail in Section VI.

OVERVIEW

Before attempting to locate underground cable faults on direct buried primary cable, it is necessary to know where the cable is located and what route it takes. If the fault is on secondary cable, knowing the exact route is even more critical. Since it is extremely difficult to find a cable fault without knowing where the cable is, it makes sense to master cable locating and tracing and to do a cable trace before beginning the fault locating process.

Success in locating or tracing the route of electrical cable and metal pipe depends upon knowledge, skill, and perhaps, most of all, experience. Although locating can be a complex job, it will very likely become even more complex as more and more underground plant is installed. It is just as important to understand how the equipment works as it is to be thoroughly familiar with the exact equipment being used.

All popular locators/tracers consist of two basic modules:

The transmitter — an ac generator which supplies the signal current on the underground cable or pipe to be traced.

The receiver — detects the electromagnetic field produced by the transmitted ac current flow. See Figure 11.

Before starting, it will be helpful to obtain the following information:

- What type of cable is it?
- Is the cable the same type all the way along its length?
- Is the target cable the only cable in the trench?
- Are there any taps?
- Is the cable run single phase or multiphase?
- Is the cable shielded or unshielded?
- Is the cable direct buried or in conduit?
- Are there metal pipes or other underground structures under, over or near the target cable?
- Is the target cable connected to other cables or pipes through grounded neutrals?

This information will help to select the most appropriate locator and to prepare to locate the cable successfully. See Figure 12.

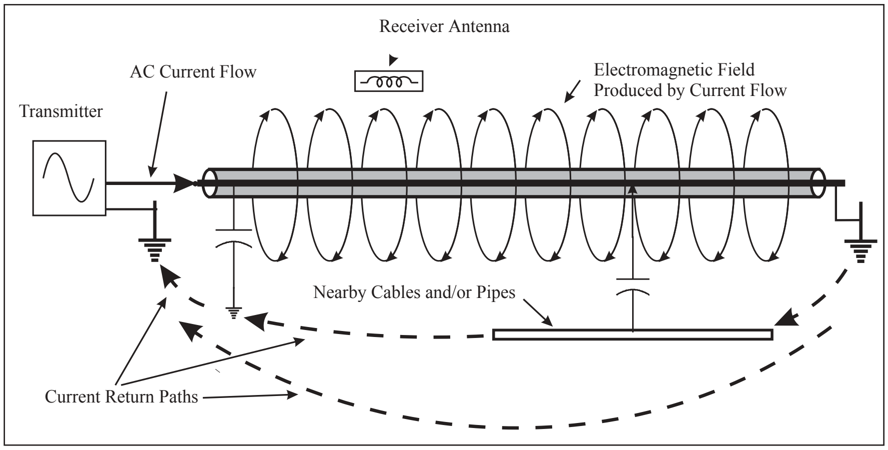


Figure 11: How cable locators work

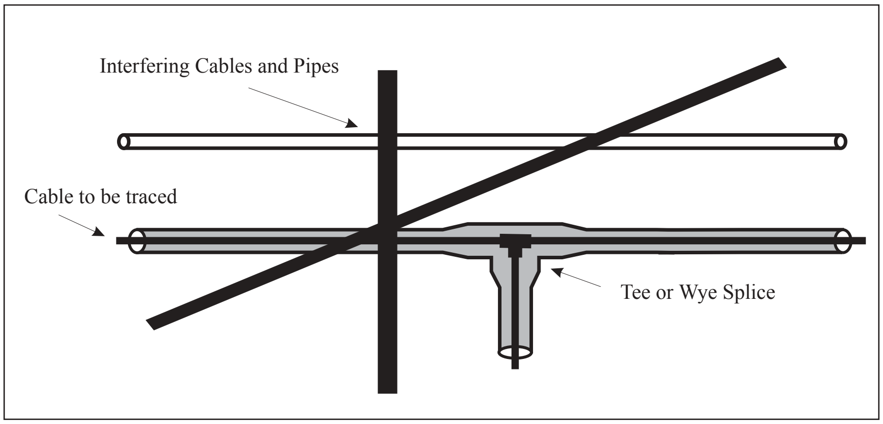


Figure 12: Cable under test

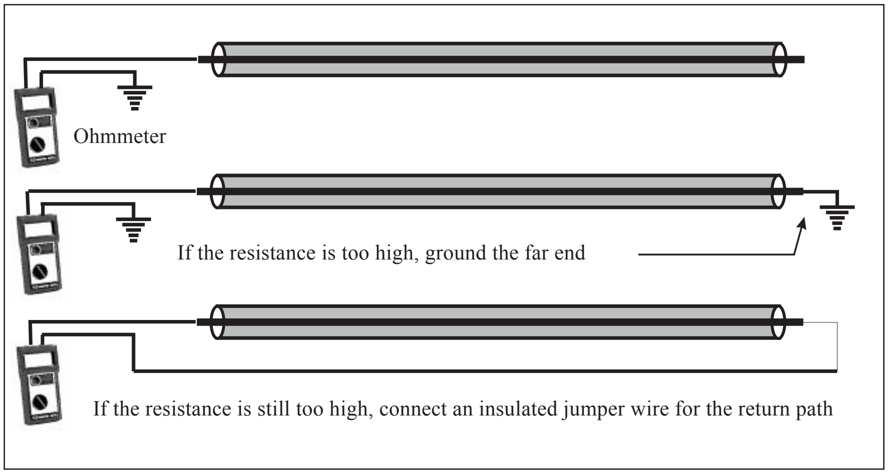


Figure 13: Using an ohmmeter to measure resistance of the circuit

Many transmitters are equipped with some means of indicating the resistance of the circuit that it is trying to pump current through and can indicate a measurement of the current actually being transmitted. Output current can be checked in several ways as follows:

- By measuring the resistance of the circuit with an ohmmeter. When the resistance is less than approximately 80,000 Ω, there will typically be enough current flowing in the cable to allow a good job of tracing. This is no guarantee that the transmitted current is passing through the target cable. The measured resistance may be affected by other circuits or pipes electrically connected to the target cable acting as parallel resistances. See Figure 13.
- By observing the actual signal strength being transmitted by the transmitter. Many transmitters provide a measurement or some indication of output current. A loading indicator on the Portable Locator Model L1070 blinks to indicate the approximate circuit resistance. A rate of four blinks per second indicates a low resistance, almost a short circuit providing a very traceable signal. A rate of one blink every three seconds shows a high resistance and a weaker signal.
- By observing the signal power detected by the receiver. Signal level indicator numbers are displayed digitally on most receivers and older models may display signal power with analog meters. The L1070 has both an analog style signal strength bargraph plus a digital numeric readout. Tracing experience gives the operator the ability to judge whether or not the numbers are high enough. This is the most practical way to check signal current flow.

Remember, the more current flow through the conductor the stronger the electromagnetic field being detected by the receiver and the further from the conductor being traced the less field is being detected.

SELECTING A LOCATOR

Cable locating test sets, often referred to as cable tracers, may be grouped as follows:

- Low frequency — usually less than 20 kHz sometimes referred to as audio frequency (AF).
- High frequency — usually higher than 20 kHz and in the radio frequency (RF) range to about 80 kHz.
- 60 Hz — most tracers provide this mode to allow tracing of energized cables.

Low frequency (AF) is considered the general-purpose selection because it is more effective in tracing the route of cables located in congested areas due to less capacitive coupling to everything else in the ground. Low frequency can be more effective over greater distances due to less capacitive leakage and because higher signal power is allowed by the FCC. The use of high frequency (RF) is typical in non-congested areas on relatively short lengths of cable or when a return path cannot be provided from the far end. If a proper return path is provided, either low or high frequencies can be used effectively for very long distances. The L1070 allows selection of AF, RF, both AF and RF, or 60 Hz as required by the specific application.

HOOKUPS

When a direct-buried secondary cable is to be traced, the transmitter is connected to the conductor. When coaxial types of primary cable are traced, the signal may be transmitted along either the phase conductor or the neutral.

Whenever possible use the direct connection method with the test leads supplied with the locator. This is often referred to as the conductive method. Connect one output lead (usually red) from the transmitter to the conductor under test making sure that the alligator clip is making good contact. Connect the other lead (usually black) to a temporary metal ground probe and check that the pin is making good contact with the earth. When the earth is dry it may be necessary to use a longer metallic ground stake or to pour water on the ground rod to give it better contact with the earth. Place the ground rod off to the side as far away from the target cable as practical, but try to avoid crossing over neighboring cables and pipes. It may be necessary to vary the location of the ground rod to obtain suitable results.

For best results, install a temporary ground connection to the far end of the conductor being traced. See Figure 14. In this case either AF or RF can be used. If a ground cannot be applied to the far end, use RF and expect that the effective traceable length may be as short as 200 feet. See Figure 15. The only current flow in this situation is due to capacitive current flow and after some point the signal disappears.

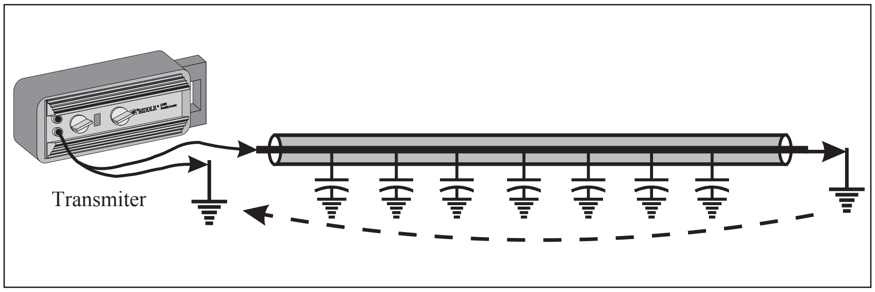


Figure 14: Hookup showing ground rod at far end of cable under test

If a direct connection is impossible, a clamp coupler can be used to induce the signal current onto the target cable. See Figure 16. If tracing a primary cable, place the loop around the neutral. When tracing secondary, connecting jumper wires from the conductor to earth at both ends of the cable may be necessary to obtain an adequate signal current flow through the target cable. Remember that for sufficient current to flow to produce a strong traceable field there must be a loop or return path provided back to the source.

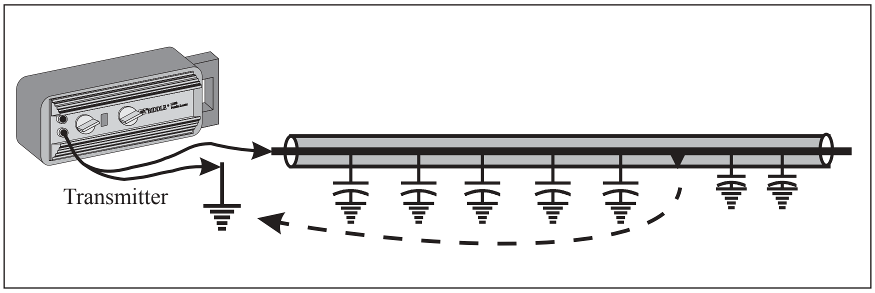


Figure 15: Hookup with far end of cable under test isolated

If a current coupler is not available, the transmitter module itself can be used to couple the signal inductively from an antenna in the base of the transmitter into the cable. See Figure 17. The transmitter is set on the earth directly over the target cable with the arrow on the top panel in line with the cable. Use the RF frequency selection and keep the transmitter and receiver at least 25 feet apart to avoid interfering signals generated directly through the air.

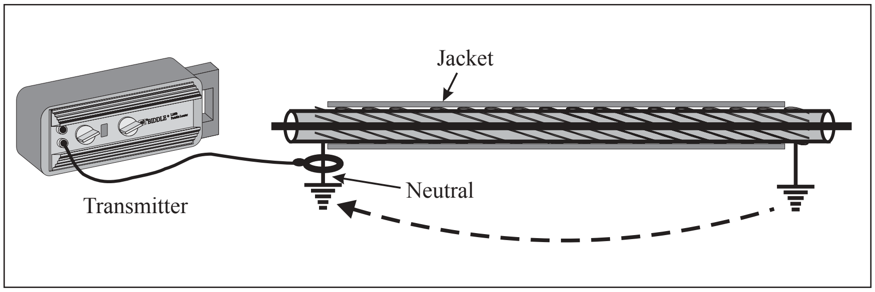


Figure 16: Current coupler connection to neutral on primary jacketed cable

Keep in mind that the best technique is to connect the isolated far end of the target cable to a temporary ground rod beyond the far end of the cable. This will reduce the loop resistance, increase the transmitted current flow, and maximize the strength of the signal to be detected by the receiver. See previous Figure 14.

When the far end is parked and isolated, loop current is entirely dependent upon capacitive coupling through the insulation or jacket of the cable and through any faults to ground that may be present. See previous Figure 15.

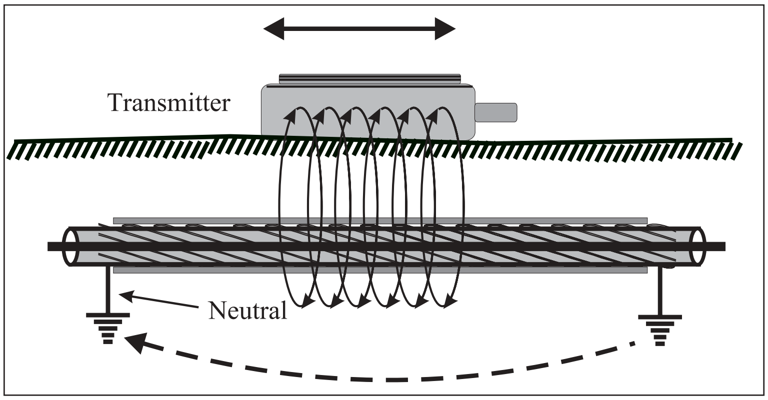


Figure 17: Inductive coupling to neutral on primary jacketed cable

Figure 18: Use of return wire to improve current loop

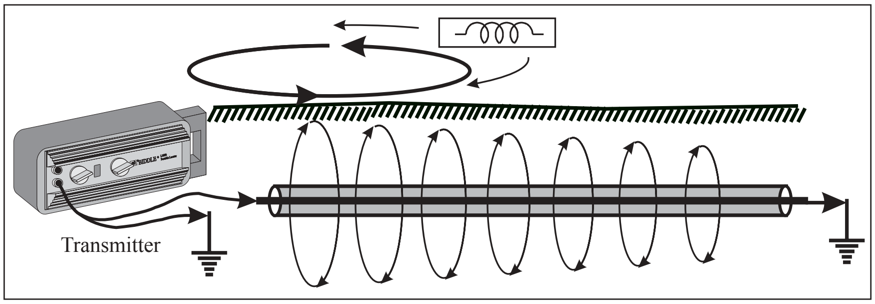


Figure 19: Circling path with receiver

If all else fails and in a very congested area, complete the current loop by using a long insulated jumper wire connected between one side of the transmitter and the far end of the cable under test. This technique has limitations as to length but will definitely limit current flow to the target cable. See Figure 18. Remember to keep the route of the return wire well off to the side to avoid interference.

Direct buried concentric neutral cable can be traced by connecting the transmitter to the conductor or the neutral. Remember that when connected to the neutral, the signal can more easily bleed over to other cables and pipes that may be connected to the ground. A stronger tracing signal can sometimes be developed when the transmitter is connected to the neutral. This is particularly true when using a current clamp or coupler as shown previously in Figure 16.

