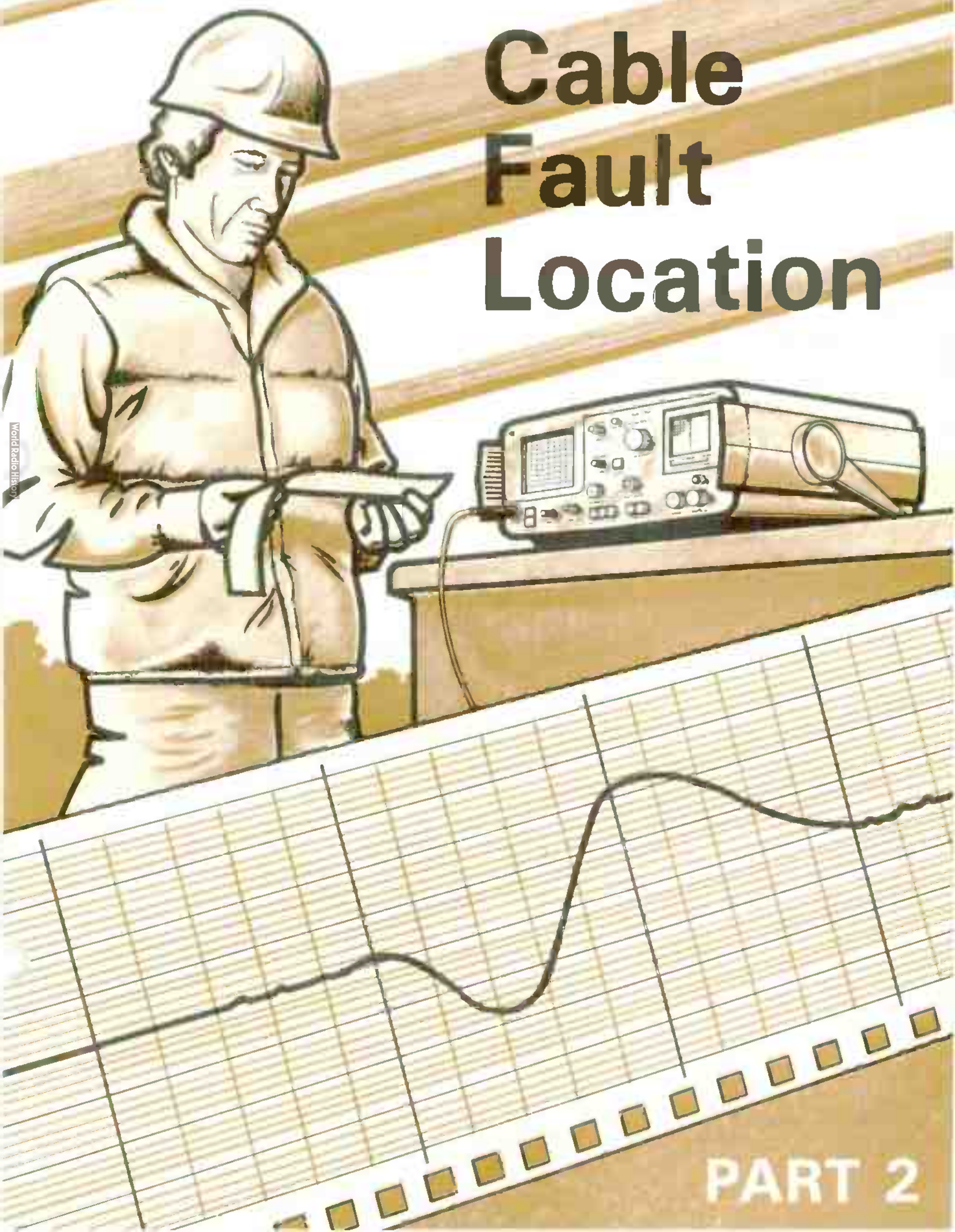
GTE LENKURT

DEMODULATOR

MAY/JUNE 1980

Cable Fault Location



PART 2

The first article, in this series, explained how test equipment employing bridge balancing and tone tracing techniques is used to locate faults in multipair cable. This second part describes the use of equipment employing time-domain reflectometry and signal analysis techniques to test various cables including multipair, coax and optical fiber. Originally, we intended to present Cable Fault Location in two parts. However, three parts is a more logical division. The third part will describe cable testing for data communication.

A time-domain reflectometer (TDR) works on the same basic principle as radar. Pulses of energy are sent down the cable under test. If the cable has uniform impedance along its length and is properly terminated, all of the energy will be absorbed.

If, at any point along the line, the pulse encounters an impedance other than the cable's characteristic impedance, a portion of the energy will be reflected. If the cable is open circuited, the reflected pulse will be in phase (have the same polarity) with the incident pulse. If the cable is short circuited, the reflected pulse will be out of phase (have the opposite polarity) with the incident pulse.

In either case, a substantial amount of energy will be reflected. In fact, if the cable were "lossless" all energy would be reflected. Of course "lossless" cable cannot be physically realized.

The phase relationship between the incident and reflected pulses is used to determine the type of fault causing a reflection. Reflections from an impedance higher than the characteristic are in phase. Reflections from a lower impedance are out of phase.

Inductive and Capacitive Faults

Inductive faults cause a TDR to see an impedance higher than the characteristic. Capacitive faults cause a TDR to see an impedance lower than the characteristic. The reason for this is apparent when the relationships between inductance, capacitance and impedance are considered.

The impedance of an infinitely long lossless line (or one terminated in its characteristic impedance) is:

$$Z_c = \sqrt{L/C}$$

where: Z_c = characteristic impedance
L = inductance per unit length
C = capacitance per unit length

This formula is an excellent approximation of a transmission line impedance at high frequencies.

As shown by the formula, the impedance will increase if L is increased and C is held constant. Conversely, the impedance will decrease if C is increased and L is held constant. The thing to remember is that faults that cause the TDR to see a higher impedance than the characteristic impedance will cause in-phase reflections, faults that cause a lower impedance than the characteristic will cause out of phase reflections.

Reflection Coefficient

The ratio of the reflected voltage to the incident voltage is called the reflection coefficient. The reflection coefficient may be any value between +1 (open circuit) and −1 (short circuit).

The reflection coefficient, usually designated by the greek letter ϱ (rho), is quite useful. It can be used to calculate the voltage standing wave ratio, return loss and actual impedance of a cable fault. For example, return loss equals 20 log ϱ. In the telephone industry, this equation is usually written; return loss = 20 log $(1/|\varrho|)$. The first reference in the bibliography presents a complete discussion of characteristic impedances and reflection coefficients.

Distance

A finite, measurable amount of time is required for the energy to travel down the cable to the reflection point and return to the input. The time is directly proportional to the distance the energy travels. Since the velocity of propagation is constant for a given transmission medium, the distance (length of cable) from the input to the reflection point can be accurately determined.

$$d = vt$$

where: d = distance
v = velocity
t = time

Since the energy travels down the cable and is reflected back to the input, its travels twice the distance from the input to the reflection point. The distance to the point is vt/2.

