

LOCATING FAULTS WITH A TDR

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Time-domain reflectometry (TDR) is a cable-testing technique that was originally developed to detect faults along power transmission lines, but it is now used to detect faults on telephone cables. TDR pulses a voltage along the line that searches for voltage reflections caused by cable abnormalities; reflection times are measured from the reflection location on the cable to the TDR device attached to one end of the cable.

In wireline communications, a pulse of energy is transmitted down the length of a telephony cable. When the transmitted energy pulse encounters the end of the cable or a problem area (e.g., a bridged tap or an open circuit), part or all of the energy is reflected back to the TDR measuring equipment. The TDR equipment measures the time it takes for the energy pulse to travel down the cable and reflect off of any impairment. Time is usually measured in nanoseconds (ns) or microseconds (ms). A calculation is made using the total pulse travel time and the velocity of propagation (VOP) of the cable (e.g., cable size, material, etc.) to determine the distance from the TDR equipment to the cable problem ($d = v/t$).

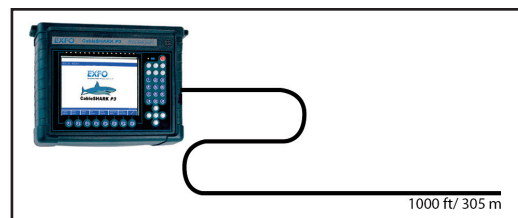


Figure 1. CableSHARK using TDR on a 1000 ft (305 m) cable

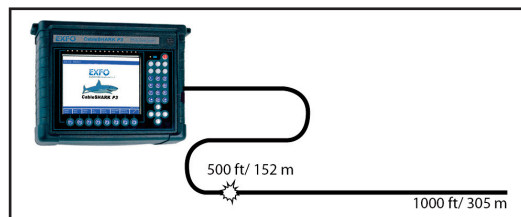


Figure 2. A pulse reflection indicates a fault at 500 ft (152 m)

TDRs can use various testing methods to determine the location of problems along the length of the cable under test. Realizing changes in impedance is key in TDR testing. TDR equipment looks for a change in impedance, which could be caused by improper cable installation, cable damage, end of cable, load coils and bridged taps. How much the impedance changes will determine the amplitude of the reflection.

The following will explain some important TDR aspects that all TDR users should be familiar with.

Attenuation

Not every cable is created equal; hence, the variations in VOP depend on cable type. Likewise, not every local loop is created equal either; some are longer than others, while others are more susceptible to noisy environments. Basically, all signals on these loops, regardless of length or environment, are subject to attenuation. Attenuation will affect the TDR's transmitted and reflected signals, and if the signal-to-noise ratio is too low, impairments may not be identifiable. To overcome the effects of attenuation, using a larger pulse width (more energy) may locate impairments, or the user can measure from both ends of the cable.

Velocity of Propagation

Velocity of propagation is an important value to calculate the distance to an impairment or cable fault. VOP is defined as the speed at which energy travels through a medium. In the case of xDSL, the medium is twisted-pair copper. VOP is indicated as a percentage of the speed of light in a vacuum. Users of TDRs may see VOP expressed as 0.66 (ratio) or 66% (percentage); both are acceptable. The CableSHARK allows users to enter the VOP as a ratio.

VOP is an extremely important parameter, and it has to be correct, as any deviations may give the user false readings. Most cable manufacturers indicate the VOP for their particular cable. The VOP depends on cable diameter, cable material and cable impurities (e.g., other metals or air pockets).