USING THE RECEIVER

To begin the tracing process, start by circling the connection point to the target cable at a radius of 10 feet or so to find the position with the strongest signal when using the peaking mode. See Figure 19. The L1070 receiver allows pushbutton selection of either the peaking or nulling modes of tracing. See Figure 20. Some older models require a change in position of the antenna head from horizontal to vertical. Most receivers now also provide an automatic depth measurement, usually with the push of a button. Older units require positioning of the antenna head at a 45-degree angle and following the process shown in Figure 21.

In the peaking mode of operation, a maximum signal level is obtained when the receiver is positioned directly over the target cable. In the nulling mode, a minimum signal is detected when directly over the target cable. Some units provide a simultaneous display of both modes. In general, if the object of tracing is simply to locate the approximate path of the target cable, the peaking mode is recommended. If a more accurate trace is required such as prior to secondary fault locating or splice locating, the nulling mode may be the better choice. An analog bar-graph display, a digital numeric readout, a variable volume audible tone or all three may indicate the receiver signal level.

While walking along the route with the strongest signal level, note the value of signal strength. Also while tracing, periodically check the depth. If the signal level numbers drop as you proceed along the path away from the transmitter, there should be a corresponding increase in depth. If the signal level increases as you proceed along the path, there should be a corresponding decrease in depth. If signal level decreases, even though the depth does not increase, it could mean that you have just passed a fault to ground or a wye splice.

The transmitter current flow beyond a fault may be significantly reduced to only capacitive leakage so the resulting drop in signal level may be enough evidence to conclude that a fault to ground has been passed.

When no interference is present, the combined antennas in the receivers of newer locators will sense both a null and a peak magnetic field at the identical spot directly over the target cable. Interfering conductors and pipes can cause the magnetic field around the target cable to become oval, or egg-shaped rather than circular and concentric. This will cause an offset between the detected and actual location. See Figure 22. This problem is often not possible to detect at the time the locating is being carried out and is only discovered when digging begins. To prevent this, every effort should be made to prevent signal current from bleeding or leaking onto other conductors in the area, which is often impossible.

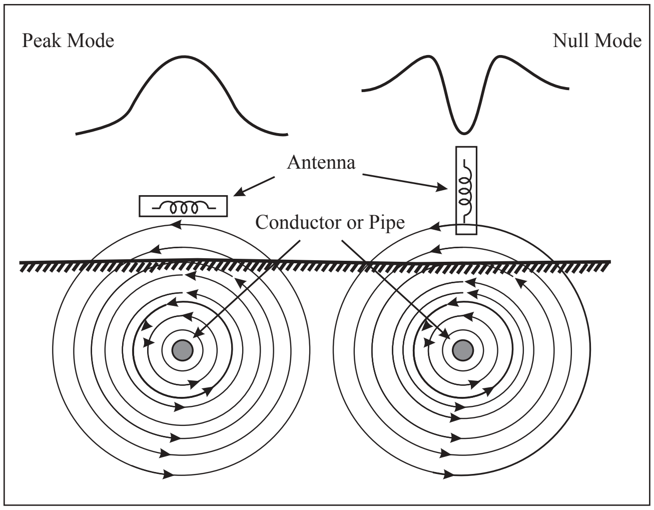


Figure 20: No interference — no offset between magnetic field center and center of cable

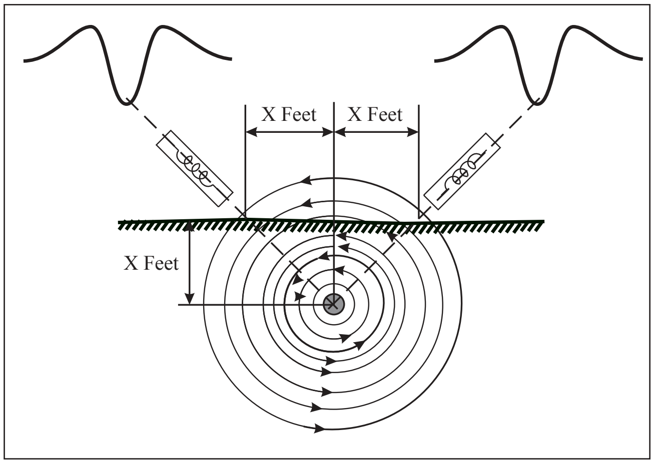


Figure 21: Depth measurement using null method with antenna at 45-degree angle

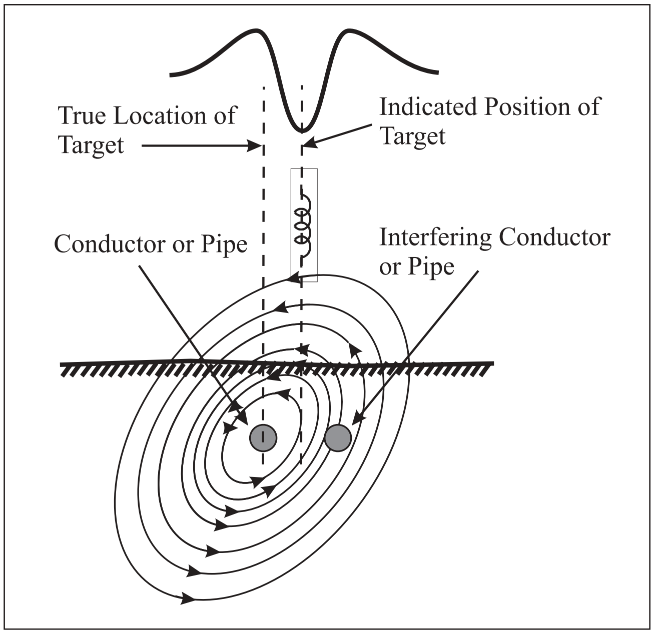


Figure 22: Offset caused by interference from non-target cable

METHODS OF OPERATION

Cable analyzers provide a visual display of various events on electrical cable and may serve as the control center for advanced cable fault locating test systems. Displays include cable traces or signatures which have distinctive patterns. Signatures represent reflections of transmitted pulses caused by impedance changes in the cable under test and appear in succession along a baseline. When adjustable markers, called cursors, are moved to line up with reflections, the distance to the impedance change is displayed. When used as a TDR, approximate distances to important landmarks, such as the cable end, splices, wyes and transformers can also be measured.

Time Domain Reflectometry

The pulse reflection method, pulse echo method or time domain reflectometry are terms applied to what is referred to as cable radar or a TDR. The technique, developed in the late 1940's, makes it possible to connect to one end of a cable, actually see into the cable and measure distance to changes in the cable. The original acronym, RADAR (RAdio Detection And Ranging), was applied to the method of detecting distant aircraft and determining their range and velocity by analyzing reflections of radio waves. This technique is used by airport radar systems and police radar guns where a portion of the transmitted radio waves are reflected from an aircraft or ground vehicle back to a receiving antenna. See Figure 23.

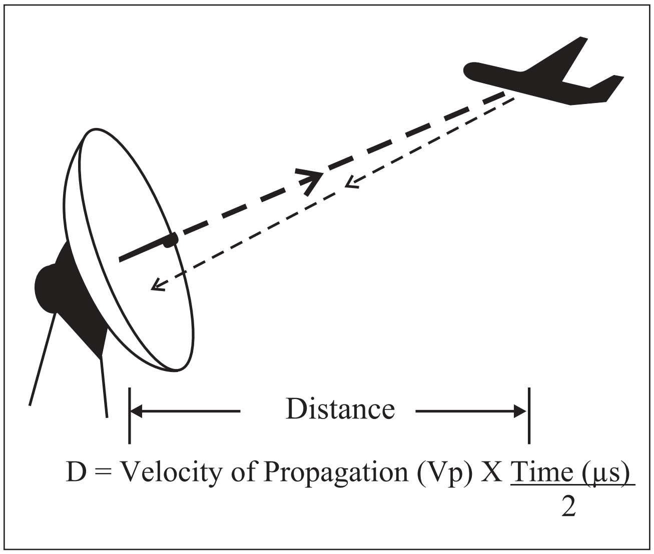


Figure 23: Aircraft radar

The radar set, other than the electronics to produce the pulses of radio frequency energy, is basically a time measuring device. A timer starts counting microseconds when a pulse of radio frequency energy leaves the transmitting antenna and then stops when a reflection is received. The actual time measured is the round trip, out to the target and back. In order to determine simply distance out to the target, the round trip time is divided by two. If the speed of this pulse as it travels through the air in microseconds is known, distance to the target can be calculated by multiplying the time measured divided by 2 times the velocity.

$$\text{Distance} = V_p \frac{\text{time}}{2}$$

The speed or Velocity of Propagation (Vp) of this pulse in air is nearly the speed of light or approximately 984 feet per microsecond.

This same radar technique can be applied to cables if there are two conductors with the distance between them constant for the length of the run and a consistent material between them for the length of the run. This means that a twisted pair, any pair of a control cable, any pair of a triplex cable, or any coaxial cable are radar compatible. When applied to underground cable, 10 to 20 volt, short time duration pulses are transmitted at a high repetition rate into the cable between the phase conductor and neutral or between a pair of conductors. A liquid crystal or CRT display shows reflections of the transmitted pulses that are caused by changes in the cable impedance.

Any reflections are displayed on the screen with elapsed time along the horizontal axis and amplitude of the reflection on the vertical axis. Since the elapsed time can be measured and the pulse velocity as it travels down the cable is known, distance to the reflection point can be calculated. Pulses transmitted through the insulation of typical underground cable travel at about half of the speed of light or about 500 feet/µs. Movable cursors when positioned at zero and a reflection point provide a measurement of distance to that point in feet.

The TDR sees each increment of cable, for example each foot, as the equivalent electrical circuit impedance as shown in Figure 24. In a perfect length of cable, all of the components in every foot are exactly like the foot before and exactly like the next foot.

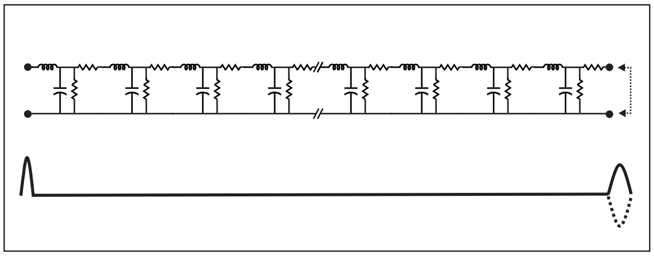


Figure 24: TDR reflections from perfect cable

This perfect run of cable will produce no reflections until the end of the cable appears. At the end of the cable the pulses see a high impedance (an open circuit), causing an upward reflection. If the cable end is grounded (a short circuit), the pulses see a low resistance and a downward reflection is caused. A low-voltage TDR is an excellent tool for the prelocation of series open circuits and conductor to conductor shorts. For cable shunt or ground faults with a resistance higher than 200 ohms the reflection is so small it is impossible to distinguish from normal clutter reflections on the cable. Unfortunately, almost all faults on primary underground distribution cable are high resistance faults in the area of thousands of ohms or even megohms. Due to the reflection characteristics of these high resistance faults, they are impossible to see using only the low-voltage TDR. An alternate technique such as arc reflection must be utilized to prelocate these faults as discussed in Section VI.

Differential TDR/Radar

When a TDR such as the Megger Model CFL535F which has two inputs and is programmed to allow a display of the algebraic difference between two input traces, a technique referred to as differential TDR can be used. If the two traces (L1 and L2) are identical, the display will show a totally flat line. When using differential TDR, any difference between the two phases (L1 minus L2) will be easily identified on the display. This can be useful when fault locating on a three-phase system where the faulted phase can be compared to a good phase. The fault is likely where the difference is and the cursor can be positioned to measure the distance to that point.

DESCRIPTIONS AND APPLICATIONS

Low-Voltage TDR/Cable Radar

A low-voltage TDR is an appropriate method to localize faults and other impedance changes on electrical cable such as twisted pair, parallel pair, and coaxial structure. TDRs are available in small hand-held, larger portable, and rack mount configurations for a broad variety of applications. Low-voltage, high-frequency output pulses are transmitted into and travel between two conductors of the cable. When the cable impedance changes, some or all of transmitted energy is reflected back to the TDR where it is displayed. Impedance changes are caused by a variety of disturbances on the cable including low resistance faults and landmarks such as the cable end, splices, taps, and transformers. See Figures 25 through 31 for typical reflections or cable traces.

Faults That a Low-Voltage TDR Will Display

Low resistance faults of less than 200 Ω between conductor and ground or between conductors are displayed as downward reflections on the screen. Series opens, since they represent a very high resistance, are displayed as upward going reflections. See Figures 27 and 28.

Landmarks That a Low-Voltage TDR Will Display

A TDR can localize cable landmarks, such as splices, wye or T-taps, and transformers. See Figures 29 through 31. The TDR helps to determine the location of faults relative to other landmarks on the cable. This is especially true on complex circuits. Traces of complex circuits are necessarily also very complex and difficult to interpret. To make sense of these complex traces, it is extremely helpful to confirm the position of landmarks relative to the faults observed. See Figure 32.

For every landmark that causes a reflection, there is slightly less transmitted pulse amplitude traveling from that point down the cable. This means on a cable run with two identical splices, the reflection from the first splice will be larger than that of the second down the cable farther. No conclusions can be drawn based on the size or height of reflections at different distances down the cable.

CONTROLS AND INPUTS TO THE TDR

Velocity of Propagation

Certain information must be provided to the TDR before it can provide distance information. Most important is velocity of propagation (VP), the speed at which the transmitted pulse travels down the cable under test. This value is used by the analyzer to convert its time measurement to distance. This velocity is primarily dependent on the type of cable insulation although technically is also affected by conductor size and overall cable diameter. The table to the right shows typical velocity values for various primary cable types.

An alternate method to determine an unknown velocity value is to:

1. Set the right cursor to the upward-going reflection at the end of the cable section.
2. Determine the true length of the section of cable under test.
3. Adjust the velocity until the correct distance is displayed.

If a known length of cable is available on a reel, the above procedure may be used. The longer the sample of cable the better for an accurate determination of velocity.