TDR Instruments

Commercially available TDR instruments perform these computations electronically and incorporate oscilloscope displays which can be calibrated to read distance directly. A digital readout is often provided for ease of use and reading accuracy.

TDR's designed to test telephone cable often include a precision logarithmic amplifier to enable return loss to be measured directly. One such instrument is the Tektronix 1503 shown in figure 1.

Referring to the figure, return loss is measured by first using the 0 dB set control to adjust the incident pulse to some convenient amplitude, say two vertical divisions on the scope display. The sensitivity control (calibrated in dB) is then adjusted to bring the reflected pulse to the preset amplitude of the incident pulse. The return loss is read directly form the sensitivity control.

High energy signals are required for long range measurements. One

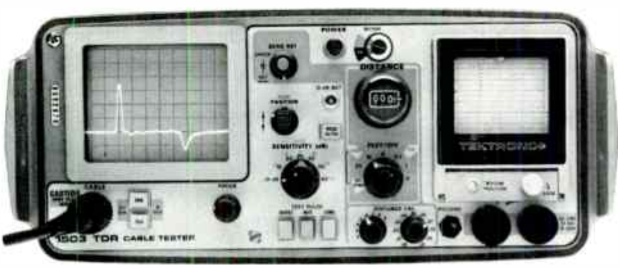


Figure 1. Tektronix model 1503 TDR.

Courtesy Tektronix, Inc.

method for achieving a high energy signal, without resorting to brute-force power, is to concentrate the available energy into a controlled bandwidth pulse. This kind of signal is suitable for long range measurements over cables with a limited bandwidth (twisted pair etc..) It is also suitable for measurements over coaxial cables greater than 100 feet in length. Figure 2 is a simplified schematic of the 1503, which uses a controlled bandwidth pulse.

A half sine wave shaped pulse meets the bandwidth requirements. As shown in the graph at the lower left of figure 2, the pulse amplitude decreases rapidly with frequency change.

Normally, personnel maintaining cable are more interested in determining the location of the fault than they are in determining the exact impedance change at the fault. The following paragraphs discuss factors that affect the accuracy of locating faults with a TDR.

Resolution and Accuracy

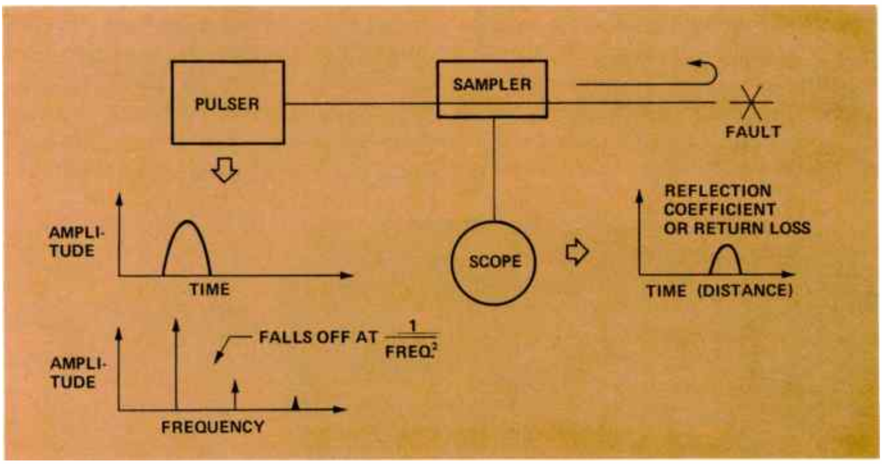
Occasionally, someone uses the terms Resolution and Accuracy interchangeably. Actually, they are two completely different things.

Resolution is the quality which enables a TDR to distinguish between faults which are close together. In other words, resolution is a measure of how close together two faults can be before the TDR "sees" them as one fault.

Resolution is determined primarily by the rise time of the reflected pulses received by the TDR. The rise time is determined by both the instrument and the cable being measured.

It is self-evident that the rise time of a reflected pulse could hardly be faster than that of the incident pulse. So, for measuring very short cable runs the resolution is largely determined by the TDR instrument. A TDR for testing short cable runs is described later.

However, for cable runs longer than about 100 feet, the resolution is largely determined by the cable. For example, the rise time of the reflected pulse through 50 feet of RG 58 coax is 78 nanoseconds. The rise time increases as the increase in the cable length squared. One hundred feet of cable has four times the rise time of



Courtesy Tektronix, Inc.

Figure 2. Pulse-type TDR.

50 feet; 1,000 feet has 100 times the rise time of 100 feet.

A typical pulse type TDR can resolve faults within 3 feet on short lengths of high quality cable. A typical step type, described later, can resolve faults within 0.6 inches under the same conditions. However, the useful resolution of the pulse type is as good as the step type on lengths of cable greater than 100 feet.

Accuracy

Two types of accuracy, vertical and horizontal, are of interest to the TDR user. The following paragraphs discuss each type in turn.

Vertical accuracy is a measure of how accurately a TDR can display ϱ or return loss. It is determined by the input to output relationship of the vertical amplifier, the precision of the gain control and the quality of the cathode ray tube.

A vertical accuracy of about $\pm$ 3% is typical of an average TDR. This accuracy can be enhanced by substitution measurements. This method involves comparison measurements between a precision reference cable, with the same nominal characteristic impedance, and the unknown cable. This and other techniques for improving accuracy are described in some of the references in the bibliography.

Horizontal accuracy is a measure of how precisely the electrical distance to a fault can be measured. It is determined by the TDR time base stability and linearity and by how accurately the propagation velocity of the cable is known. The time base accuracy of a typical TDR is $\pm$ 2% of full scale.

Propagation velocity is the speed at which a signal travels down a cable. It is dependent upon the dielectric constant of the material used for cable insulation and the geometry of the cable cross section.

Cable manufacturers usually carefully control the propagation velocity of their products. However, variations in propagation velocity between cable of the same type but different manufacture may be in excess of 2 percent.

Substantial changes in propagation velocity occur when sections of different cable types are spliced together; pulp insulated spliced to polyethylene insulated (PIC) for example. Pumping reclamation compound through a cable section also changes its propagation velocity. From the foregoing, it is apparent that each cable section may have its own propagation velocity. This must be taken into account when making distance measurements with a TDR. Measurements should be limited to single cable sections unless successive sections use the identical type of cable.

Fortunately, the signal propagation velocity of a particular cable section is less susceptible to variations than other characteristics such as resistance which varies widely with temperature. Once the velocity has been accurately determined, the accuracy of TDR measurements is very good.

It is important to remember that a TDR measures the electrical length of the cable from the instrument to the fault. Cable "snaking", twists and loops, as well as the ability to accurately measure the physical length of the cable, must be taken into account to determine the actual distance to the fault.

Snaking is caused by cable take-up and by ups, downs and zig-zags of the cable in the trench or conduit. On the average, a distance loss of about one percent results from snaking.

