AN205

Comparison of Time Domain Reflectometry vs. Frequency Domain Reflectometry (TDR vs. FDR)

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Abstract

A few manufacturers of test equipment tout the technology of an FDR as being superior to a TDR. One has gone so far as to publish brochures that compare their $6000 FDR's performance against a bare bones $300 TDR (without mentioning that the TDR they comparing against is a low end unit). You can get a quality TDR for under $1500 that outperforms an FDR in a number of categories. The FDR manufacturers' statement that "The FDR measures at frequency and therefore is better than a TDR" is true under special circumstances. This paper compares and contrasts the FDR and TDR technologies and explains the advantages of each type of instrument. In particular, the AEA Technology's VIA Echo™ 2500 FDR's readings are compared with an AEA 20/20 TDR™ (step TDR).

The TDR takes measurements in the time domain and is independent of frequency. Here's another way to think of it…the step TDR makes its measurements over all frequencies, while the FDR concentrates its measurement over a selected sweep of frequencies. This paper explains the conditions when an FDR measurement "at frequency" has an advantage over a TDR. However, the FDR process to convert return loss information into a reflectometry measurement uses an inverse FFT. This return loss/inverse FFT process introduces major limitations to the displayed information. For a fraction of the cost of an FDR, a step TDR displays the information about your cable in much greater detail.

Introduction

One FDR manufacturer makes claims about how poorly TDRs perform (the "FDR is better than a TDR" myth). It is not fair to use the limitations of a low end $300 TDR and infer that all TDRs have these limitations. A quality TDR costing under $1500 can see the defects that the $6000 FDR shows (plus a few things the FDR can't see).

Here are some of the claims made about TDRs. Only ONE of these claims is true when a quality TDR like the AEA 20/20 TDR is used in a comparison against the FDR. We will discuss each of these issues in detail in the next section.

Claim Statement	Claim Accuracy
A TDR only measures open or short faults	FALSE
A TDR operates at DC	FALSE
A TDR has poor sensitivity	FALSE
A TDR cannot monitor small performance changes	FALSE
A TDR cannot find a corroded junction	FALSE
A TDR cannot support a preventative maintenance program	FALSE
A TDR cannot measure return loss	FALSE
A TDR uses a different measurement technique than FDRs	TRUE

Not only does the 20/20 TDR find virtually all defects found by FDRs, but the 20/20 TDR has several advantages not found in FDRs:

Advantages of a TDR over an FDR
The 20/20 TDR differentiates series faults from shunt faults
The 20/20 TDR displays accurate loop resistance vs. distance
The 20/20 TDR allows the user to zoom in on a section of the cable
The 20/20 TDR does NOT use odd ball step increments on the distance scale
The 20/20 TDR does NOT require that you know the length a cable in advance
The 20/20 TDR does NOT give false distances caused by aliasing
The 20/20 TDR costs significantly less.

Note that the limitations of the FDR cannot be overcome by buying a more expensive unit; the FDR limitations are inherent to the FDR technique.

The FDR does have some advantages over the TDR. If measurements are required in any of the following situations, then the FDR would be a better choice, even with the loss of the TDR advantages listed in the table above.

Advantages of an FDR over a TDR:
FDR measurements can see through narrow band inline frequency selective components (diplexers) and show information on the far side.
FDR's operate with higher levels of interference.

If the cable under test contains frequency selective components (duplexers, diplexers, cavities etc.), or if the antenna at the end of the cable receives signals greater than -10dBm, then the FDR performs better. The 20/20 TDR has filters that allow the unit to operate with some interferers, such as an ADSL modem, broadband signals, or 60 cycle noise etc, but these filters do not effectively reject strong broadcast signals.

In the absence of the above situations, the 20/20 TDR provides more information about the cable than any FDR.