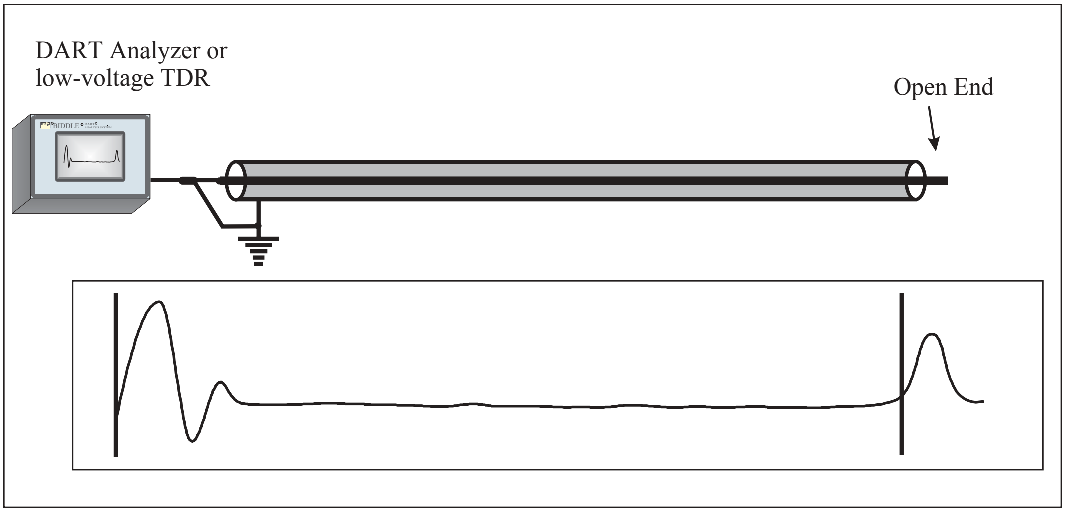


Figure 25: TDR used to measure length of cable with far end open

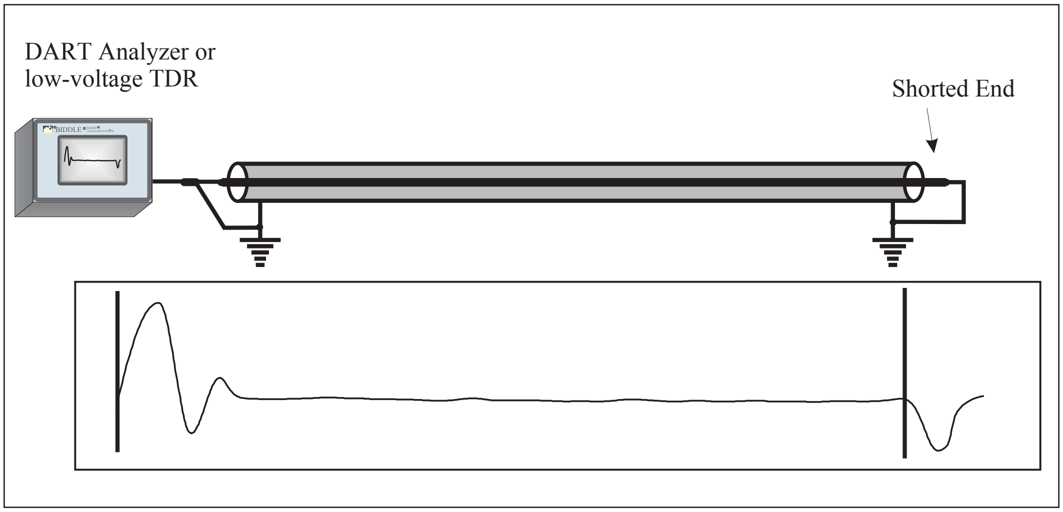


Figure 26: TDR used to measure length of cable with far end shorted

The units of velocity can be entered into the DART Analyzer or TDR in feet per microsecond (ft/μs), meters per microsecond (m/μs), feet per microsecond divided by 2 (Vp/2) or percentage of the speed of light (%).

The values in the Velocity of Propagation Table are only approximate and are meant to serve as a guide. The velocity of propagation in power cables is determined by the following:

- Dielectric constant of the insulation
- Material properties of the semiconducting sheaths
- Dimensions of the cable
- Structure of the neutrals, integrity of the neutrals (corrosion)
- Resistance of the conductors
- Additives in the insulation
- Propagation characteristics of the earth surrounding the cable

With such a large number of variables and a number of different manufacturers, it is impossible to predict the exact velocity of propagation for a given cable. Typically, utilities standardize on only a few cable types and manufacturers and have soil conditions that are similar from installation to installation. It is highly recommended that fault location crews maintain records of propagation velocities and true locations. Using this information, accurate, average propagation velocities can be determined.

Velocity of Propagation Table

Insulation Type	kV	Wire Size	Vp Percent	Vp Ft/μs	Vp M/μs	Vp Ft/μs
EPR	5	#2	45	443	135	221
EPR	15	#2 AL	55	541	165	271
HMW	15	1/0	51	502	153	251
XLPE	15	1/0	51	502	153	251
XLPE	15	2/0	49	482	147	241
XLPE	15	4/0	49	482	147	241
XLPE	15	#1 CU	56	551	168	276
XLPE	15	1/0	52	512	156	256
XLPE	25	#1 CU	49	482	147	241
XLPE	25	1/0	56	551	168	276
XLPE	35	1/0	57	561	171	280
XLPE	35	750 MCM	51	502	153	251
PILC	15	4/0	49	482	147	241
XLPE	0.6	#2	62	610	186	305
Vacuum	—	—	100	984	300	492

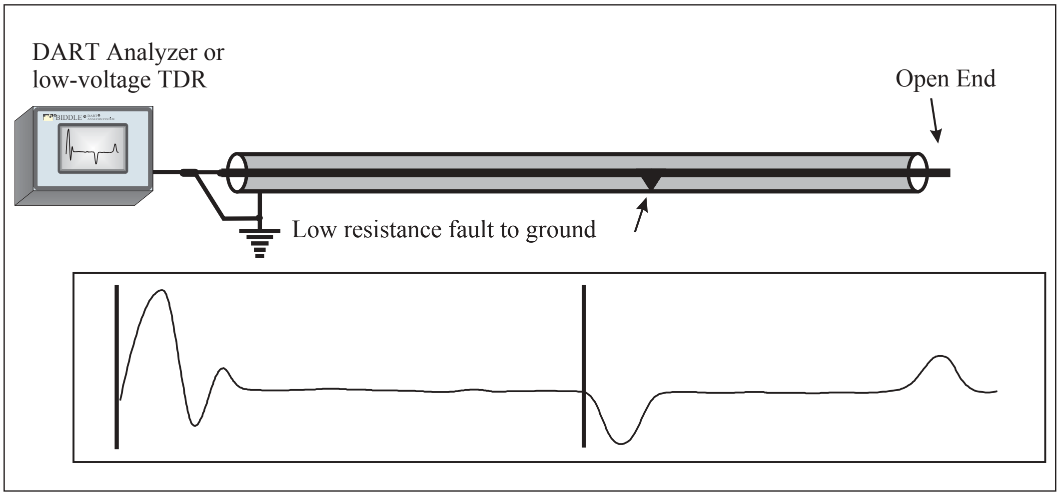


Figure 27: TDR measuring distance to a low-resistance fault to ground

Range

Range is the maximum distance the TDR sees across the face of the display. Initially, select a range longer than the actual cable length so the upward-going reflection from the end can be identified. Move the right cursor to that upward reflection and measure the total length. Does the measurement make sense? A range can then be selected that is less than the overall cable run but the TDR will only see out the distance of the range setting.

Gain

Gain changes the vertical height or amplitude of reflections on the display. It may be necessary to increase the gain on a very long cable or a cable with many impedance changes along its path to identify the end or other landmarks. Gain adjustment has no effect on measurement accuracy.

Cursors

For all TDR measurements, the cursor is positioned at the left side of the reflection, just where it leaves the horizontal baseline either upward or down. Move the right cursor to the reflection of interest just as it leaves the base line so that the TDR can calculate its distance. If the left cursor is set to the left of the first upward-going reflection, its zero point is at the output terminals of the instrument. If you do not recalibrate, it will be necessary to subtract your test lead length from all distances measured. Remember, the TDR measures every foot of cable from the connector on the instrument to the reflection of interest.

When the test leads are especially long (such as 125 feet long on most high-voltage radar systems), it is often desirable for you to set the left cursor to the end of the test leads. When this offset is calibrated, the distance indicated by the right cursor will not include the length of the test leads. To do this calibration in the field simply touch the ends of the test leads and position the left cursor at the toggle point as the TDR sees an open and then a short. Press the Save Offset to set the left cursor zero to that point.

Zoom

When you have set the cursor at the reflection of interest, the distance to that point on the cable run will appear in the distance readout. When a zoom feature is provided, the area centered around the cursor is expanded by the zoom factor selected: X2 (times 2), X4 (times four), etc. It is often possible to set the cursor to a more precise position when the zoom mode is activated and the reflection is broadened.

Pulse Width

The width of the pulses generated by the TDR typically ranges from 80 nanoseconds up to 10 microseconds. As range is changed from shorter to longer, the pulse width is automatically increased in width so that enough energy is being sent down the cable to be able to see some level of reflection from the end. The wider the pulse the more reflection amplitude but the less resolution. The narrower the pulse the more resolution but less reflection amplitude. For the best resolution or in order to see small changes on the cable, a narrow pulse width is required and in order to see the

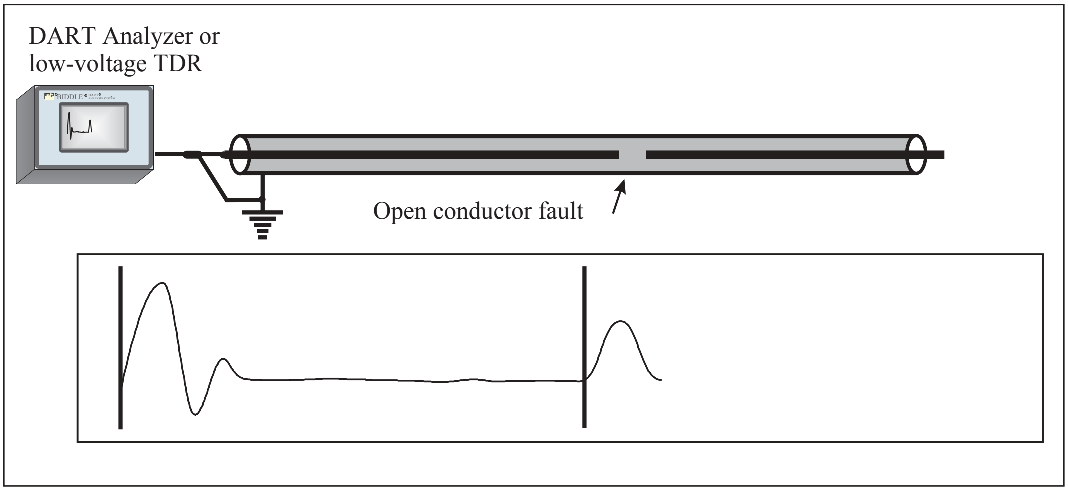


Figure 28: TDR used to measure distance to open in conductor

end a wide pulse width may be required. The pulse width may be changed manually to override the automatic selection. An effect termed pulse dispersion widens the pulse as it travels down a long run of cable so resolution may be worse toward the end of a long cable.

DISTANCE MEASUREMENTS

Three-Stake Method

Measurements to a fault using a low-voltage TDR are strictly a localizing technique. Never dig a hole based solely on a TDR measurement. There are too many variables that include:

- The exact velocity
- The exact cable route
- The accuracy of the TDR itself

The three-stake method is a means to get a reasonably accurate fault pinpoint using only the TDR. The method consists of making a fault distance reading from one end (terminal 1) of the faulted line and placing a marker (stake 1) at that position as shown in Figure 32. With the TDR connected at the other end of the line (terminal 2), find the fault distance for a second marker (stake 2). In actual practice, stake 2 may fall short of stake 1, may be located at the same point, or may pass beyond stake 1. In any case the fault will lie between the two stakes. It is important that the same velocity setting is used for both measurements and the distance measurements are made over the actual cable route. This may mean tracing the cable.

Location of the third marker (stake 3), the actual fault, may be found by using the proportionality that exists between the fault distances, d1 and d2, and their error distances, e1 and e2. To locate stake 3, measure the distance d3 between stakes 1 and 2 and multiply it by the ratio of distance d1 to the sum of distances d1 and d2. Stake 3 then is placed at this incremental distance, e1, as measured from stake 1 toward stake 2.

$$e_1 = d_3 \frac{d_1}{d_1 + d_2}$$

Alternatively, stake 3 can be placed at the incremental distance, e2, as measured from stake 2 toward stake 1.

$$e_2 = d_3 \frac{d_2}{d_1 + d_2}$$

This third stake should be very close to the fault.

A practical field approach (with no math involved) is to make a second set of measurements from both ends with a different velocity. If the distance between stakes 1 and 2 was 50 feet, by adjusting the velocity upward the new distance measurements may reduce the difference to 30 feet. With enough tests at differing velocities the distance can be lowered to a reasonable backhoe trenching distance.