Telephone cables can contain more than 2,400 twisted pairs. Those pairs on the outer part of the cable are longer than those on the inner part. Because of the twist, twisted pair lengths always differ from reel length. Futhermore, long cable runs are sometimes looped for strain relief and to provide extra length for splicing.

The ability of a person to measure distance accurately is another factor which must be taken into account to determine the exact location of a fault. Assume a TDR measurement shows a fault exists 1,500 feet out from the measuring point. If the terrain between the two points is clear and level, the distance can be mechanically measured or even paced off with reasonable accuracy.

However, how accurately can distance be measured through brush, ditches or even torn-up paving? Under these conditions an error or 20 feet per thousand would be unusually good. Most plate maps are not that accurate. From the foregoing, it can be seen that the total error from physical measurements exceeds the TDR electrical errors.

At this point, it may seem that using a TDR is not a practical method for locating cable faults. After all a 2 percent error equates to ± 200 feet on a 10,000 foot cable. However, there are several simple ways to improve accuracy.

Accuracy Improvement

One method for improving accuracy is to take multiple readings, with each successive reading taken at a point closer to the fault. The distance errors are all percentage errors. The ± 200 feet error at 10,000 feet reduces to ± 8 feet at a distance of 400 feet and to ± 2 feet at 100 feet.

Accuracy can also be improved by using all available information about the cable. Known points on the cable can be used to calibrate the TDR timing for a high degree of accuracy, providing the cable dielectric is the same along its entire length.

This is practical because a TDR can "see" any disturbance in cable impedance. Changes in cable impedance as little as 0.5 percent (46 dB return loss) can easily be detected. A skilled operator can recognize faults with up to 60 dB return loss. This is about the extent of 1503 performance in the field, although the actual limit is 76 dB.

For example, if you know there is a cable splice or connector at exactly 2,500 feet from the TDR connecting point, you can calibrate the instrument for a short term accuracy within a few tenths of a percent on that particular cable.

Another way of improving accuracy, on a cable of known length, is to measure from both ends of the cable. Measuring the distance to the fault from each end and splitting the difference is sufficiently accurate in most cases. If greater accuracy is desired, use the following formula:

$$d'_2 = \frac{L}{\left[\frac{d_1}{d_2} + 1\right]}$$

where: L = actual cable length (known)
d_1 = indicated distance to fault from end 1 (known)
d_2 = indicated distance to fault from end 2 (known)
d'_2 = actual distance to fault from end 2 (unknown)

The formula assumes that the percentage error is the same for both measurements. That is:

$$\frac{d'_1}{d_1} = \frac{d'_2}{d_2}$$

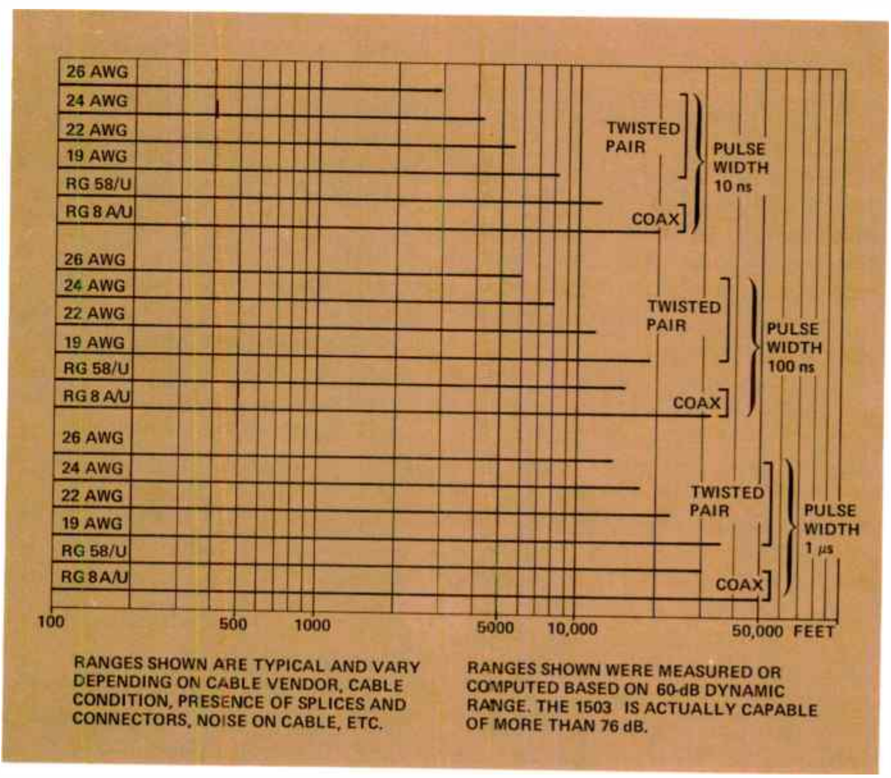
where d_1 equals the indicated distance to the fault from end 1. The assumption is valid providing the same TDR is used for both measurements and the instrument is not recalibrated between measurements. Without loss of generality, the formula assumes the fault is closest to end 2. The complete derivation is presented in Appendix C to Tektronix Application Note 25M1.0, Copyright 1978 Tektronix Inc. (see bibliography).

Until now, our discussion has mostly centered on pulser type TDR's, using the Tektronix 1503 as an example. This type of instrument is used for testing long cable runs like those used in telephone and CATV applications. Figure 3 shows the useful range of the 1503 for locating shorts or opens in various sizes of coax and grade twisted pair.

Another type of TDR, which preceeded the pulser type, is referred to as the "step type". These instruments are most suitable for testing short cable runs like those used in aircraft and ships. They are also used for comparison testing of antennas and components. These applications are discussed later.

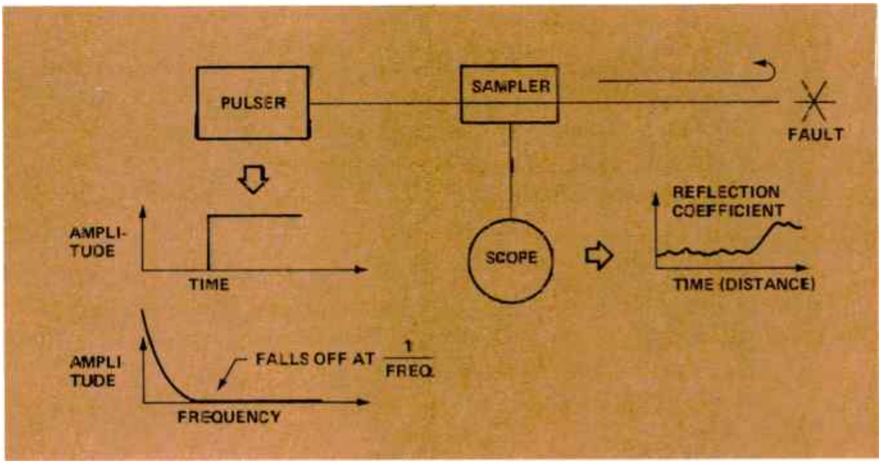
Figure 4 is a simplified block diagram of a step type TDR; the Tektronix 1502. Referring to the figure, ultra-short rise time voltage steps are sent down the cable under test. The sampler detects voltage and sends it to the oscilloscope for display.