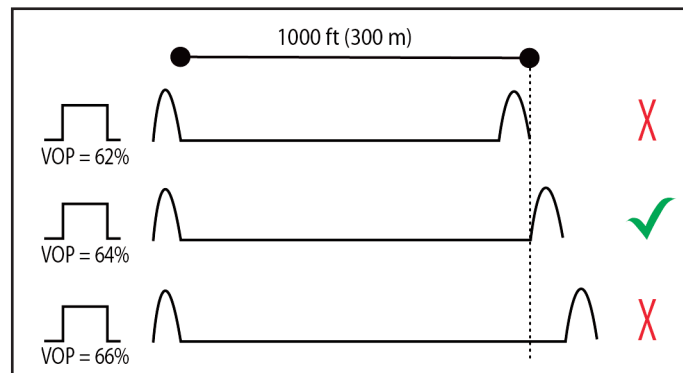


Figure 3. Knowing the correct VOP is important for accuracy

VOP can also be represented in terms of distance per unit time (m/ms). The following will allow users of m/ms to easily determine the VOP in terms of a percentage of the speed of light used by the CableSHARK.

Here are some examples of typical VOP values for various telephone cables, given by insulation type and wire gauge/size:

Pulp

— AWG 22 0.6 mm	VOP = 0.68 (102 m/s)
— AWG 24 0.5 mm	VOP = 0.67 (100 m/s)
— AWG 26 0.4 mm	VOP = 0.6 (99 m/s)

PIC

— AWG 19 0.9 mm	VOP = 0.72 (108 m/s)
— AWG 22 0.6 mm	VOP = 0.67 (100 m/s)
— AWG 24 0.5 mm	VOP = 0.66 (99 m/s)
— AWG 26 0.4 mm	VOP = 0.64 (96 m/s)

Jelly

— AWG 19 0.9 mm	VOP = 0.68 (102 m/s)
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Filled

— AWG 22 0.6 mm	VOP = 0.62 (93 m/s)
— AWG 24 0.5 mm	VOP = 0.60 (90 m/s)
— AWG 26 0.4 mm	VOP = 0.58 (87 m/s)

Polyethylene

— VOP = 0.66 (99 m/s)

Polypropylene

— VOP = 0.66 (99 m/s)

Teflon

— VOP = 0.67 (100 m/s)

Another important note about TDRs is that, ideally, the cable under test should not be terminated. Terminated cables can absorb most or all of the generated energy pulse, which in turn means that no energy will be reflected back to the TDR for measurement, unless there are other impairments on the line. When using a TDR, ensure that the far end of the cable is configured as an OPEN or SHORT circuit for the most accurate measurement. It is also best if all other equipment or hardware is disconnected from the cable under test to avoid interpretation errors.

Calculating the Correct VOP of a Cable

The exact VOP of a cable of known length can be determined with the CableSHARK by running a successful TDR test and reading the time (in ns) between the sent pulse and the reflection pulse from the end of the cable, regardless of the VOP setting for the TDR test. Then, the exact VOP of the cable can be calculated as follows:

Metric: $VOP = \text{cable length (m)} / \text{time reading (s)} / \text{light speed} / 2$ (where the speed of light is 299792458 m/s)

Imperial: $VOP = \text{cable length (ft)} / \text{time reading (s)} / \text{light speed} / 2$ (where the speed of light is 983559096 ft/s)

Note: The division by two is due to the return trip that the pulse has traveled.

Determining the Correct VOP

Given a cable of known length, users can determine the correct VOP of that cable. By manually adjusting the VOP, users can test from both ends of the cable until the CableSHARK measures the exact length of the cable from both ends.

Blind Spots

When the TDR test sends the test pulse, reflections that may occur during the interval of time of the outgoing test pulse may be obscured from the user. The interval of time in which this effect occurs is known as the blind spot. If a fault is suspected within the blind spot range of the cable under test, it is advisable to add a length of cable between the CableSHARK and the cable being tested. Any faults that were hidden in the blind spot may now be visible. Another alternative is to vary the pulse width—smaller pulse widths will reduce or eliminate the blind spot, but at the expense of distance.