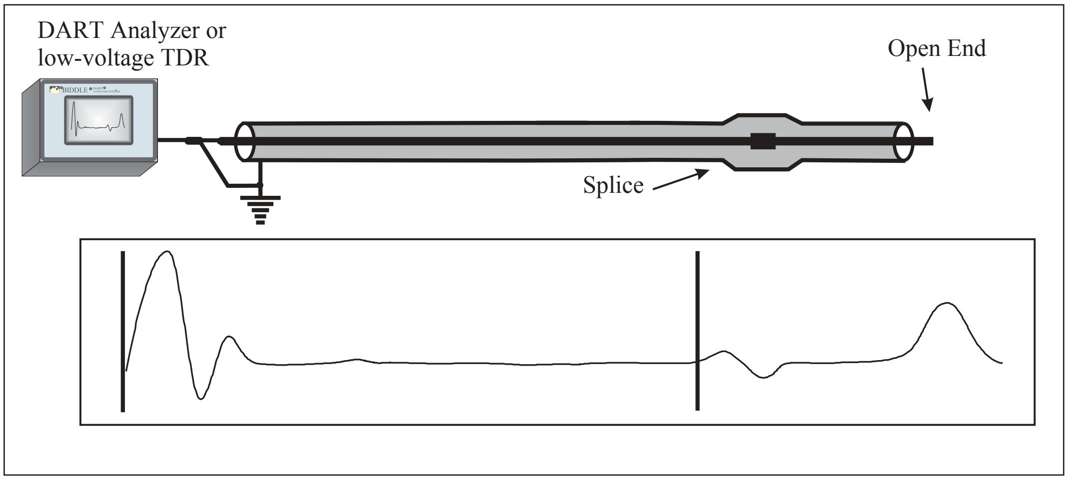


Figure 29: TDR used to localize distance to a splice

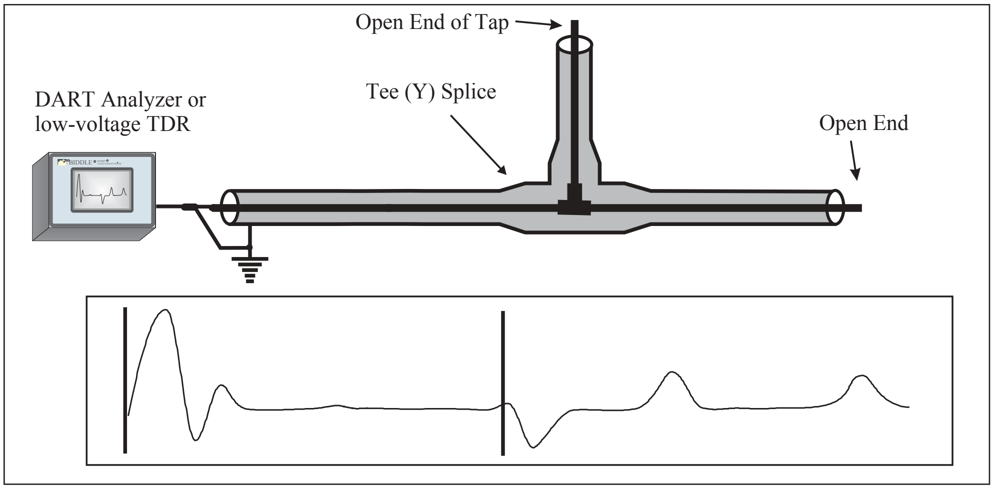


Figure 30: TDR used to localize distance to a T-tap

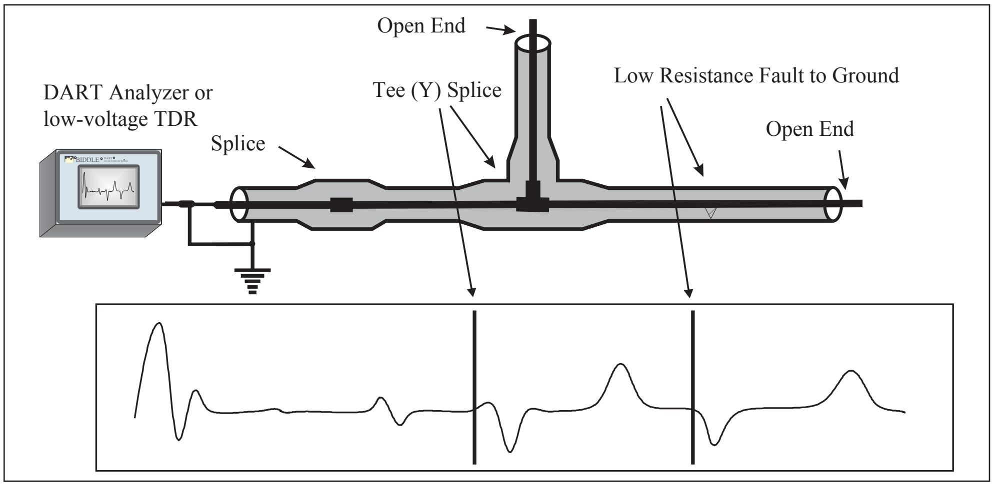


Figure 31: TDR used to localize distance to a fault relative to a landmark

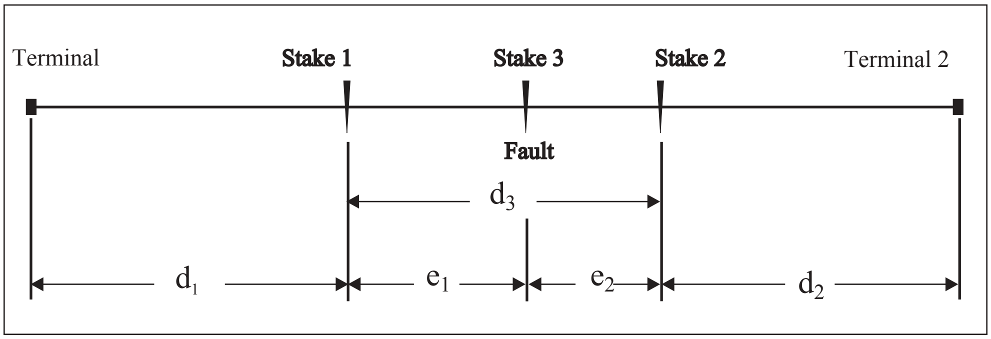


Figure 32: Three-stake method

SURGE GENERATORS

The first commercially available surge generators for underground cable fault locating were introduced in the late 1940's. The device is basically a high voltage impulse generator consisting of a dc power supply, a high voltage capacitor, and some type of high voltage switch. See Figure 33.

The power supply is used to charge the capacitor to a high voltage and then a contact closure discharges the capacitor into the cable under test. If the voltage is high enough to break down the fault, the energy stored in the capacitor is rapidly discharged through a flashover at the fault creating a detectable sound or "thump" at ground level. The important specifications of a thumper are the maximum voltage it can develop and how much energy it delivers to the fault.

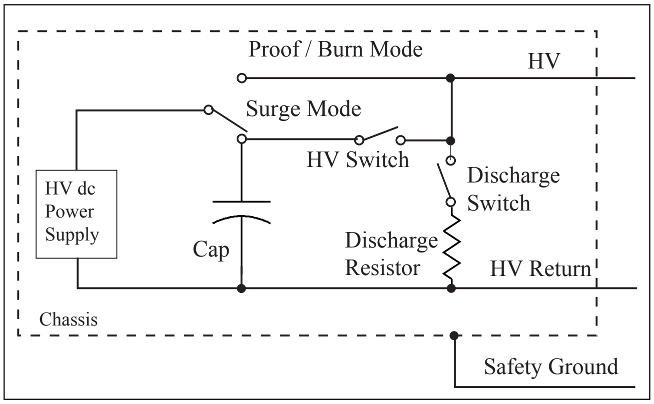


Figure 33: Block diagram of surge generator

The classical fault locating process has been to hook up the surge generator, crank up the voltage, and walk back and forth over the cable route until the thump is heard or better yet to feel the earth move. This process pinpoints the fault allowing a repair crew to dig a hole and repair the cable. In some cases, it may take hours (or days) to walk the cable and definitely locate the fault. During that time, the cable is being exposed to high voltage thumping.

A few years after polyethylene cable began to be installed underground, evidence began to surface that due to "treeing" in the insulation, high-voltage thumping of this plastic cable for long periods of time was doing more harm than good. The same is not true for PILC cables where typically higher voltage and more energy is required to locate faults with no damage to the cable. There is mixed opinion as to the treeing situation in EPR. Due to this treeing situation, many utilities issued work rules reducing the maximum allowable voltage to be used for fault locating.

Energy

The energy output of any surge generator measured in Joules (Watt-Seconds) is calculated as follows:

$$E = V^2 \frac{C}{2}$$

where E = Energy in Joules, C = capacitance in μf,

V = voltage in kV

To increase the "bang" at the fault the only two options are to increase the voltage which can be done by the operator or increase the capacitance which must be done by the manufacturer. Figure 34 shows the output energy curve of a typical four microfarad surge generator that generates 1250 Joules at a maximum voltage of 25 kV. If the fault locating crew is told that the output voltage of the thumper must be limited to 12.5 kV (one half of 25 kV), the output energy of their thumper is reduced by a factor of four down to 312 Joules.

In a practical world, 300 to 400 Joules is the threshold for hearing a thump at ground level with no acoustic amplification and with very little background noise. If the thump at the fault can not be heard, the only option is to increase voltage in order to find the fault, make a repair and get the lights back on.

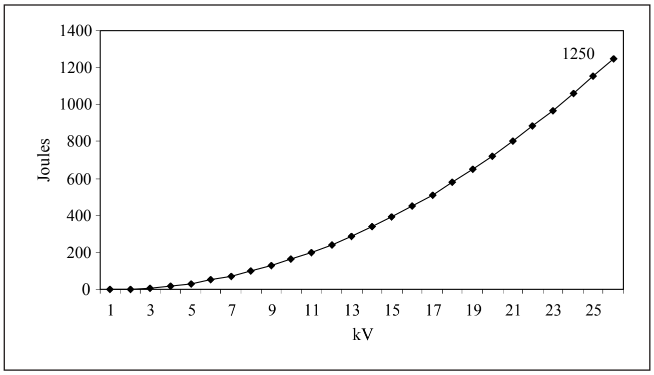


Figure 34: Energy vs. voltage for a 4-μF, 25-kV surge generator

To help in lowering the voltage required to locate underground faults, the PFL-4000 Surge Generator uses a 12 microfarad capacitor producing 1536 Joules at 16 kV. See Figure 35. This allows thumping at lower voltages while still delivering reasonable energy to the fault. Thumping at 12.5 kV, as above, now produces a very audible 937 Joules.

Different surge generator energy levels are required to do fault locating on different lengths and types of cable constructions. XLPE and EPR insulated cables typically require much less energy to locate a fault than a lead cable of comparable size and construction. For long runs or complex systems of lead cable that cannot be broken down into small manageable sections, high voltage and energy may be required to flashover a fault.

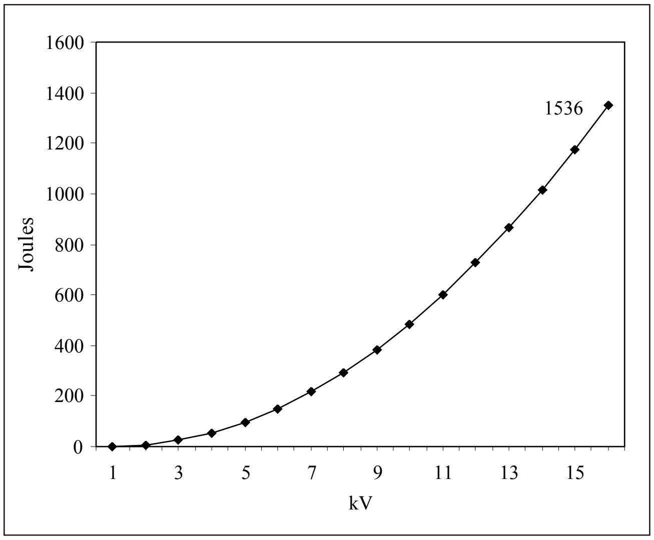


Figure 35: Energy vs. voltage for a 12-μF, 16 kV surge generator

There are currently two types of surge generators available, one referred to as progressive energy as described above and the second, constant energy. The constant energy units contain two or more capacitors with a corresponding voltage range for each capacitor. The energy is only constant at the maximum voltage on each range. A typical example is a PFL-6000 with two voltage ranges of 0 to 16 kV and 0 to 32 kV. When the 16 kV range is selected, a 24 μF capacitor is switched in and when the 32 kV range is selected a 6 μF capacitor is used. In this case, at 16 kV or 32 kV the energy output will be a constant 3072 Joules. See Figure 36.

Capacitance

Cables by their very nature are capacitive since they consist of two conductors separated by an insulator. The two conductors in power cable are the phase conductor and the shield, sheath, or concentric neutral. These two conductors are separated by XLPE, EPR, or oil impregnated paper.

Safety is always a priority even when a cable is not energized because, as any capacitor, the cable will hold a charge until discharged or grounded. A cable must always be grounded before making any connections even if the cable has been parked and isolated as it may pickup up a charge from the field of adjacent energized phases.

The longer the cable or the more complex the system or network, the higher the capacitance. If the surge generator capacitor is smaller than the cable capacitance, the fault will not discharge until cable capacitance is fully charged which could take multiple surges. If the cable capacitance is smaller than the surge generator capacitance, the fault will typically flashover on the first try.

Voltage

Deciding on surge generator voltage levels is extremely important. Without a high enough voltage, the fault will not break down. Very high voltage surging for long periods of time may promote the growth of treeing and reduce cable life. If the fault does not flashover, there will be no thump that identifies and pinpoints the fault. A very important factor to consider is that the voltage pulse doubles in peak-to-peak amplitude on a good cable as it reflects from the isolated open

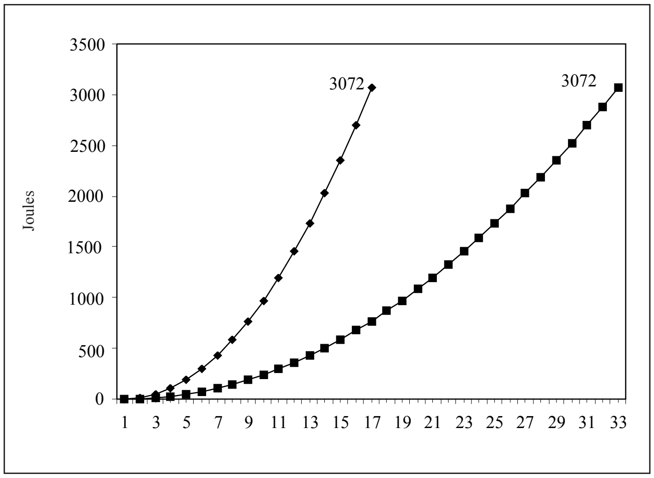


Figure 36: Energy vs. voltage for a 12-μF, 16/32-μF surge generator

end. This also applies if the cable is faulted but the voltage doubling only occurs between the fault the open isolated end of the cable.

When surging at 15 kV, the cable between the fault and the end is exposed to a shock wave of 30 kV peak-to-peak. A hint for fault locating on a cable that has several splices and has been worked on from the same end is to look for the current fault past the last splice. That section of cable was exposed to voltage doubling during the previous fault locate with a high probability that the present fault is at a weak spot in that length of cable.

BASIC SURGE GENERATOR OPERATION

Proof/Burn

A proof test is performed to determine whether or not a cable and accessories are good or bad. The result of a proof test is on a go/no-go basis. The voltage is increased on the cable under test to the required voltage level and held there for a period of time. If there is little or no leakage current and the voltage reading is stable, the cable is considered to be good. If a voltage is reached where the reading becomes unstable or drops with a dramatic increase in current, it is considered to be bad. This test should be done initially as described in Section I to help establish that the cable is actually bad and then to gain some information on the fault condition. A quick check can also be done after repair to be sure there is not another fault and to check workmanship on the splice.

The burn mode is used when the fault will not flashover at the maximum available voltage of the surge generator. This condition is due to the electrical characteristics of the fault that may be altered by applying voltage to the cable until the fault breaks down and then supplying current flow. This causes conditioning or additional damage at the fault location that in turn decreases the fault resistance and reduces voltage required for breakdown.

When applied to paper-insulated cable, the insulation actually burns and becomes charred, permanently altering the fault characteristics. As applied to XLPE cable, heat produced by arcing at the fault can soften the insulation but when arcing is stopped the insulation returns to a solid condition without changing its characteristics drastically. Burning can be effective on a splice failure or a water filled fault.

Surge

In the surge mode, the internal capacitor is charged up to the level selected with the voltage control and then discharged into the cable. This process can be automatically repeated on a time basis by adjusting the surge interval control or manually by push-button on some models. A surge of current from the discharging capacitor travels down the cable, arcs over at the fault, and returns back to the capacitor on the neutral or sheath. This rapid discharge of energy causes an audible explosion and the sound created travels out through the earth and is used to pinpoint the fault location. See Figure 37. It is assumed that the sound travels in a straight and direct path up to the surface of the earth. Sometimes the soil conditions are such that the sound travels away in a downward direction or is absorbed and cannot be heard. In this case, some type of listening device or surge detector may be needed to assist in pinpointing. If the surge of current sees a high resistance path back to the capacitor, as is the case when the neutral is corroded, the sound level created at the fault will be minimal. This current flow back through the earth can also cause a rise in potential of any metallic structures mounted in the ground and a difference in potential on the surface.

Ground

If the surge generator safety ground is connected properly, the ground mode absolutely and positively grounds and discharges the surge generator's capacitor and the cable under test. After turning the main power switch off, which discharges the capacitor and cable through a resistor, always move the mode switch to ground before removing test leads.