As the voltage steps travel down the cable, each fault will cause some



Courtesy Tektronix, Inc.

Figure 3. Useful 1503 range on coax and grade twisted pair.



Courtesy Tektronix, Inc.

Figure 4. Conventional "step-type" TDR.

energy to be reflected. The reflected voltage will be detected by the sampler and displayed on the scope as a step-up or step-down transition superimposed on the inital step.

In-phase reflections cause a step-up transition. Out-of-phase reflections cause a step-down transition. Just as with the pulse type TDR, in-phase reflections result from an impedance higher than the cable's characteristic. Out-of-phase reflections result from an impedance lower than the charcteristic.

A comparison between Figure 2 and Figure 4 shows that both instruments operate on the same principles. The main difference between the two is the shape of the incident voltage. Also the vertical amplifier on the 1502 is calibrated in ϱ whereas the 1503 is calibrated in return loss (dB).

From the discussion of resolution, we know that the fast rise time voltage step is better than the half-sine pulse for resolving faults on short cable lengths. We also know that this advantage is lost on cable lengths greater than 100 feet.

The amplitude versus frequency curves, at the lower left of each figure, show that the half-sine pulse voltage falls off much faster with frequency than the step pulse. This fact makes the pulse more suitable than the step for testing long lengths of limited bandwidth cable such as twisted pair.

Fault Signatures

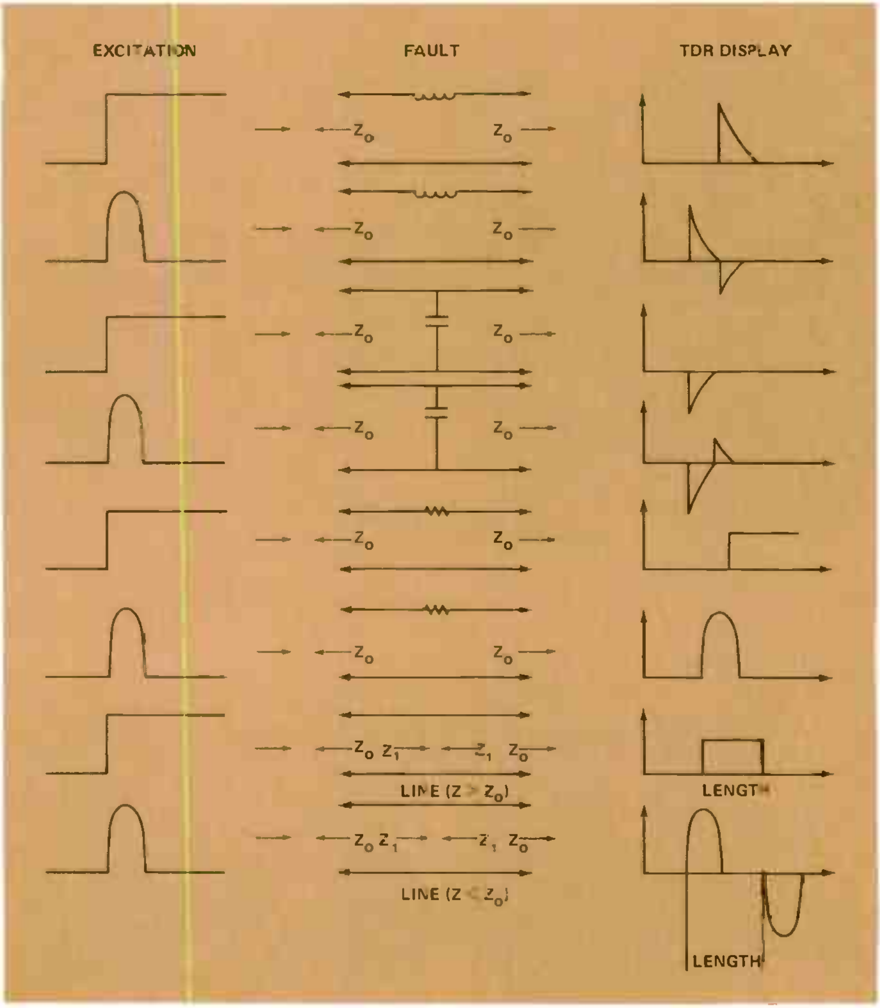
The shape of the reflected voltage waveform uniquely defines the fault that is causing the reflection. These wave shapes are known as fault "signatures". Figure 5 shows idealized signatures for some of the faults most commonly encountered in the field. Figures 6 through 10 show some actual TDR signatures for twisted pair faults. Figures 11 through 14 show signatures for some coax cable faults.

Practical Cable Testing

Some cables carry voltages which could be hazardous to personnel and/or test equipment. Some instruments, particularly the pulse type, can withstand substantial voltages. Others require an accessory isolation network to prevent damage. For example, the 1503 is protected against up to 400 volts (d.c. + peak a.c. up to 400 H_Z). However, an isolation network is recommended for personnel safety. The 1502 cannot withstand any significant voltage on the cable. Power should be removed and the cable shorted or terminated, to bleed-off any static charge, before connecting it to a 1502.

Many cables will have contaminating signals, such as 60 H_Z power, at levels high enough to swamp out TDR signals. Most TDR's provide selectable noise filters to improve the signal to noise ratio under these conditions.

Impedance matching is critical to TDR measurements, if the return loss or reflection coefficient is to be measured. Incorrect matching also reduces the range of the instruments.



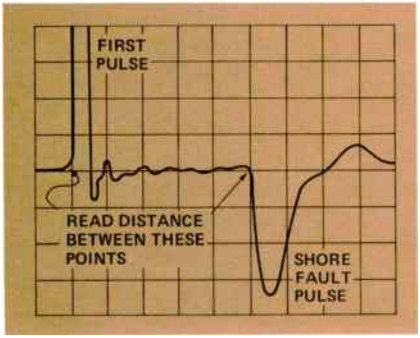
Courtesy Tektronix, Inc

Figure 5. Sample TDR fault signatures.

Impedance matching puts as much energy as possible into the cable under test.

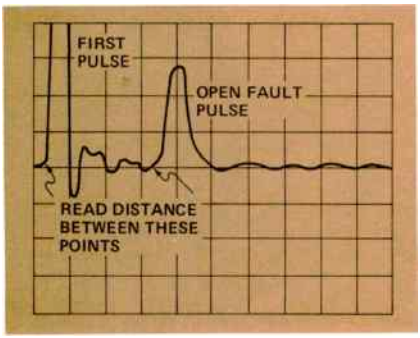
Impedance matching is not critical if only the distance to a fault and its signature is to be measured. If the impedance of the cable to be tested is not known, use the setting or adapter which reduces the incident signal closest to 50% when the cable is connected.