Pulse Width

A wider pulse width increases the energy. The greater the energy, the further the pulse can travel along the cable, resulting in longer cable lengths that can be tested. Normally, if the cable length is unknown or there are some impairments near the end of the cable, one should always start with a shorter pulse width. If no cable end or no large impairment can be found, one can then move to the next wider pulse width. For example, start with a pulse width of 200 ns, and look for any impairment up to 2500 ft (760 m). If this does not yield any results, the following template can be used:

Pulse width distance:

100 ns 50 ft/16 m to 2000 ft/660 m

1 ms 400 ft/120 m to 6000 ft/2000 m

3 ms 1850 ft/560 m to 16 000 ft/4850 m

A wider pulse width makes it easier to detect small faults on the cable or faults located at a greater distance. Starting from the shorter pulse width is useful for locating any fault that may otherwise be hidden in the blind spot of a sent pulse of wider width.

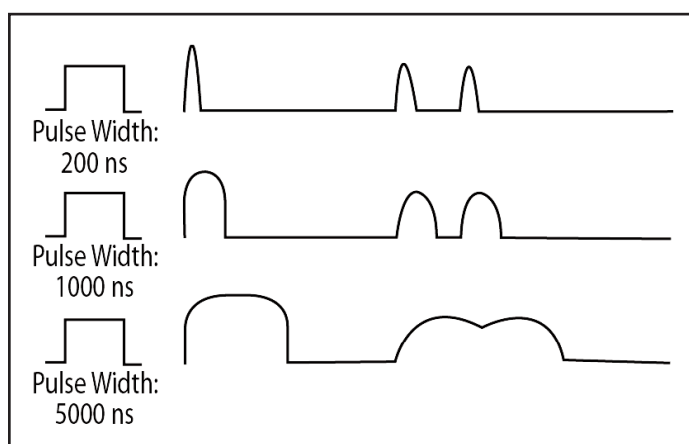


Figure 4. Adjusting the pulse width can yield better results

A gradual increase in the pulse width is necessary to avoid a pulse that is too wide, so that one reflection is hidden behind another or to prevent the reflections from two or more faults from overlapping.

Reflection Polarity

The phase relationship between the sent pulse and the reflected pulses can be used to determine the cause of a reflection. Reflections from sharp, increasing points of impedance are in-phase (i.e., open-end, load coil, lower impedance wire connected to higher impedance wire, series resistance fault, etc.). Reflections from sharp, decreasing points of impedance are out-of-phase, (i.e., shorted end, connection point of a bridge tap, higher-impedance wire connected after lower-impedance wire, wet splice, water in the cable, etc.). In-phase reflection shows an upward bump on the trace.

Locating and Measuring Bridged Taps

Bridged taps are unterminated lengths of wire connected at some point along the local loop. Bridged taps can have different names, depending on the area, region or country you are in, but their effect is the same. As common practice, most bridged taps were installed as a planning measure to make plenty of local loops available for subscribers without doubling the capacity of distribution bundles.

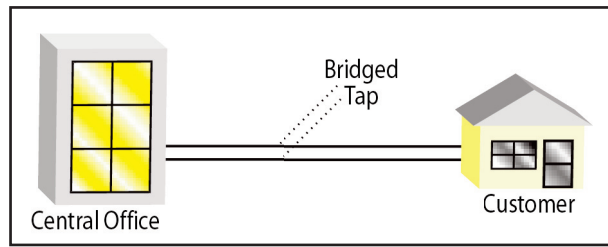


Figure 5. Visual representation of a bridged tap

Most homes are wired with multiple telephone jacks. If these appearances are not treated with micro-filters or some other method of termination, they act as small bridged taps. If left unterminated, bridged taps reflect back original signals that are delayed in time and somewhat attenuated. These signals can confuse receivers and cause digital bit errors. In addition, the extra attenuation caused by bridged taps may reduce the data rates of DSL transmission. Shorter-length bridged taps are considered more harmful than longer-length ones, in that there is less attenuation to weaken the reflected signal that may interfere with the original signal.

Many negative effects caused by bridged taps can be reduced or eliminated by echo cancellers and adaptive equalizers found in most xDSL systems. The taps that create the most problems are near the CO or the remote terminal; these taps need to be found and removed. Bridged taps produce a dip in the trace followed by a transition to a hump (ringing). In ideal situations, the distance between the null and the peak can be used to determine the length of the bridged tap.