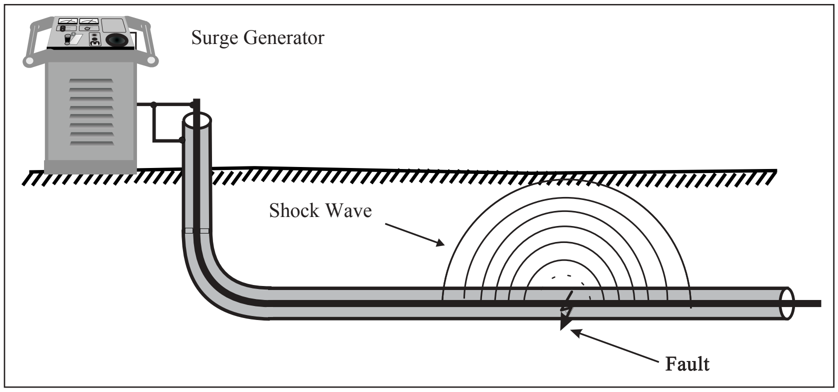


Figure 37: Acoustic shock wave from arcing fault

SINGLE POINT GROUNDING

For safety, always use the single point grounding scheme as shown in Figure 38 when using a surge generator. When making or removing connections to a cable always follow your company's safety rules and regulations.

Check the isolated cable for voltage and ground it. Connect the surge generator safety ground to the ground rod at the transformer, switch cabinet or pole. Next, connect the high-voltage return lead to the shield or neutral as close as possible to the high-voltage connection. Leave the neutral grounded at both ends of the cable. Finally, connect the high-voltage test lead to the phase conductor. When removing test leads, use the opposite sequence by removing the high voltage, high voltage return and lastly the safety ground. The local ground is only required if company safety procedures demand it. The safest and lowest resistance safety ground connection is system neutral which will keep the equipment at zero volts in the case of a backfeed.

ARC REFLECTION FILTERS AND COUPLERS

In order to reduce the cable exposure to high voltage surging and thereby avoid the possibility of setting the cable up for future failures, some method of fault prelocation should be used. The surge pulse and arc reflection methods of prelocation have been used for many years. In order to use either method, additional equipment is required including a DART® Analysis System as discussed in detail in Section VI.

A signal coupler must be added to the surge generator to provide the additional capability of using the surge pulse reflection method of prelocation. See Figure 39. The coupler can be an inductive or capacitive type that is used to pick up reflections on the cable and send them to the DART Analyzer. Both types of couplers work effectively and the only difference is that the captured wave shapes vary slightly.

An arc reflection filter is necessary to provide the capability of using the arc reflection method. This filter allows a TDR developing 10 to 20 volt pulses to be connected to the same cable that is also being surged at 10,000 volts. The filter also does some pulse routing to make sure both high- and low-voltage pulses are sent down the cable under test. The primary purpose of the filter is to allow the TDR or analyzer to look down the cable while it is being surged and, of course, to allow this while not destroying the analyzer in the process. The filter may also contain the coupler necessary to provide surge pulse capability.

There are two types of arc reflection filters, inductive and resistive. Both types are placed in the circuit between the surge generator and the cable under test. The inductive filter, as shown in Figure 39, uses a choke that slows the surge generator pulse down, extending it over time. This makes the arc at the fault last longer and reflects more TDR pulses, providing a higher probability that a downward going reflection will be captured. The inductance of the choke also blocks the TDR pulses from

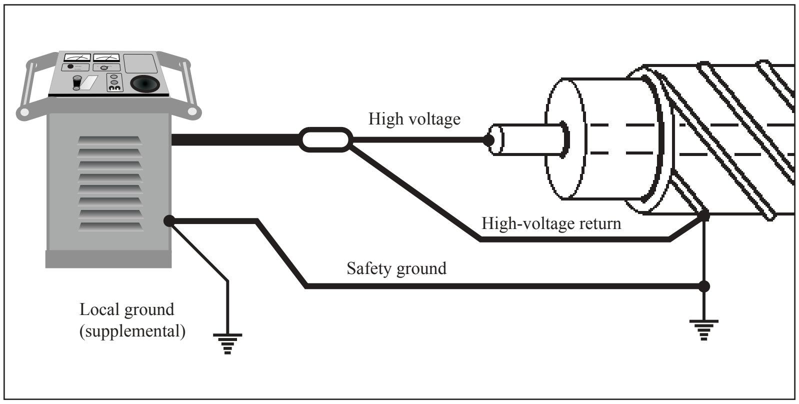


Figure 38: Single point grounding

going back to the surge generator's capacitor and basically being shorted out. One advantage of the inductive filter is that it helps to clamp or limit the voltage applied to the cable under test to only the level required to breakdown the fault. The choke in the inductive filter also absorbs less energy created by the surge generator, letting more down the cable to arc over at the fault.

The second type of filter, as shown in Figure 40, uses a resistor to do the job of pulse routing and has the benefits of lower cost and smaller size. The resistor still blocks the TDR pulses and changes the surge generator pulse slightly but does not limit or clamp the voltage. The resistive filter tends to absorb somewhat more of the surge generator energy than the inductive filter.

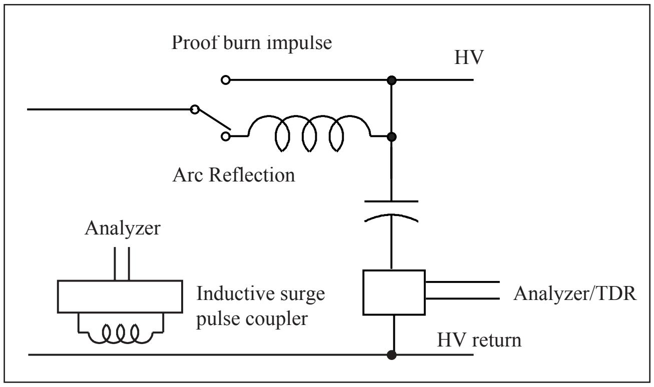


Figure 39: Inductive arc reflection diagram

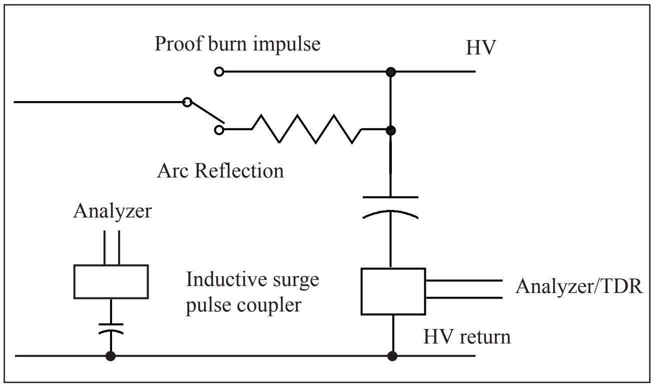


Figure 40: Resistive arc reflection diagram

OVERVIEW

Localizing or prelocation methods provide an approximate distance to a fault. With cable in conduit or duct, an approximate distance is all that is required because the bad cable will be pulled out and new back in. With direct buried underground residential distribution loop fed circuits, localizing can be used to isolate a bad section between two pad-mount transformers. The bad section can then be parked and the loop fed from both ends. In the case of a radial feed localizing must be followed by an appropriate pinpointing method. Some early localizing methods are as follows:

Sectionalizing

The earliest sectionalizing method has been called the "Cut and Try Method" or the "Divide and Conquer Method." This was among the first techniques to be used for fault locating on direct-buried cable. Hopefully, its use today is limited to that of a last resort. See Figure 41.

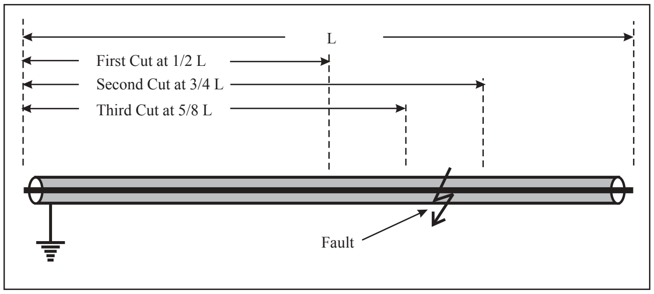


Figure 41: Sectionalizing method

After isolating both ends of the cable section under test, a Megger® Insulation Tester is connected between the conductor and neutral or ground. A faulted cable will have a lower insulation resistance than a cable with no fault. After measuring the fault resistance, a hole is dug half way down the length of the cable section. The cable is cut at that location and a resistance measurement is made on each half. The "bad" half of the cable with the fault will a have lower resistance than the "good" half and the resistance value on the "bad" half should be the same as the fault resistance measured on the complete length of cable. A second dig is made half the distance down the "bad" half. Again, the cable is cut and a resistance measurement is made on each section to identify the faulted part of the remaining section. Eventually, the relatively short "bad" section remaining can be replaced. If the cable is in duct or conduit, the bad section can be replaced. This relatively primitive method is usable on most types of phase-to-ground and phase-to-phase faults.

Resistance Ratio

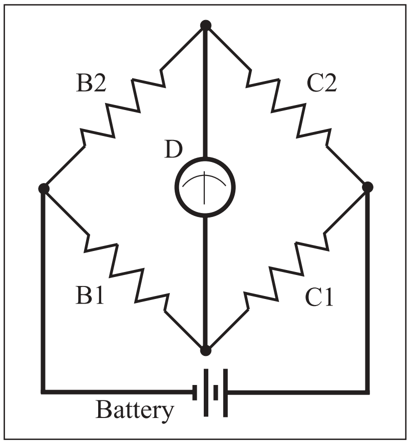


Figure 42: Basic Wheatstone Bridge

Often called the bridge method, a variation of the Wheatstone Bridge is an example of the resistance ratio methods. See Figure 42.

When using a Wheatstone Bridge, B1, B2, and C2 represent known resistances. C1 represents the unknown resistance.

At balance, typically by adjusting the resistance values of B1 and B2 when the zero center null detector D indicates zero, C1/C2 = B1/B2

Therefore, C1 = (C2 x B1)/B2

A variation on the Wheatstone Bridge is the Murray Loop Bridge. Figure 43 shows that the adjacent resistances, RC1 of a faulted cable in a loop with RC2 of a good cable can be made to represent C1 and C2 of the Wheatstone Bridge. Similarly, corresponding portions of a slidewire resistor RB1 and RB2 can be made to represent the resistances B1 and B2. At balance in the Murray Loop Bridge, RC1/ RC2 is equal to RB1/RB2.

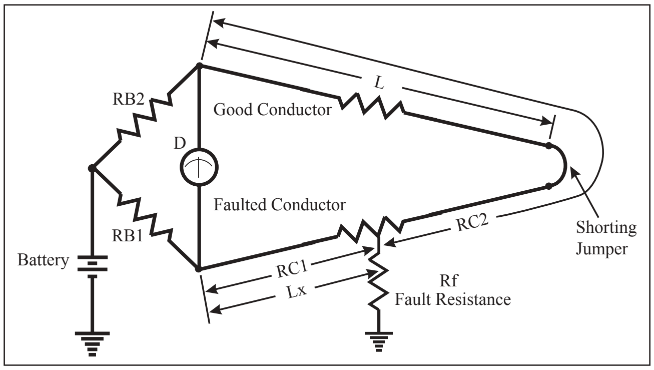


Figure 43: Murray Loop Bridge application

When it is assumed that the resistance of a uniform conductor is linear and proportional to its length, and the total length of the cable section under test is L, the distance to the fault, Lx, is calculated as follows:

$$Lx = 2L\ RB1/RB2$$

When using the Murray Loop method the series resistance and length of the good phase and faulted phase must be identical. If the resistances are different, as would exist if one phase contains a splice and not the other, the resulting accuracy is drastically affected. This is a localizing method not a pinpointing method. Figure 44 illustrates the practical application of an instrument that combines a TDR and Murray Loop Bridge in one instrument.

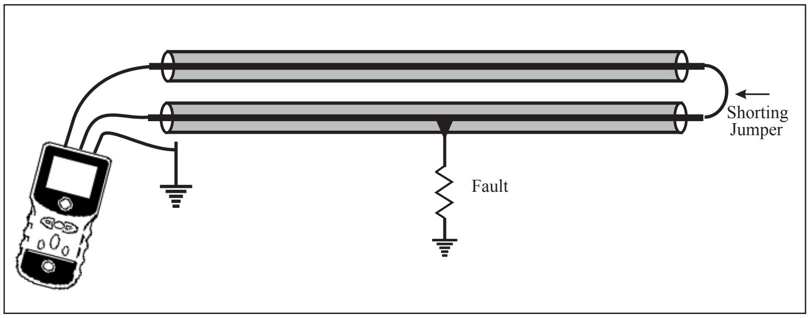


Figure 44: Application of Bridge/TDR

Electromagnetic Surge Detection

Electromagnetic surge detection techniques have been used to localize faults on power cable for more than 50 years. Theoretically, the methods can be used to locate faults on many types of power cable but they are generally used only to identify faulted sections of cable in conduit or duct and mostly on network lead paper cables. Electromagnetic detection methods are used with a surge generator which provides the impulse of current necessary to produce the strong electromagnetic field required to make the method practical.

Since the current impulse is polarized, the field is also polarized which gives the method much of its usefulness. An iron core sheath coil with a secondary winding will induce a polarized output when subjected to this field. When a zero center microammeter is connected to the sheath coil secondary winding, the direction of the net electromagnetic field can be determined. This characteristic allows a determination of whether the fault is ahead of or behind the detector. See Figures 45 and 46. Since the sheath coil is polarized, and to maintain consistent information, always place the coil with arrow on top pointing toward the surge generator.

Single Phase, Coaxial Power Cable with Neutral Bridges Over the Splices

Electromagnetic detection methods can be used to locate faults on coaxial cable systems with access points such as manholes, cabinets, and pull boxes as shown in Figure 45. When the cable system is designed with neutral bridges over the splices, the pickup coil is placed directly on the cable under the neutral. The current impulse produced by a surge generator will produce a strong polarized indication as it passes through the phase conductor and the direction of the current impulse can be determined. As long as a strong positively polarized electromagnetic field can be sensed, the fault is located in the portion of cable still ahead. Since the phase conductor is isolated at the far end, the current impulse flows through the fault and then back to the surge generator through the neutral. Either a weak or no electromagnetic field will be sensed past the location of the fault. Therefore, it is possible to determine in which direction the fault is located.

If the sheath coil is placed over the neutral, the electromagnetic field produced by the current impulse in the conductor is balanced exactly by the return current back through the neutral and the meter provides no indication and stays at zero. When bonded grounds are present in a

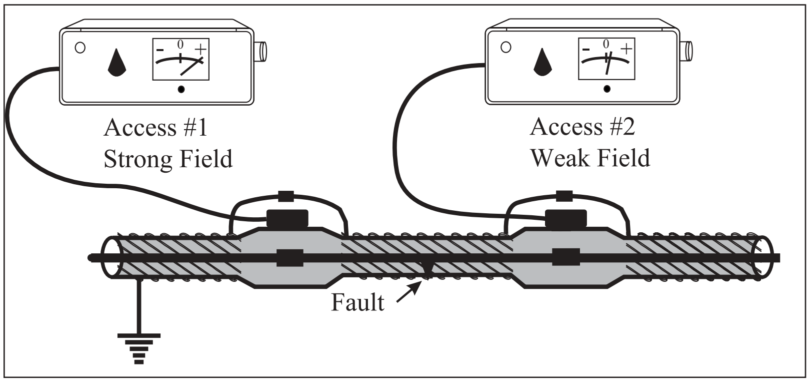


Figure 45: Coaxial power cable with neutral bridges over the splices

system such as usually found in paper-insulated, lead-covered cable (PILC) construction, it may be possible to use a fault locating technique involving electromagnetic detectors, even though the pickup coil must be placed over the leaded neutral.