In any case, it is important to establish a good connection to the cable under test. TDR signals contain high frequency information that is not efficiently transmitted through poor connections or inadequate test leads.



Courtesy Tektronix, Inc.

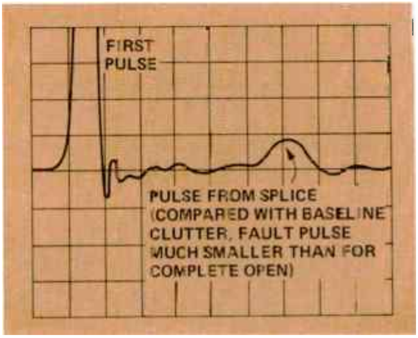
Figure 6. Display of pair with conductor short.



Courtesy Tektronix, Inc.

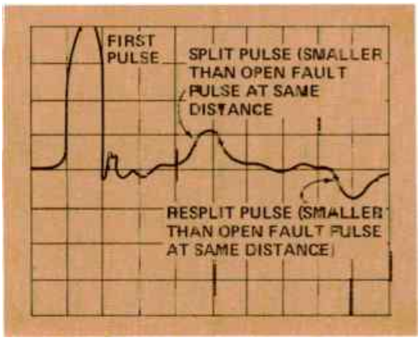
Figure 7. Display of pair with conductor open.

One useful TDR application is the detection of water in a PIC cable. A TDR can locate where the water begins and ends (see Figure 10).



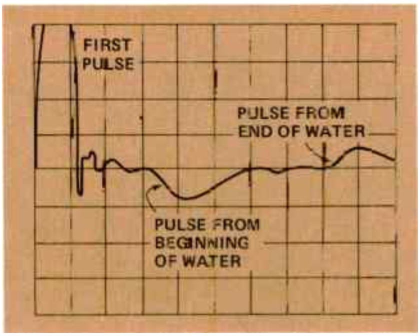
Courtesy Tektronix, Inc.

Figure 8. Display of resistive splice.



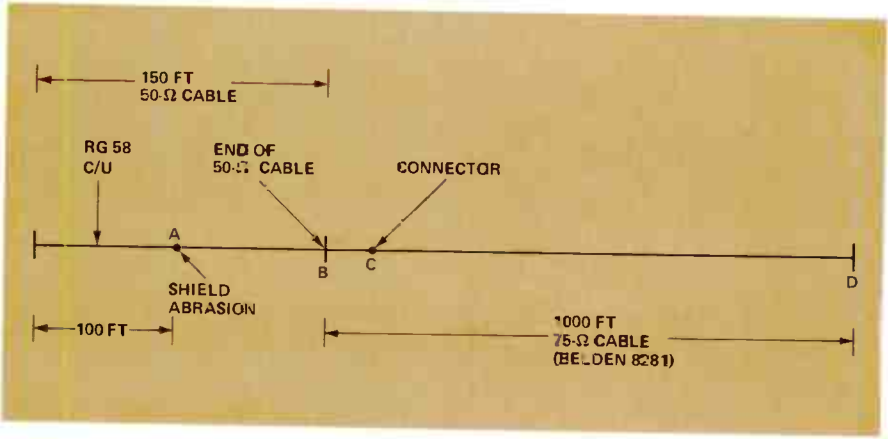
Courtesy Tektronix, Inc.

Figure 9. display of split-resplit.



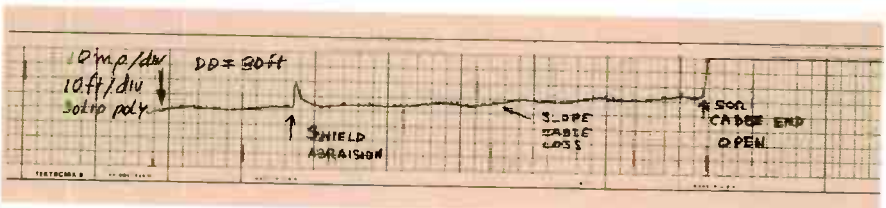
Courtesy Tektronix, Inc.

Figure 10. Display of water in the cable.



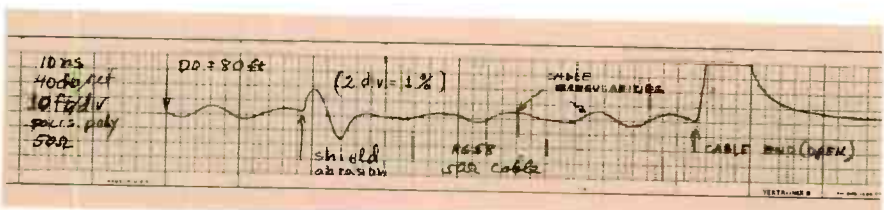
Courtesy Tektronix, Inc

Figure 11. Coaxial cable assembly.



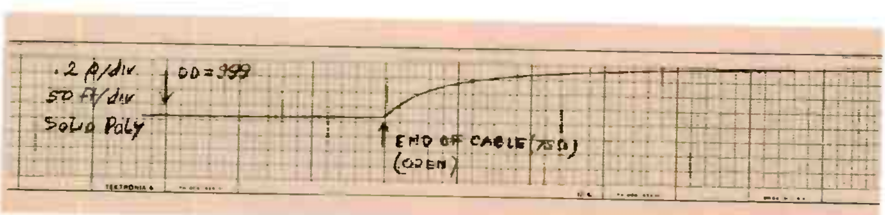
Courtesy Tektronix, Inc.

Figure 12. 1502 strip chart showing cable discontinuities at points "A" and "B" (see figure 11).



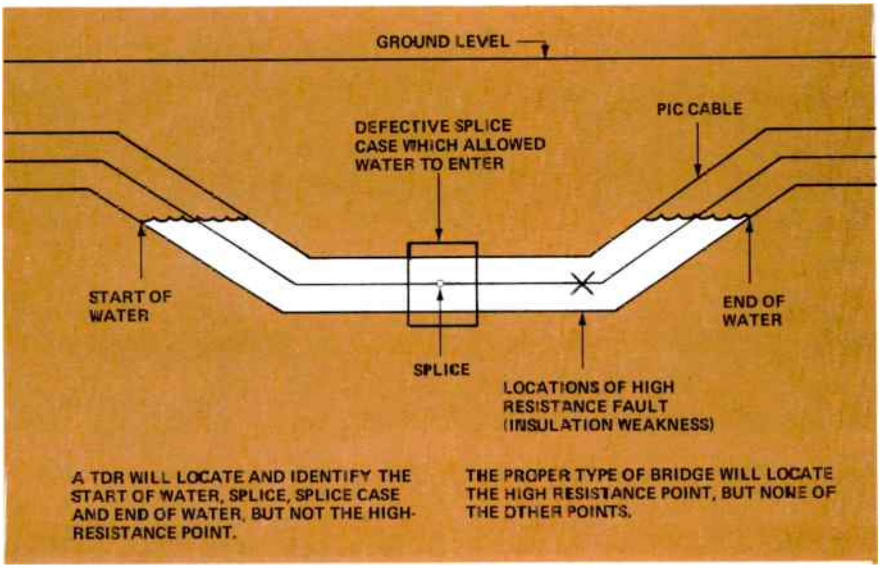
Courtesy Tektronix, Inc

Figure 13. 1503 strip chart showing cable discontinuities at points "A" and "B" (see figure 11).