Detecting Load Coils

Load coils were introduced in the local loop to lessen the effect of attenuation on voice circuits, usually on lines exceeding 5.5 km (including all bridged taps). These series inductors cause a flattening of the frequency response that allows long length loops to carry acceptable voice transmissions. Load coils result in a great loss at higher frequencies, making DSL traffic inoperable. As a result, it is necessary to find and remove all load coils on a circuit intended for such services.

For detecting load coils, it is easier to use the CableSHARK's Load Coil Detection feature first, rather than guessing whether or not an open-like reflection on a TDR result graph is a load coil. If the load coil detection test indicates that there is a load coil on the line, the user can use the TDR test to quickly locate and remove any load coils on the cable.

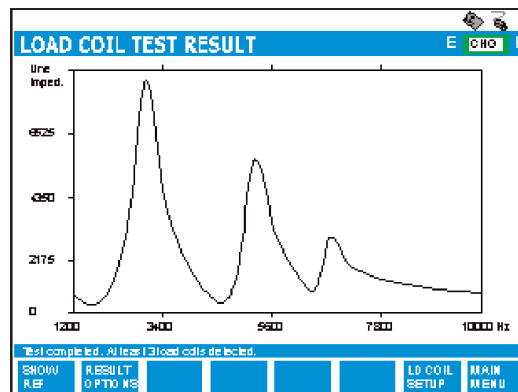


Figure 6. Screen shot of the CableSHARK's Load Coil Detection test result

When finding the location of load coils with a TDR, remember that at the location of a load coil, the waveform will generally show a more rounded appearance than an open one.

Load coils come in two values: the H88 (88 mH), which are normally placed 3000 ft from the CO and every 6000 ft thereafter; and the D66 (66 mH), which are normally placed 4500 ft apart. Depending on the location in the section, load coil spacing is very particular—at 3000 or 6000 ft intervals for H88 load coils. Suspect a load coil if you see an open-like reflection on the waveform at approximately 3000, 4500 or 6000 ft from the TDR, although not all load coils look the same and, depending on your entry point to the network, distances may be different as well.

The first load coil is all you will see, since the TDR's signal cannot pass through a load coil. Since TDRs typically operate in the frequency range from 100 kHz to 35 MHz, the load coil simply blocks these high frequencies from passing through. Once you find the first load coil, remove it, and retest the cable to locate other load coils or cable faults.

Locating Split Pairs

The pairs of wires within cable bundles are twisted in order to reduce the amount of crosstalk coupled to/from adjacent pairs. Telephone-company personnel utilize pairs as needed for their customers' services. In neighborhoods or business parks where spare pairs have become scarce, telephone-company personnel have often turned to split pairs to deliver service. A split pair is created from two semi-defective loops that each contains a broken conductor. By using the remaining good conductor from each pair, an additional pair is gained.

Split pairs are acceptable for voice frequency applications, but for DSL applications, however, the increased amount of crosstalk, as compared to normal pairs, is unacceptable. In the case of DMT-based ADSL, it may cause upstream and downstream connection rates to be unnecessarily low or may prevent the establishment of a connection. Crosstalk rejection is greatly reduced on split pairs because the rejection, caused by twisting the wires around each other, is not present.