Single-Phase PILC Cable with Bonded Grounds in Conduit

As shown in Figure 46, this method only applies to circuits with good bonded grounds at every manhole location as commonly provided in network systems. Without bonded grounds, the surge current through the phase conductor is exactly the same magnitude as the return surge current through the neutral. With bonded grounds, the current impulse through the phase conductor is slightly greater than the returning surge current in the neutral. This differential is caused by the small amount of surge current that flows through the neutral beyond the fault and into earth through the bonded ground at the next manhole and back to the surge generator through the bonded grounds before the fault. See Figure 46. No current flows through the second bonded ground after the fault. When relative readings are taken with the sheath coil placed on the cable both before and after the fault, they will all be positive. Readings taken on the conductor before the fault will almost always be noticeably higher in magnitude than those after the fault. However, the difference is often too small to instill confidence in the cable fault location. More importantly, readings taken on the bonded grounds before the fault will become progressively higher as the faulted section is approached. Also, the reading taken on the bonded ground in the first manhole after the fault will also be high. Readings taken on the bonded ground in the second and succeeding manholes after the fault will be zero. This process allows the faulted section of cable can be identified.

Three-phase PILC

Strange as it may seem at first, it is usually easier to locate a fault in three-phase PILC coaxial cable than in single phase. See Figure 47. The current pulse from a surge generator through one phase of a three-phase cable will generate a stronger magnetic field at the cable surface closest to the faulted phase. When the detector is placed at various positions around the cable ahead of the fault, the readings will vary in magnitude. When the detector is placed at various positions around the cable in the first manhole past the fault, all readings will be the same. Note that almost all of the current pulse returns to the surge generator through the neutral at the fault site. A small amount of surge current passes through the neutral past the fault and out of the next bonded ground. This small current finds its way back to the surge generator from earth through the bonded grounds ahead of the fault.

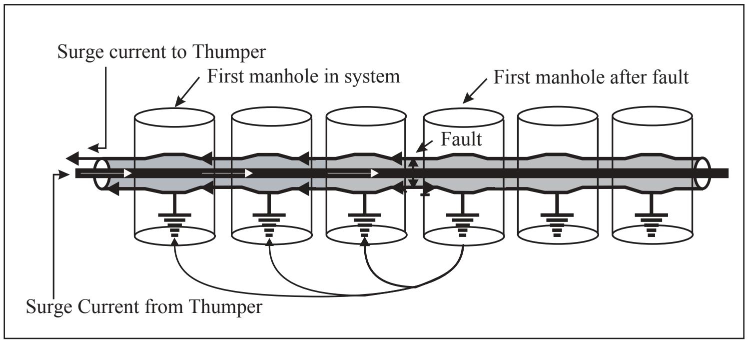


Figure 46: Electromagnetic detection in single-phase PILC cable with bonded grounds

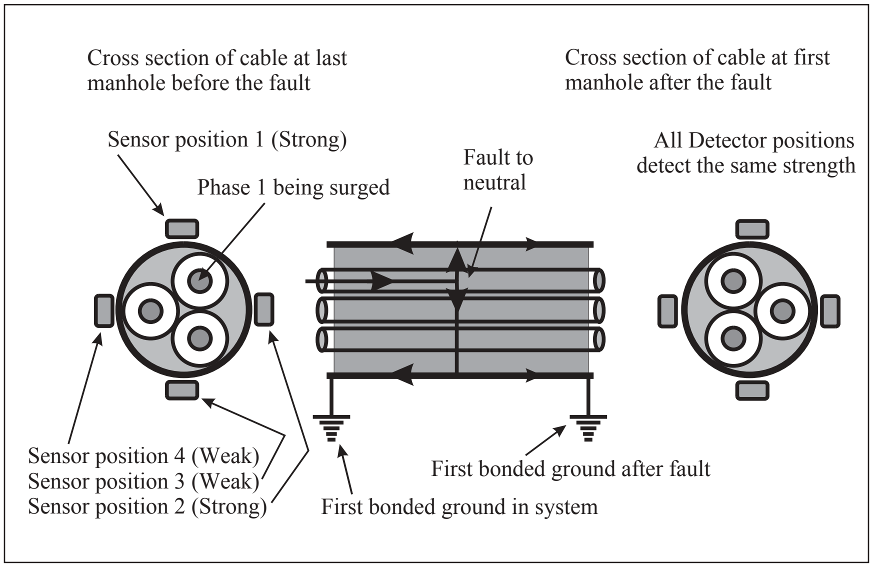


Figure 47: Electromagnetic detection of faults on three-phase power cable

DART® ANALYZER/HIGH-VOLTAGE RADAR

Because the low-voltage TDR is unable to identify high resistance shunt faults, its effectiveness as a fault locator on power cables is limited. When used in a high-voltage radar system with surge generators, filters or couplers, the TDR/Analyzer is able to display both low and high resistance faults. The DART Analyzer provides both TDR and storage oscilloscope functions and is able to utilize all of the cable fault locating methods listed below.

Arc Reflection

This method is often referred to as a high-voltage radar technique that overcomes the 200 Ω limitation of low-voltage radar. In addition to the TDR, an arc reflection filter and surge generator is required. The surge generator is used to create an arc across the shunt fault which creates a momentary short circuit that the TDR can display as a downward-going reflection. The filter protects the TDR from the high-voltage pulse generated by the surge generator and routes the low-voltage pulses down the cable.

Arc reflection is the most accurate and easiest prelocation method and should be used as a first approach. The fault is displayed in relation to other cable landmarks such as splices, taps and transformers and no interpretation is required.

Arc reflection makes it possible for the TDR to display “before” and “after” traces or cable signatures. See Figure 48. The “before” trace is the low-voltage radar signature that shows all cable landmarks but does not show the downward reflection of a high resistance shunt fault. The “after” trace is the high-voltage signature that includes the fault location even though its resistance may be higher than 200 Ω. This trace is digitized, stored and displayed on the screen allowing the cursors can be easily positioned in order to read the distance to the high resistance fault.

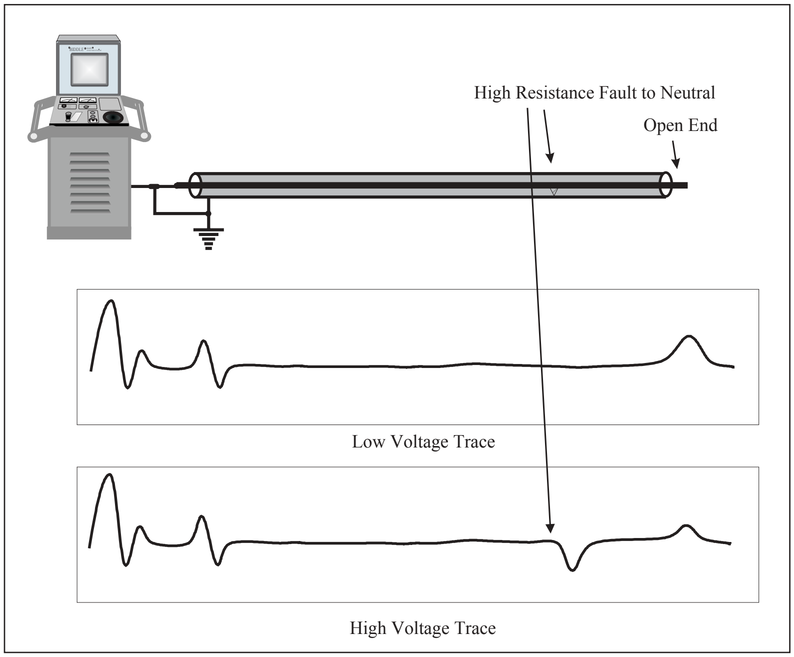


Figure 48: Arc reflection method of high-voltage radar

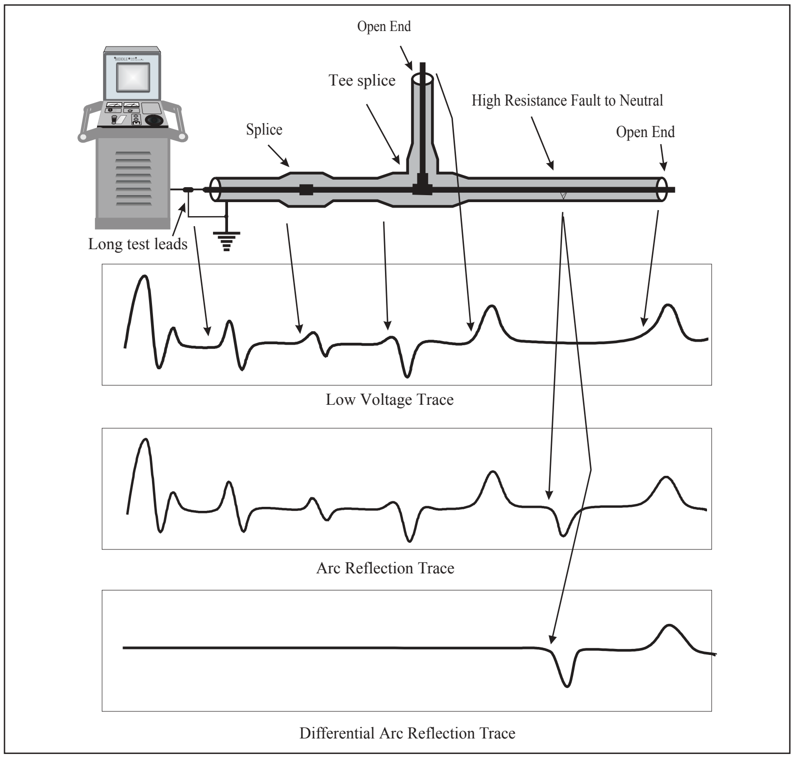


Figure 49: Arc reflection and differential arc reflection methods of high-voltage radar

Differential Arc Reflection

This high-voltage radar method is basically an extension of arc reflection and it requires the use of a surge generator, an arc reflection filter, and an analyzer. Using an algorithm, the DART Analyzer displays the algebraic difference between the low-voltage trace and the captured high-voltage trace on a second screen. See Figure 49 on previous page. As in differential TDR, differential arc reflection eliminates all identical reflections before the fault and the first downward-going reflection to appear is easily identified as the cable fault. This simplifies the fault prelocation particularly if the fault reflection is not well defined or the fault is on a complex system with lots of clutter and unidentifiable reflections.

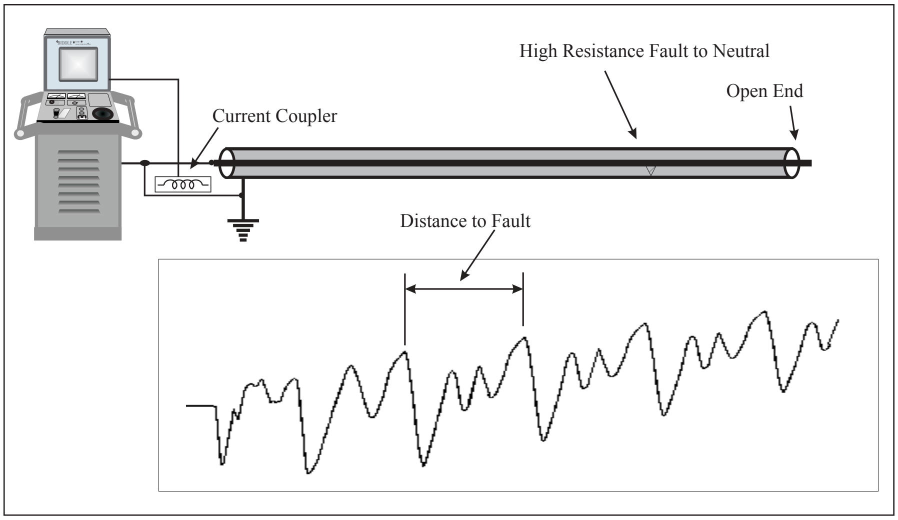


Figure 50: Surge pulse reflection method of high-voltage radar

Surge Pulse Reflection

This method requires the use of a surge coupler, a surge generator, and an analyzer. The analyzer acts as a storage oscilloscope that captures and displays reflections from the fault produced by the surge generator high-voltage pulse. The analyzer operates in a passive mode and is not acting like a TDR by actively sending out pulses. Surge pulse is effective in locating faults on long runs of simple circuits and on faults that are difficult to arc over which do not show up using arc reflection. This method will find most of the same faults that can be prelocated using arc reflection, but usually with reduced accuracy and confidence due to greater difficulty in interpreting the displayed signature. The captured trace does not show landmarks on the cable as arc reflection does.

In this method, a surge generator is connected directly to the cable without the use of a filter which can limit both the voltage and current applied to the fault. Some faults with water or oil in the fault cavity require more ionizing current and higher voltage than arc reflection can provide.

The surge generator transmits a high-voltage pulse down the cable creating an arc at the fault that causes a reflection of energy back to the surge generator. This reflection repeats back and forth between the fault and the surge generator until all of the energy is depleted. A current coupler senses the surge reflections which are captured by the analyzer and displayed on the screen as a trace. See Figure 50.

To determine the location of the fault, cursors are positioned at succeeding peaks in the trace. The analyzer measures time and calculates the distance to the fault using the velocity of propagation. For the trace shown in Figure 50, there is little difficulty in determining where to position the cursors to obtain the distance to the fault. In many cases, interpretation of the waveform can be extremely difficult due to additional reflections that can be produced by splices and taps.

Surge pulse is also affected by accuracy problems due to changes in the velocity of propagation with distance from the fault. Despite its shortcomings, this method provides an alternate tool to locate some faults that would not show up using arc reflection and would be much more difficult to locate.

Voltage Decay Reflection

This method requires the use of a surge coupler, a high-voltage dc test set, and an analyzer. The analyzer does the job of a storage oscilloscope that captures and displays reflections from the fault produced by the flashover of dc voltage at the fault. The analyzer operates in a passive mode and is not acting like a TDR by actively sending out pulses. Decay is used primarily to locate faults on transmission class cables that require breakdown voltages greater than typical surge generators will provide. Dc dielectric test sets with output capability up to at least 160 kV may be required to break down the fault and capture the voltage transient using an appropriately rated coupler and an analyzer. See Figure 51.

High dc voltage is applied gradually to the cable under test charging its capacitance until the high resistance fault breaks down. At breakdown, the cable capacitance is discharged through the fault and generates a voltage pulse that travels back to the test set where it reflects back to the fault. When the voltage pulse reaches the fault, its polarity is reversed and it again travels back to the test set. These reflections continue back and forth until the energy contained in the wave is dissipated. A current coupler senses the surge reflections that are captured and displayed on the screen as a trace. To determine the location of the fault, cursors are positioned at a succeeding peak and valley in the trace. The analyzer measures time and calculates the distance to the fault using the velocity of propagation. All three phases can be tied together at both ends of the cable run to take advantage of the additional capacitance.