Courtesy Tektronix, Inc.

Figure 14. 1502 strip chart showing cable discontinuities at point "D" (see figure 11).



Courtesy Tektronix, Inc.

Figure 15. A wet PIC cable starting to fail.

Figure 15 illustrates what kind of faults a TDR can and cannot locate in a wet cable that is starting to fail.

A TDR can determine where the water begins because water causes an increase in cable capacitance. From our previous discussion, we know this will cause an out-of-phase reflection. At the end of the water, the capacitance decreases. This can be thought of as an increase in inductance, i.e. the L/C ratio increases. This will cause an in-phase reflection. (see Figure 10).

General Telephone Company of the Northwest has developed a cable reclamation technique which uses the ability of a TDR to define the wet portion of a cable. Highlights of this technique are described in the following paragraphs.

The method uses dry air purging to restore a wet section of cable to its original configuration, without changing its capacitance or transmission characteristics. In this respect Gen Tel of the Northwest believes their method is superior to compound reclaiming methods that do increase cable capacitance.

The company also states that significant savings can be realized by reclaiming cable instead of replacing it. They used the air purge method to reclaim 480 feet of 200 pair, 19 gauge, buried cable at a cost of 929 dollars. The cost for replacing the same cable would have been 3,789 dollars.

The following procedure is reprinted, with permission, from a document prepared by Mr. Joe D. Peterson, Transmission and Protection Administrator, General Telephone Company of the Northwest, Incorporated. The portable air dryer package referred to in the procedure is a type MPU-9F from the Systems Equipment Company, Hickory, North-Carolina. In his paper, Mr. Peterson mentions that the air dryer used in his early reclamation experiments was borrowed from Continental Telephone.

Procedure for Reclaiming with the Portable Air Dryer

Determining Wet Cable and Isolation Methods

There are several ways of determining if you have wet cable. Usually there will be noise, customer complaints, service outages and possible physical trouble. Wet cable trouble will, in most cases, involve several cable pair. A review of transmission parameters on customer loops will sometimes indicate a group of cable pairs that are in trouble.

Wet cable trouble will usually be very high resistance faults in the megohms and has a tendency to "dry up" or fluctuate when normal fault locating equipment is placed on the trouble in an effort to locate it, in some cases disappearing completely.

Attempts should be made to isolate the trouble to the smallest possible section of cable. In rural areas this could be in excess of a 2,000' section. Sectioning the trouble can be achieved using the Radar Scope and Megger. ("Megger" is the registered trademark of the James G. Biddle Company. Meggers are used for insulation and resistance testing. "Radar Scope" and "Radar Cable Test Set" are terms James G. Biddle Company use in describing their time-domain reflectometers.)

The cable can be reclaimed, if the trouble is very high resistance and fluctuating, however, if the trouble is solid and can be located with normal test equipment, the cable has deteriorated to the point that the trouble will have to be located and repaired prior to reclaiming.

The physical footage of the isolated section should be accurately determined by chain measuring or sequential footage marks on the cable. Remember to add extra footage for pedestals, risers, and deviations from the plow line (on buried cable). It is recommended that both methods be used when possible.

Capacitance readings must be taken and compared to the physical footage, so it is very important to get an accurate physical footage measurement. The Radar Scope is the only type of test gear that is capable of determining if a section of cable has water in it, and where it physically starts and stops, when observed from both ends.

The impedance bridge measures the capacitance of the cable in microfarads. Modern Day Pic Cable is manufactured at a .083 microfarads of capacitance per mile or .0000157 m/f per foot. Older cable and some newer cable may not have been manufactured to this standard and will not measure .083 per mile, usually something greater than .083 per mile.

When water is in a cable, the capacitance will increase. The amount of increase will depend of the amount of water in the cable. A length of cable may exhibit twice the normal capacity, depending again, on the above factors.

A method of determining whether you are dealing with an old cable (with excessive capacitance) or a wet cable, would be to divide the questionable section in half, expose the cable and take capacitance readings both ways (from the middle). Cable manufactured with excessive capacitance will be uniform. When the cable is divided equally the capacitance will be approximately the same both ways. If it is water in the cable the reading will be irregular (one half will read greater than the other). At this point the Radar Scope, can be used to confirm the fact that it is water and where it starts and stops, when observed from both ends.

The above procedure should be followed and all tests made and recorded before the section is prepared for reclaiming. Failure to do so may result in the possibility of reclaiming a cable that may not be wet.

Preparation of Wet Cable Sections Prior to Reclaiming

From the results acquired so far it appears the section to be reclaimed should not exceed 1,000'. Access to the cable in rural *areas will sometimes exceed this. When this is the case the longer sections will have to be divided into at least 1,000' sections. It is expected that on 19 gauge cable, the distance may be increased.*

Consideration should be given to the terrain in the immediate area. Reclaiming should be down hill if possible. This will take advantage of the effects of gravity. The air dryer should be placed on the high end and the discharge end at the low end. The dryer and discharge ends are optional on flat terrain.

The proper preparation of the cable cannot be over stressed. The effectiveness of this method depends on how well the cable is prepared. A poor job will result in wasted time, poor results, and utter frustration.

New pressure dams should be placed at each end of the section to be reclaimed regardless of what is existing in the form of moisture or pressure dams.

The pressure dams should be sheath injected using channeling pins. A constriction should be applied about 8-10 inches below the injection point. An aero-seal clamp (hose clamp) should be used. With double sheath cable, the outer sheath should be removed and the inner sheath dammed. Do not attempt to dam the outer sheath on a double sheath cable as it is coated with a substance to which the damming compound will not adhere, and the outer sheath may be damaged between test points, but the inner sheath be intact.

The discharge end should be left open at the start about 12-18 inches. With double sheath cable the outer sheath should be removed.

The inlet valve does not need to be at the grade of the cable, but it is very important that it be placed in such a manner to avoid any compound that has passed the constriction point of the pressure dam.

An inlet valve placed too close to the dam may restrict the air flow and increase the reclaiming time or render the reclaiming ineffective.

The compressor will be applying 50 P.S.I., or more on these pressure dams, so it is very important that they are of the highest quality. Any less may invite failure.

Pressure dams, inlet and discharge fittings should be flash tested (soaped) before applying static pressure. A static air pressure of 20 pounds should be applied to the section to be reclaimed and monitored after 24 hours to insure there are not air leaks.

All leaks must be located before proceeding. Locating all the possible leaks in the buried section or duct system may prove replacement economically more sound than reclaiming.