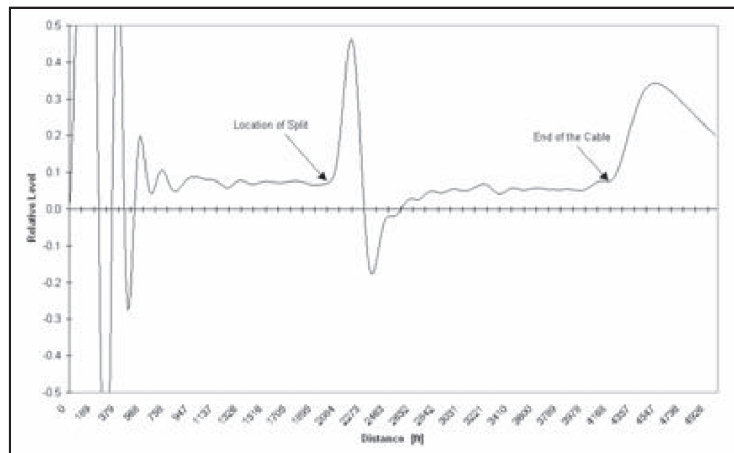


Figure 7. Graph representing sample crosstalk of a split pair

Testing from Both Ends of the Cable

It is always good practice to test a cable from both ends to locate and confirm any faults, as this can reduce errors in the VOP setting and uncover any hidden faults. For example, consider a 5000 ft cable with a fault located at 2000 ft. If the test result shows that the fault is at 2050 ft when tested from one end and that the fault is at 3075 ft when tested from the other end, it will indicate that the VOP setting is too fast. If, in this case, the user tested only from the first end and started to dig the ground to fix the fault, the crew would be digging in the wrong place. Therefore, testing from both ends will save costs in the long run.

Interpreting TDR Results

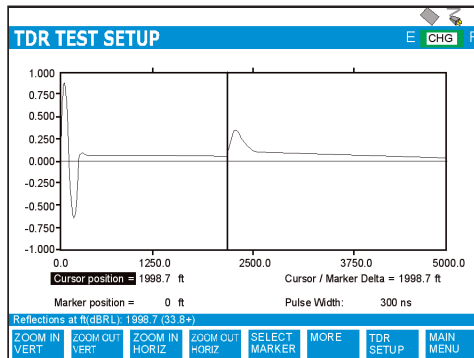
Interpreting a TDR graph is not always an easy task. Many TDR testers perform some interoperation of results, but their interpretation of the TDR result may not be 100% accurate. The accuracy of locating a cable fault according to the reported TDR distance can depend on several factors, such as:

- Was the VOP set correctly?
- Was a range of pulse widths used?
- Was the far end terminated or unterminated?
- What was the level of noise interference being injected into the cable under test?
- Did various cable gauges make up the local loop?

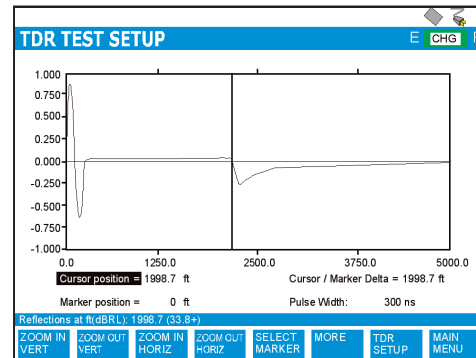
In addition, cables may not be perfectly straight when buried. A distance reported by a TDR may not match the distance from the test point if the cable is wound or curved when in the ground or overhead.

TDR Diagrams

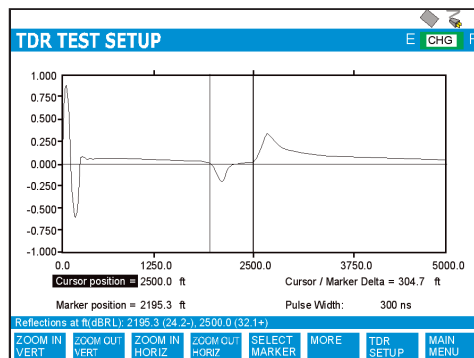
The following diagrams depict possible TDR traces and their causes.



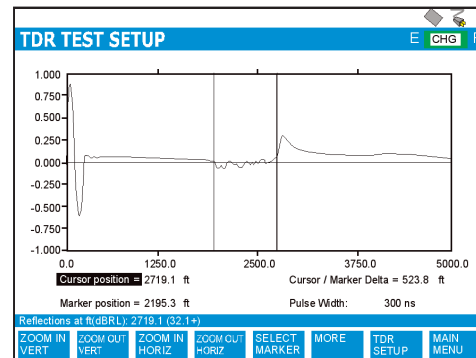
This diagram depicts an *open* circuit or a high-impedance fault. Depending upon the size of the reflected pulse, the *open* could be a partial (small pulse) or complete (large pulse) open circuit. Of course, the length of the cable, attenuation on the line, and the size of the outgoing pulse play a big role in determining the reflection location.