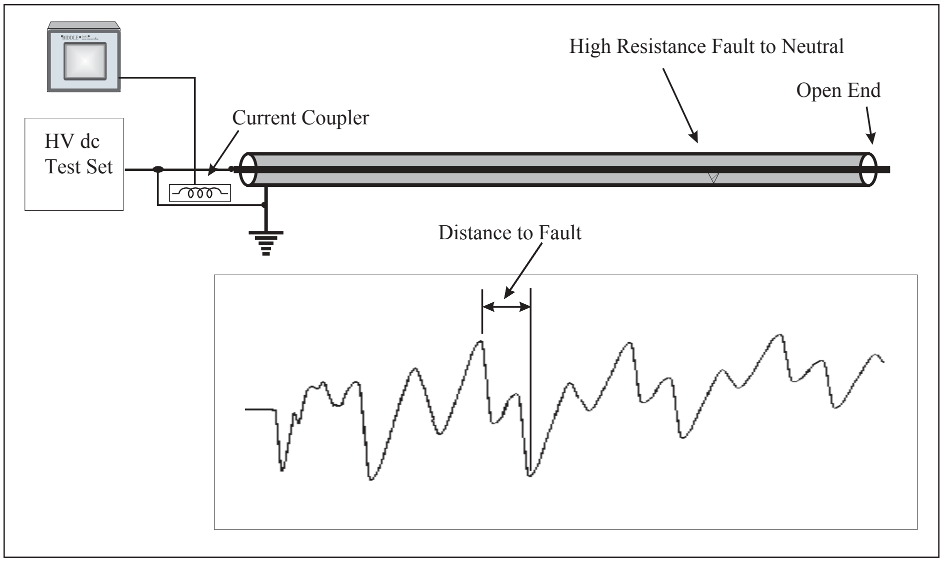


Figure 51: Decay method of high-voltage radar

ACOUSTIC DETECTION

No matter what method is used for fault locating on direct buried underground cable, at some point an “x” must be marked on the ground to say “dig here.” The most commonly used prelocation methods such as arc reflection or current impulse will get reasonably close to the fault, but are not accurate enough to define the exact fault location. Before digging, in order to repair the faulted cable, some type of pinpointing technique must be used.

The classical methods all revolve around a way to zero in on the sound produced by the thump or discharge of energy at the fault created by a surge generator. A simple and well-used method is the fault-locator-ear-on-the-ground-butt-in-the-air technique. Under some conditions such as after a rain or heavy morning dew this can be a shocking experience, literally. Under certain conditions such as created by a corroded neutral, when surging the cable, current will flow in the earth itself rather than back to the generator through the neutral. When this occurs, a voltage drop is produced between the spread hands of the fault locator each time the surge generator discharges.

Other less painful approaches involve old reliable tools such as traffic cones, shovel handles, and modified stethoscopes.

Slightly more sophisticated equipment uses an acoustic pickup or microphone placed on the ground, an electronic amplifier, and a set of headphones. This setup amplifies the sound and helps to zero in on the source at the fault. An improvement on this technique is the addition of a second pickup. See Figure 52. A switch and meter on the amplifier allow comparison of the magnitude of the sound from each pickup. The higher signal is from the pickup closest to the fault and the sensors are moved in that direction. With pickups straddling the fault, the sound levels are equal. These acoustic techniques all assume that the sound produced at the fault travels directly to ground level unimpeded and that the loudest sound is heard precisely above the fault. If the cable happens to be in duct or conduit, under paving or surrounded by tree roots, this assumption may not be valid. In duct or pipe, the loudest sound occurs at either end or at a break. If the fault is under paving, the loudest sound may be at a crack or seam. Root systems seem to carry the sound off in all directions.

Position #1 — Sound louder from right pickup
Position #2 — Sound equal from left and right pickups
Position #3 — Sound louder from left pickup

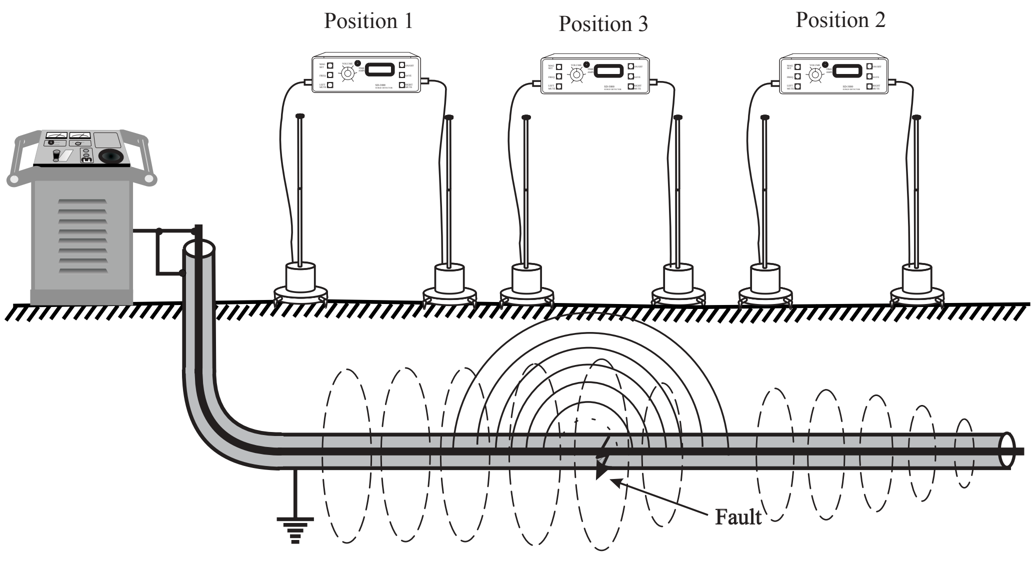


Figure 52: Acoustic surge detection

ELECTROMAGNETIC SURGE DETECTION

An alternate technique is the use of an electromagnetic impulse detector. See Figure 53. The discharge from a surge generator creates a current impulse that travels down the cable through the fault and back to the capacitor of the surge generator. Using the proper antenna or surface coil and an amplifier, the magnetic field created by this current impulse can be detected and measured while walking above the cable. This is similar to cable route tracing where the maximum signal is detected directly over the cable, except that this signal is only present each time the thumper discharges. As the fault location is approached, the intensity of the magnetic field will generally increase and after passing the fault the magnitude falls off fairly rapidly. This increase and then rapid decrease can sometimes be used to pinpoint an underground fault accurately enough to dig. Unfortunately, in the case of direct buried, bare-concentric neutral cables, a portion of the impulse current may follow the neutral for some distance past the fault making it difficult to determine a precise pinpoint location. This method may be the only hope if the fault is very low resistance and the surge generator is producing little or no sound at the fault.

ELECTROMAGNETIC/ACOUSTIC SURGE DETECTION

The Model SD-3000 Surge Detector combines both electromagnetic and acoustic pickups to efficiently pinpoint the fault. See Figure 54. A pickup in the receiver detects the magnetic field produced by the current impulse and also displays its magnitude on a bar graph display every time the thumper discharges. The indicated magnitude of the impulse will decrease if the fault has been passed or if the receiver is no longer over the cable route. After detecting an impulse, an acoustic pickup placed on the ground listens for a thump as a result of the discharge. The detected impulse starts a timer in the receiver and when an audible thump is sensed, the timer is stopped. This measurement is the time it takes the sound wave

Position #1 — Detect electromagnetic signal from surge
Position #2 — Detect increase in electromagnetic signal as fault is approached
Position #3 — Detect decrease in electromagnetic signal as fault is passed

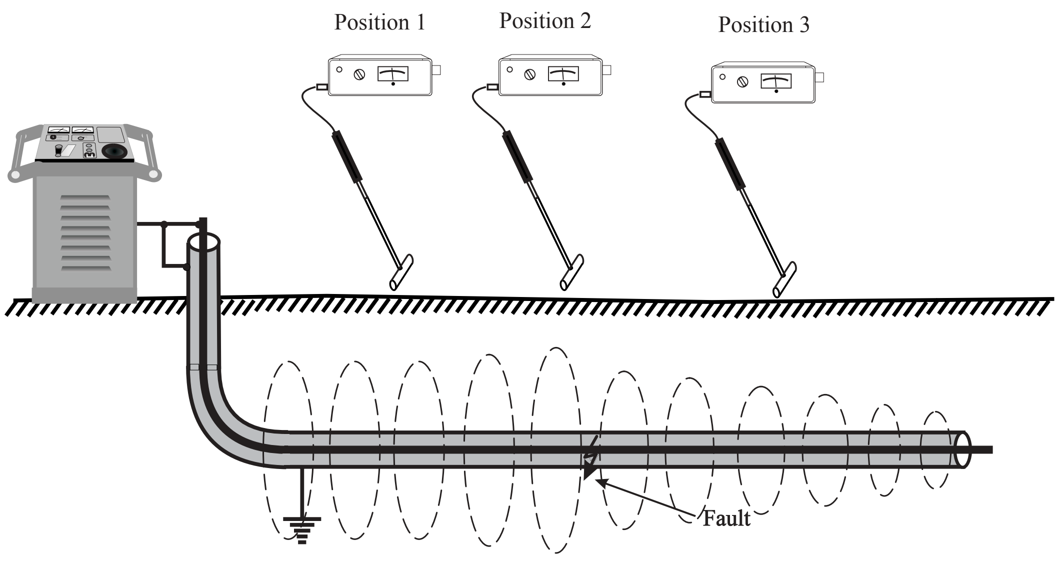


Figure 53: Electromagnetic pinpointing

produced at the fault to travel to the acoustic pickup and is displayed in milliseconds. As the fault is approached, this time interval decreases to a minimum directly over the fault and increases again as the fault is passed. The time never goes to zero because there is always the depth of the cable between the pickup and the fault. This technique relies on the elapsed time between the two events, not simply the loudness of the sound and thereby eliminates the problems of accurate pinpointing even under difficult conditions.

If two acoustic pickups are used, the receiver makes dual measurements and indicates with an arrow on the display which direction to move toward the fault. As the fault is approached, the tail on the arrow becomes shorter until the fault is passed when the direction of the arrow reverses. At this point, small movements of the pickups are made. When they actually straddle the fault, two arrowheads appear pointed toward each other. Once the instrument "hears" the thump, headphones are no longer necessary and the measurements will lead the operator directly to the fault. The receiver also measures and displays a digital value of the sound level, which typically increases as the fault is approached. By using the Save function in the unit, two sets of time and sound level values can be saved and displayed while observing the current values which confirms that the direction being taken is correct.

The SD-3000 provides information on its liquid crystal display, which will efficiently and quickly guide the operator to within inches of the exact fault location:

- Intensity of the surge impulse.
- Elapsed time between the impulse and thump.
- Magnitude of the sound.
- Direction and relative distance to the fault.

Figure 55 shows typical displays of the SD-3000.

Position # 1 — Sound detected. Arrow points toward fault. Electromagnetic signal detected. Time decreases as fault is approached.

Position # 2 — Sound detected. Arrow points toward fault. Electromagnetic signal detected. Time decreases as fault is approached

Position # 3 — Loud sound detected. Arrows point toward each other. Time measurement at minimum.

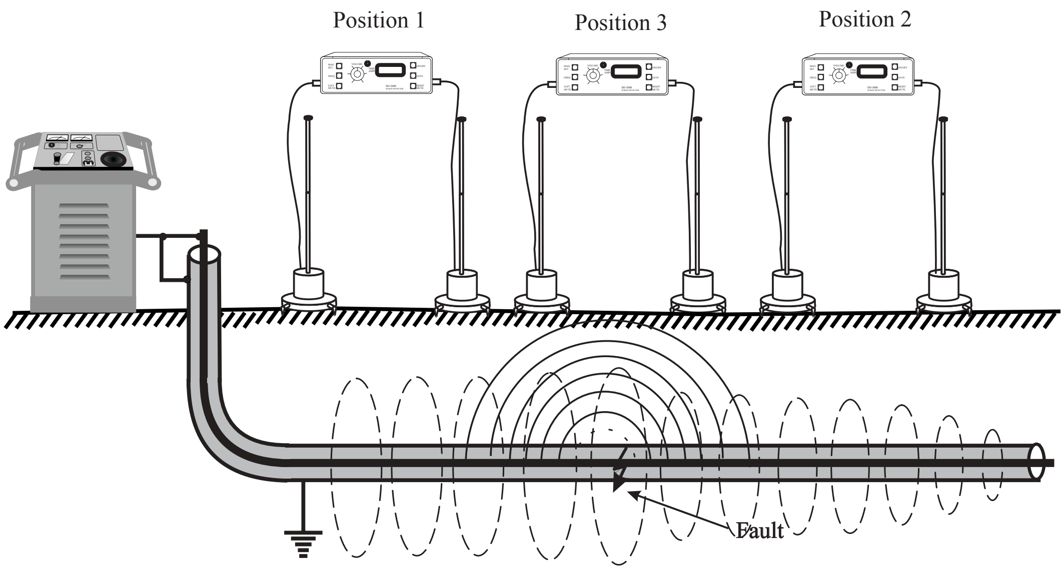


Figure 54: Acoustic/electromagnetic pinpointing

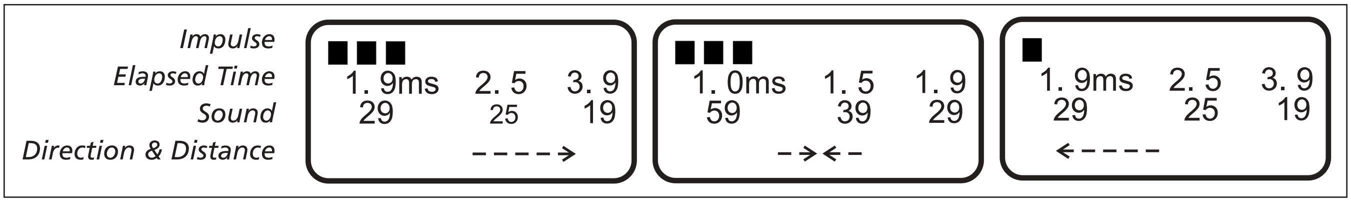


Figure 55: SD-3000 display at positions 1, 2, and 3

EARTH GRADIENT

Although primarily designed to pinpoint faults on direct buried secondary cable, an earth gradient test set can at times be used to pinpoint faults on jacketed primary cables when all else fails. A generator is used to produce a flow of current between the point of the fault through the earth and back to the generator by way of an earth contact. Because the earth is a resistance, current flow will develop a difference in potential or earth gradient along the surface.

The A-frame, with two isolated measuring probes connected to its receiver, measures and displays the value of this potential difference. The A-frame must be moved along directly over the cable route so tracing the cable before hand is essential. If the current flow is equal in all directions, measuring the voltage drop along the cable route will lead to the point of the fault. If the current flow finds its way onto another conductor such as a buried pipe, this technique will likely be ineffective because no voltage gradient is developed.

When using an ac transmitter as shown in Figure 56, the voltage measured increases as the A-frame is moved closer to the fault. When the A-frame straddles the fault, the measurement drops to zero and after the fault is passed, the voltage increases again. At the indicated point of the fault, turn the A-frame at a right angle and follow the same procedure. This will confirm the fault location when moving left and right at ninety degrees to the cable path.

A similar technique uses a dc generator that produces a several second pulse of voltage at a regular time interval. In this case, a zero-center meter on the A-frame will jog in one direction for every pulse as you approach the fault, read zero when directly over the fault, and jog to the opposite direction after the fault is passed. This approach has the advantage that in most cases the voltage is much higher than that produced by an ac generator. Higher voltage creates a larger current flow through the earth producing a higher earth gradient voltage. See Figure 57.