Reclaiming the Cable

Megger and capacitance readings should be taken and recorded, on a sampling of cable pairs prior to placing the air dryer on the wet cable. A picture should be taken of the scope trace at this time. This information will serve as a reference of what the cable was and how much improvement has been achieved during the reclaiming process.

The number of cable pairs used in the sampling will depend on the size of the cable under test. Separation of these cable pairs is important. The readings taken will be averaged to reflect the condition of the cable and the movement of water in the cable. The following is a guide for determining the number of cable pair to use:

Cable Size	*Number of Pair*
50	*3*
100-200	*4*
300-400	*6*
1,200-2,400	*8*

It is recommended that the above test pairs be selected from different binder groups. These represent minimum requirements, additional cable pairs may be used if desired. The pictures taken of the scope trace should be taken on the same cable pair each time, and only one cable pair is required. However, spot checking other pairs in the cable is encouraged. Capacitance readings should be taken every 24 hours, and scope *pictures the same unless there is no change in the trace.*

The air dryer should be shut down at 72 hour intervals and the gas and oil levels checked. The discharge end of the cable should have a piece of plastic hose (or equivalent) attached to the discharge valve, and the hose run to a container to collect the bulk water that is removed. A 3'' sheath opening should be made (at the discharge valve location), after the bulk of the water has been removed, to allow maximum air flow. The discharge valve may be taken off and the sheath removed at this point.

A pressure setting of 50 P.S.I. should be placed on the cable at the start of the reclaiming. The cable sheath will stand 50 P.S.I. with no ill effects. The pressure setting (discharge from the air dryer) can be increased after the bulk water has been removed and the 3'' sheath opening is made at the far end.

Summary

This method of reclaiming wet cable has two (2) phases:

1. Removing the bulk water.

2. Vaporizing the remaining moisture.

It is difficult to estimate the time required to reclaim any given cable, because the amount of time required is directly related to the amount of water in the cable. Our present test gear can tell us if there is water in the cable, and where the bulk of the water is located, but not the volume of water. Logically a cable completely full of water would require longer to reclaim that a cable half full.

Although this method seems lengthy, there is a big advantage in reclaiming the wet cable at its original characteristics without changing its transmission qualities. This is not the case when reclaiming with compound. The water is removed, but the cable will exhibit an increase of 30, 50% above the original capacitance, which destroys the load spacing and may render some carriers inoperative through these sections.

Component/Antenna Testing

As previously stated, a fault signature uniquely defines the fault. It is possible to make a detailed analysis of TDR reflections and determine the exact value of the fault or component which is causing the signature. These kinds of analyses are of value in the design laboratory, or for a detailed engineering evaluation of a complex system, but are of little use for cable maintenance. However, TDR signatures can be recorded and used for ''GO/NO GO'' comparison testing.

The first step is to permanently record the signature of a known good antenna or component. After that, it is easy to quickly compare the items under test to the reference signature.

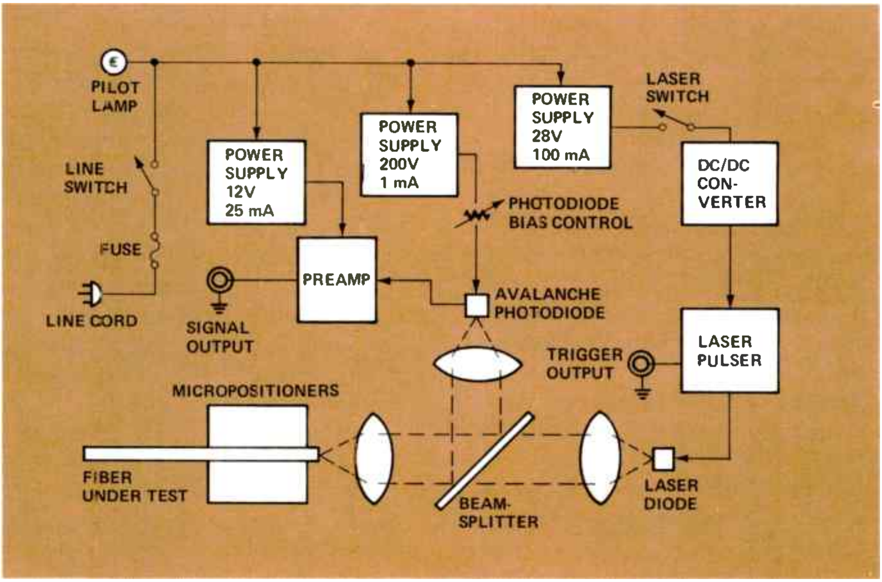
Remember, the TDR signature will vary with the length of cable from the TDR to the test item. Testing should always be done with the same length and type of cable. Best results are obtained when the cable is as short as possible.

Generally, step type TDR's are better than pulse types for antenna testing, if the cable run is short and the antenna is not in a strong rf environment. If the cable length is greater than about 100 feet or the antenna is in a strong rf environment, the pulse type TDR is best. In some cases, isolation networks may be required to improve noise immunity.

Optical TDR

An optical time domain reflectometer (OTDR) is useful for making measurements while installing, splicing, or troubleshooting optical fiber cables. These instruments can be used to make measurements when only one end of the cable is accessible. This fact makes them particularly suitable for field use.

Figure 16. Siecor model 38 optical time domain reflectometer.



Courtesy Siecor, Inc.

Figure 17. OTDR electrical/optical block diagram.

Figure 16 is a photograph of a Siecor Model 38 OTDR. This instrument can be used on fibers or cables to:

- Determine fiber length.
- Locate fiber breaks.
- Evaluate splice or connector losses.
- Measure fiber/cable attenuation.
- Assess fiber homogenity.

The Siecor OTDR uses the backscattering and far end reflections of optical fibers to base measurements on signal amplitude as well as transit time.

Figure 17 is a functional block diagram of the model 38. Referring to the figure, the injection laser diode emits near infrared light pulses which are passed through a collimating lens and 3dB splitter before being launched into the fiber through a second lens.

The micropositioner is used to properly position the test item relative to the laser beam. The positioner can accomodate a variety of fiber geometries and cables.

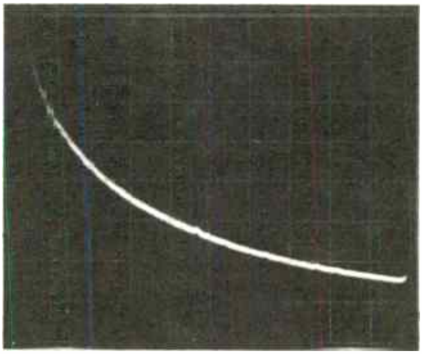
The beam splitter diverts reflections from the near and far ends, or from any other fiber discontinuity, to the input of the avalanche photodiode. The diode's electrical output signal is amplified and connected to a BNC coaxial output jack.

The signal is displayed on an external oscilloscope connected to the output jack. The oscilloscope must have a bandwidth greater than 10 MHz, a sensitivity better than 5 mV per division and an input impedance of at least 100 kilohms. Due to the low repetition rate, an acceleration voltage of at least 10 kilovolts or a long persistence phosphor CRT is desirable.