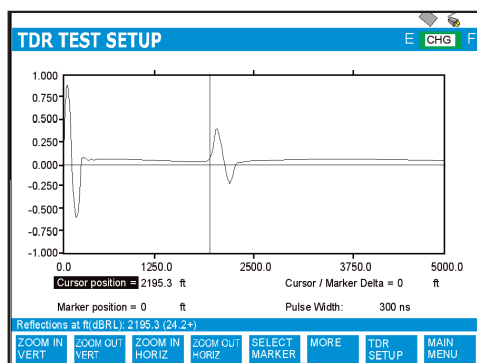
This diagram depicts a *short* circuit or a low-impedance fault. Depending upon the size of the reflected pulse, the *short* could be a partial (small pulse) or complete (large pulse) short circuit. Of course, the length of the cable, attenuation on the line, and the size of the outgoing pulse play a big role in determining the reflection.



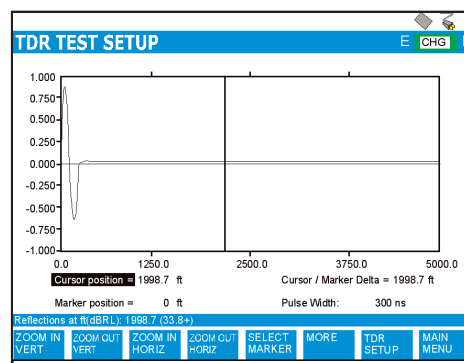
This diagram depicts a bridged tap. The bridged tap is composed of a negative pulse (start of the bridged tap) and a positive pulse (end of the bridged tap). Using the CableSHARK's Marker and Cursor functions, the user can identify the distance to the bridged tap (first line above, called the marker) and the length of the bridged tap (difference between the marker and cursor).



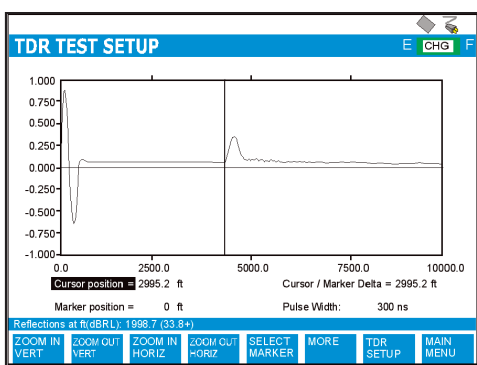
This diagram depicts a water-soaked cable with an *open* circuit. The water section could have appeared anywhere along the cable. Generally, a noisy reflection could indicate water.



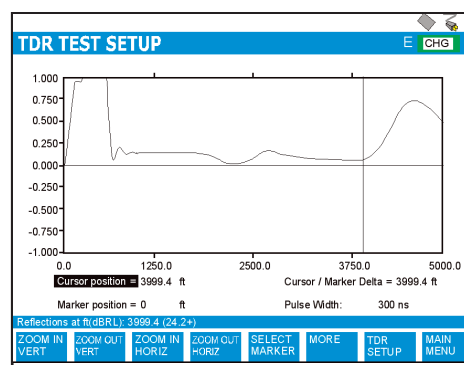
This diagram shows a *high-resistance joint* or *splice*. This is composed of a high-impedance reflection followed by a low-impedance reflection. Generally, the better the splice, the smaller the reflection. A large reflection indicates a poor splice.



This diagram depicts a terminated cable. The terminated cable absorbs the send pulse and causes no reflection. For the purposes of TDR testing, it is best to use an unterminated cable to ensure that a reflection is sent to the CableSHARK.



This diagram shows a typical response from a *load coil*. It resembles a complete *open* circuit. Although *load coils* are placed at specific intervals, a TDR does not typically “see” past the first *load coil*.



This diagram illustrates a test that was run through a plain old telephone service splitter, ending in a complete *open* circuit.

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