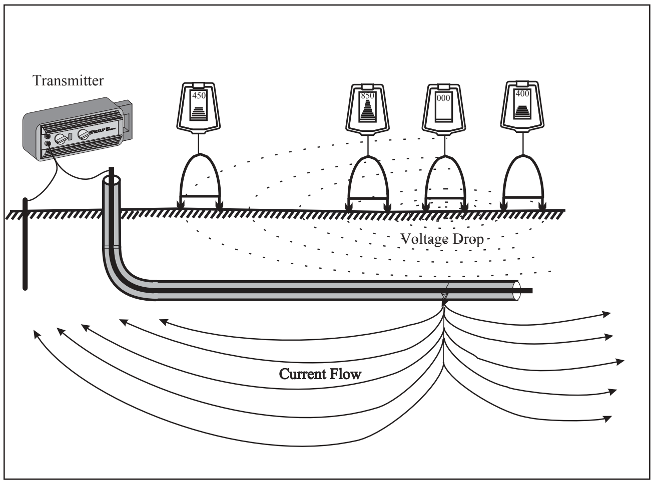


Figure 56: AC voltage gradient

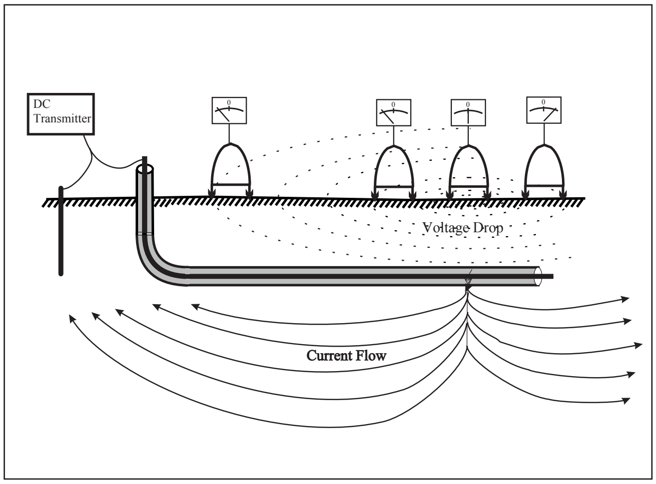


Figure 57: DC voltage gradient

Megger offers solutions for finding cable faults with its comprehensive line of Power Fault Locating (PFL) systems designed specifically for performing maintenance on underground residential distribution systems (URDs). Each Megger PFL System includes a power fault locator with your choice of mounting options and capabilities, and an advanced control device (the DART® Cable Analyzer) featuring many useful improvements. In addition to Power Fault Locating systems, Megger offers test equipment for various telecommunications applications.

An overview of the various products available is described below. For more information on these and the many other Megger products, please contact us at (800) 723-2861. Or visit our web site www.megger.com for the most up-to-date news, product and service information…24 hours a day.

UNDERGROUND UTILITY LOCATING AND TRACING EQUIPMENT

Portable Locators Models L1070 and L1050

- Selectable AF or RF signals
- High power at low frequency

Megger offers two Portable Locators in its extensive line of cable/pipe locating equipment. The L1070 and L1050 are unparalleled in their capability to successfully locate cable/pipe in various situations combining high power at low frequency eliminating coupling into adjacent objects. Both models offer 815 Hz (AF) and 82 kHz (RF) tracing frequencies. The L1070 adds 60 Hz detection capability, push-button depth measurement, current flow measurement and fault locating using the optional earth frame.

Split Box Pipe and Cable Locator

- Energized or de-energized lines tracing
- Conductive or inductive coupling
- Peak and null detection capabilities

The Split-box Pipe and Cable Locator is the classic "split-box" design consisting of a transmitter and receiver. The instrument traces underground conductive networks such as water and gas mains, telephone, CATV, and electric power cables. It determines buried lines depth and locates underground metallic masses such as valve caps and manhole covers.

AccuTrace® Cable Route Tracer

- Peak and null-tracing capability
- Traces energized or de-energized lines through inductive or conductive coupling
- Extremely lightweight receiver

The AccuTrace Cable Route Tracer locates and traces any conductive line as cable, pipe, r metallic conduit. Depth of the line can be established uickly by taking antage of the ounted antenna.

Cable Analyzer

TIME DOMAIN REFLECTOMETERS

Hand-held TDR

Model CFL510F*

Model TDR1000-2*

- Automatic event finder key
- No blocking filter required for live line testing up to 480 V ac
- Simple keypad
- Bright, backlit LCD

This TDR is designed to test all types of cable including twisted pair, coaxial, parallel conductor and concentric neutral and provides the user with the ability to perform fault diagnosis. The 510F offers six ranges of testing capability and features microprocessor control and solid-state digital signal handling processes. Among its unique features are front panel accessible controls for gain (trace amplification), balance, display contrast and display backlight.

The 510F includes four user selectable output impedance which makes the TDR multi-industry applicable: 25 Ω (Power); 75 Ω (CATV); 50 Ω (Cellular); and 100 Ω (Telephony).

**Model CFL510F TDR is sold in North America. Model TDR1000-2 is sold in all other areas of the world. Both instruments incorporate the same features.*

General-purpose TDR

Model CFL535F*

Model TDR2000-2*

- No blocking filter required for live line testing up to 480 Vac
- Output pulse amplitude control
- Automatic event finder key
- Graphical help menu

The CFL535F offers nine user-selectable ranges and measurement resolution down to four inches. Among its unique features are five user-selectable pulse widths for each range which enhances fault location on both long cable runs and close-in faults. Its display zoom feature allows the cursor to be accurately positioned at the beginning of the fault.

The 535F features a mode which allows the operator to average a number of trace samples to reduce the effect of intermittent noise. By averaging the traces, the inflections caused by the noise reduce in size, allowing the actual fault to appear more clearly. The instrument has the facility to store and recall up to 15 waveforms, with corresponding instrument settings for Velocity Factor, Range, Impedance, and Amplitude Gain. A standard RS232 serial output port enables results to be downloaded and uploaded from a pc.

Model CFL535F TDR is sold in North America. Model TDR2000-2 is sold in all other areas of the world. Both instruments incorporate the same features.

CABLE FAULT PINPOINTING EQUIPMENT

Surge Detector Model SD-3000

- Determines distance and direction to the fault
- Operates in all weather conditions
- Selectable acoustic frequency band

The SD-3000 has been designed to locate faults in shielded, direct buried cables by detecting both the electromagnetic and acoustic pulses emitted from an arcing fault when it is surged. Either single or dual detector configurations are available. As a single detector, the set provides detection of acoustic emission, measurement of time delay between acoustic and electromagnetic signals, and distance to the fault. If a second detector is added, the set will also display the direction to the fault. The SD-3000 can be used as an accessory to any surge generator.

Electromagnetic Impulse Detector

- Indicates direction of fault
- Works under all weather conditions
- Converts to voltage gradient tester with optional earth frame

The Electromagnetic Impulse Detector is used primarily to localize faults on cable in duct or conduit. The instrument is comprised of an amplifier module, a sheath coil and a carrying case. With the optional surface coil, it is possible to trace cable while surging. When used with the optional earth frame, it is possible to pinpoint faults on direct-buried cable.

HIGH VOLTAGE DC DIELECTRIC TEST SETS

70, 120, and 160-kV DC Test Sets

- Lightest weight available in air-insulated high-voltage model
- Advanced performance with long-term reliability provided by filtered half-wave rectification
- Operate like a full-wave rectified unit (filtered half-wave rectification)

The High Voltage DC Dielectric Test Sets (70 kV, 120 kV and 160 kV) provide the most dependable, portable dc high voltage sources for checking the quality of electrical power cables, motors, switchgear, insulators, transformers and capacitors. Tests are performed by applying controlled high voltages to the unit under test at or above the insulation system's operating level.

Each portable set (heaviest is 73 lb, 32.8 kg) is comprised of a control module and a high-voltage module. The three models cover a range of output voltages that meet commonly specified ratings in 5-kV to 69-kV class cable. All are suitable for testing power cable, switchgear and rotating machinery in accordance with IEEE, IPCEA, NEMA and ANSI guidelines.

SUITCASE IMPULSE GENERATOR

- Lightweight for easy transport
- Compact design
- Noiseless discharge technique

The Suitcase Impulse generator is a lightweight and compact unit that impulses at 3, 6, 9, 12, or 15-kV. Unlike conventional impulse generators, this unit incorporates a solid-state circuit generating an impulse that is transmitted to the cable by a pulse transformer.

The Suitcase Impulse Generator offers benefits that ensure efficient and effective fault locating:

Rugged construction — housed in a sturdy fiberglass case, designed to withstand the rigors of field operation

Convenient transport/storage — its light weight allows one person to carry unit easily. Its compact size allows for easy storage and transport in tight locations.

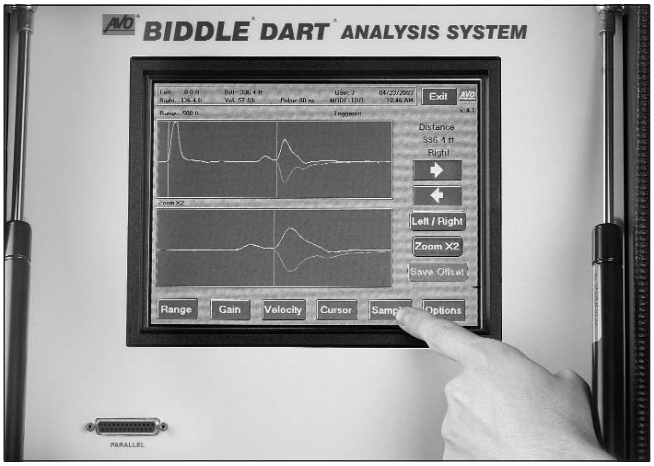
Noiseless discharge — SCR provides discharge with no air gap or moving parts. Quiet discharge is extremely desirable in confined locations.

Simple operation — minimum of controls and instrumentation to reduce operation complexity.

CABLE ANALYZER

DART® Cable Analysis System

- Simplified control functions developed in collaboration with utility service crews
- Easy-to-use touchscreen interface
- Color or monochrome display options



The DART® Cable Analysis Systems operates as the control device of each Power Fault Locating (PFL) system to simplify the process of locating high impedance cable faults. It has the capability for using arc reflection, differential arc reflection (DART) and surge pulse methods of fault locating. Windows® based operating software allows for ease of use, quicker loading and use of future software upgrades. The DART also incorporates simplified control functions developed in collaboration with utility service crews who regularly perform underground cable fault locating. Mounting options include rack mounting, a flip-top lid or stand alone package.

POWER FAULT LOCATORS

URD Loop Power Fault Locator

Model PFL-1000

- Compact design to fit into the tool bin of a service truck
- Eliminates the need for fault current indicators

This system configuration is designed specifically for use in underground residential loop sectionalizing. The PFL-1000 base unit and DART Cable Analyzer are designed for installation into the tool bin of a utility service truck. The system delivers a maximum energy surge of 1500 Joules at 16 kV providing necessary energy to overcome the capacitive loading of large URD loop circuits. It supports multiple fault location techniques including time domain reflectometry, digital arc reflection, and surge pulse reflection.

Power Fault Locator

Model PFL-4000

- Compact, rugged and designed for portability in the field
- Supports multiple test modes including arc reflection, surge pulse, surge, and proof and burn

The PFL-4000 is designed for portability featuring a rugged base unit chassis and the DART Analyzer housed in a flip-top lid for extra protection when used in the field. The system delivers a maximum energy surge at 1500 Joules at 16 kV providing the necessary energy to condition and break down faults in cables, joints, and terminations. The system also includes a 20 kV proof tester and 60-mA burner for testing and conditioning cable faults.

Power Fault Locator

Model PFL-5000

- Specifically designed for vehicle installation
- Incorporates the base PFL-5000 unit and the DART Analyzer
- Performs multiple test modes including arc reflection, surge pulse, surge, and proof and burn

The PFL-5000 is specifically designed for installation and use in utility URD troubleshooting vehicles. This system delivers full performance and a multitude of fault locating methods. It is the perfect tool for isolating a faulted cable section between transformers with one surge and measuring the distance to the fault. This system delivers a maximum energy surge of 1500 Joules at 16 kV providing the necessary energy to condition and break down faults in cable, joints and termination. It also features a 20-kV proof tester and 60-mA burner for testing and conditioning cable faults.

IMPULSE GENERATORS

Portable, Dual-Voltage, Standard and Heavy-Duty Models

- Maintenance-free operation
- Engineered to assure optimum operator safety
- Heavy-Duty model delivers up to 10,800 Joules, the highest impulse in the industry
- Simple to use, even for the infrequent operator

Impulse generators are designed to locate faults in power cable by the high voltage impulse method, in which a high-voltage impulse is transmitted down the cable to cause the fault to arc. The arcing fault is then pinpointed using an appropriate impulse detector.

The impulse generators may also be used to perform voltage versus time acceptance tests, or to burn faults that fail to break down under impulse to reduce their resistance.

Megger offers four models to meet every application:

15-kV Portable Model — For lightweight economy, this 75-lb (34 kg) portable unit delivers 536 Joules for pinpointing faults on most primary distribution cable rated to 15 kV.

Dual-Voltage Model — This 80-lb (36 kg) constant energy unit permits up to 450 Joules to be discharged of both the 7.5 and 15 kV maximum voltages of the unit. This model is designed primarily for direct buried cable in applications that require instrument transport without a truck or van.

Standard Model — This unit stores up to 1250 Joules at 25 kV to meet the requirements of a majority of applications. Although this unit is heavier than the dual-voltage model, it is still portable for convenient transport to remote sites. The energy output makes it effective on direct buried cable and simple network circuits.

Heavy-Duty Model — This powerful unit, designed for van or substation use, offers the highest impulse rating in the industry. It delivers up to 5400 Joules at 30 kV (12 μF). A 24 μF option is available which delivers up to 10,800 Joules at 30 kV. This model is designed for applications such as complex network circuits and faults located in pockets of water and oil.

Heavy-duty Model

15-kV Portable Model

Dual-voltage Model

Standard Model

Your "One Stop" Source for all your electrical test equipment needs

- Battery Test Equipment
- Cable Fault Locating Equipment
- Circuit Breaker Test Equipment
- Data Communications Test Equipment
- Fiber Optic Test Equipment
- Ground Resistance Test Equipment
- Insulation Power Factor (C&DF) Test Equipment
- Insulation Resistance Test Equipment
- Line Testing Equipment
- Low Resistance Ohmmeters
- Motor & Phase Rotation Test Equipment
- Multimeters
- Oil Test Equipment
- Partial Discharge Test Equipment
- Portable Appliance & Tool Testers
- Power Quality Instruments
- Recloser Test Equipment
- Relay Test Equipment
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- Transmission Impairment Test Equipment
- Watthour Meter Test Equipment
- STATES® Terminal Blocks & Test Switches
- Professional Hands-On Technical and Safety Training Programs

Megger is a world leading manufacturer and supplier of test and measurement instruments used within the electric power, building wiring and telecommunication industries.

With research, engineering and manufacturing facilities in the USA and UK, combined with sales and technical support in most countries, Megger is uniquely placed to meet the needs of its customers worldwide.

For more information about Megger and its diversified line of test and measurement instruments:

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