Tektronix oscilloscopes in the 465 and 475 series, or equivalent, are satisfactory. Distance measurement precision can be enhanced by using an oscilloscope capable of measuring digital differential time. The Tektronix model DM44 has this capability.

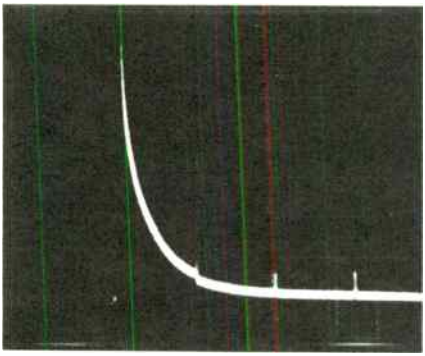
Figure 18 is a scope display of three 1 Km sections of cable joined with connectors. Figure 19 expands the first section display. Figure 20 expands the spike caused by the connector between the second and third sections.

The length of fiber is calculated from the difference in arrival times of



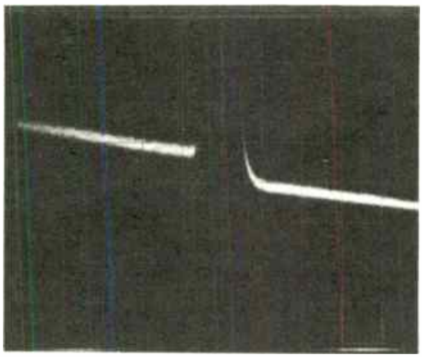
Courtesy Siecor, Inc.

Figure 19. Display for the first 1 km section of cable (5.4 dB).



Courtesy Siecor, Inc.

Figure 18. Display for three 1 km sections of cable (5.4, 5.3 and 5.2 dB/km) joined with connectors.



Courtesy Siecor, Inc.

Figure 20. Display for the connector loss (0.4 dB) between the second and third 1 km sections of cable.

the near and far end reflections; using the following formula:

$$L = \frac{c}{n} \cdot \frac{\Delta t}{2}$$

where: L = Length in meters
C = Velocity of light in free space (1×10^8 meters per second)
n = refractive index of the fiber
Δt = time difference from the near end pulse and the reflected pulse from the far end or other discontinuity.

The Δt factor is divided by 2 because the energy in the pulse from the far end has traveled down the length of fiber and back.

Cable attenuation may be approximated by the formula:

$$A = \frac{\frac{1}{2}\left[10 \log_{10} \frac{Y_1}{Y_2}\right]}{X_2 - X_1}$$

where: A = attenuation in dB/km
Y_1 = pulse amplitude at X_1 kilometers
Y_2 = pulse amplitude at a greater distance, X_2 kilometers

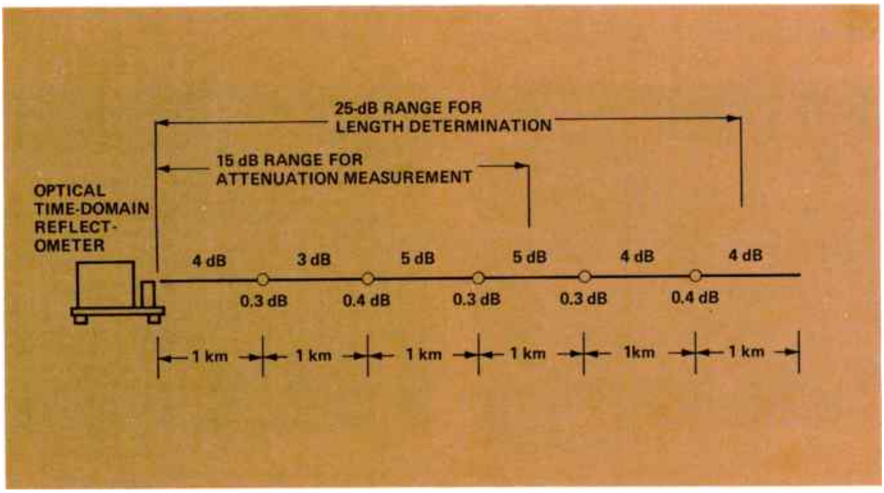
Splice attenuation, A_s can be calculated from the numerator of the above fraction by making Y_1, the pulse amplitude before the splice and Y_2 the pulse amplitude after the splice. Mathematically:

$$A_s = 5 \log_{10} Y_1/Y_2$$

Figure 21 diagrams the length and attenuation measurement ranges for the Siecor Model-38. Basically the factors that affect optical TDR measuring accuracy are the same as those which affect electrical TDR measuring accuracy.

Conclusion

This second article in our Cable Fault Locating series demonstrates that instruments based on time-domain reflectometry are versatile,



Courtesy Siecor, Inc.

Figure 21. Illustration of OTDR ranges in a typical cable system.

useful tools for locating and defining cable faults. Time-domain reflectometers can be used to test twisted-pair, coaxial and optical fiber cables.

TDR's are a valuable addition to, but not a replacement for, the bridge and tone type instruments described in Part One. Just as with these instruments, the maximum capability of a TDR can be realized only by a skilled operator who is thoroughly familiar with the instrument and the outside plant. Part three of this series will discuss methods and equipment for testing cables for data communications.

BIBLIOGRAPHY

1. Bell Telephone Laboratories Staff, *Transmission Systems for Communications*, pages 13-22, 56, 78. February, 1970—Western Electric Company, Technical Publications, Winston Salem, N.C.

2. Ivan P. Ivanov and John D. Trudel, *TDR For Cable Testing*, Application Note 25M1.0 1976 Tektronix, Inc., Beaverton, Or.

3. John D. Trudel, *Time-Domain Reflectometry, Versatile New Way of Testing Cable*, January 19, 1976, Telephony Magazine, Chicago, Il.

4. N. Kuhn, *Simplified Signal Flow Graph Analysis*, November 1963, Microwave Journal, Horizon House, Dedham, Ma.

5. GTE Lenkurt Demodulator, *Cable Test and Measurements for PCM*, Dec., 1971, Reprinted in Selected Articles from the Demodulator, Vol. 3 GTE Lenkurt, Inc., San Carlos, Ca.

6. P.R. Bark, R.A. Wey and H. Lientz, *Field Splicing of Optical Cables and Fiber Assessment with Optical Time-Domain Reflectometry*, Proceeding of First International Fiber Optics and Communications Exposition, Information Gatekeepers, Inc. Brookline, Ma.

7. S.D. Personik, *Photon Tube An Optical-Fiber Time-Domain Reflectometer*, March 1977, The Bell System Technical Journal, Bell Laboratories. Murray Hill, N.J.

8. A.E. Wilson, *How-And With What-To Find Cable Faults*, February 3, 1975, Telephony Magazine, Chicago, Il.

Editor's Note:

The use of Tektronix and Siecor Equipment for illustrative purposes does not constitute an endorsement of that equipment. The Demodulator does not recommend any particular manufacturer's test equipment.

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