Discussion

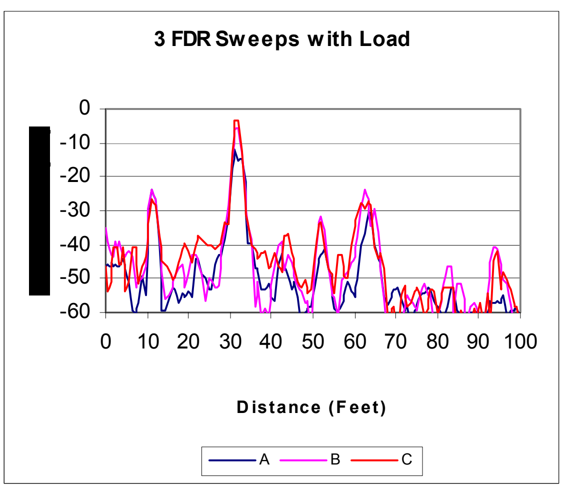
Measurement at Frequency

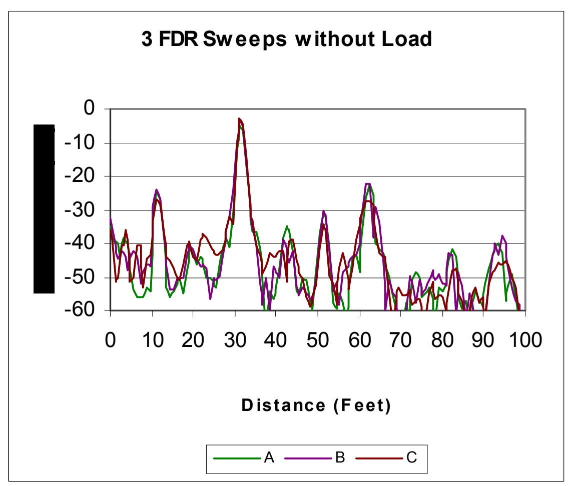
We start with the sales pitch about measuring "at frequency". This sounds very compelling, why would this not be an advantage? Major limitations to this advantage appear under real world conditions. Most antennae will have moderate to high Q bandwidths (narrow BWs) and are fed by a feedline. It will be explained in detail later that an FDR must sweep a wide band of frequencies to prevent alias distortion. The feedline, not the load, dominates the required sweep settings. This can lead to either of two problems:

1. The vast majority of the FDR sweep lies outside the antenna's bandwidth, i.e. not "at frequency" (wide sweep width).
2. The cable information gets scrunched up on the left side of the plot (narrow sweep width).

In the first case, most of the FDR sweep is not at frequency, and the readings obtained at some arbitrary frequency give very similar results as those measured "at frequency". In the second case, the feedline may only extend for 10% of the plot width, reducing detail to marginal levels. Virtually all cable faults can be detected whether the measurement is done at one frequency or another. This happens because cable faults rarely affect only a specific bandwidth but rather cause broadband degradations. Examples here show various FDR measurements on an antenna with feedline. The first chart shows a good cable/load combination at three different frequency sweeps, the second chart shows a faulty cable/load with the same three sweeps. The three FDR sweeps used are:

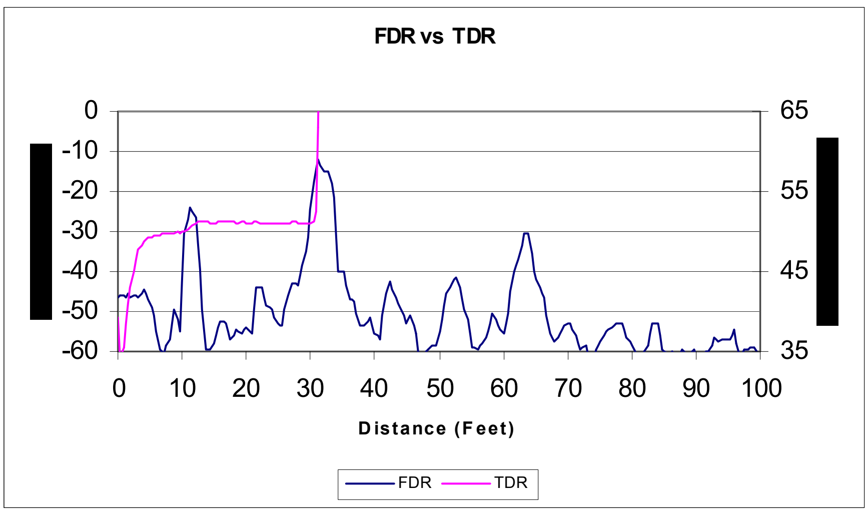
A) Sweep centered on the antenna resonant frequency
B) Sweep not centered on, but including the antenna resonant frequency
C) Sweep entirely excludes the antenna resonant frequency





All traces show a connector at 11 feet 3 inches with approximately 24 dB of return loss. The peak at 31 ½ feet is the antenna/end of feedline. All events after 31 ½ feet are aliasing artifacts and should be ignored. Note that 4 traces (no load or not on frequency) have about 4dB of return loss at the end of the feedline. The other two sweeps have lower return losses of 6 and 13 dB as the sweep has more energy at the antenna frequency. The differences overall are not huge, it would be difficult to say with certainty if the reading indicates the presence of an antenna or not unless there were previous readings to reference.

Another plot compares the FDR reading (left axis) with a step TDR reading (AEA 20/20 TDR on the right axis) using the same feedline and antenna. The TDR shows 1.4 ohms of impedance change at the connector (10 foot 2 inches). The TDR also shows the cable ending at 31 ½ feet. The first few feet of the TDR trace show a soft rise due the waveform characteristics. Returning to the connector at 10 foot 2 inches, the TDR trace shows that the cable Z0 before the connector is 49.9 ohms but after the connector the cable Z0 is 51.3 ohms. Even though both sections of the feedline are supposed to be 50 ohms (RG213/U cable), the TDR shows the actual Z0s on each section of the feedline. These impedances were confirmed using a laboratory grade vector impedance meter.

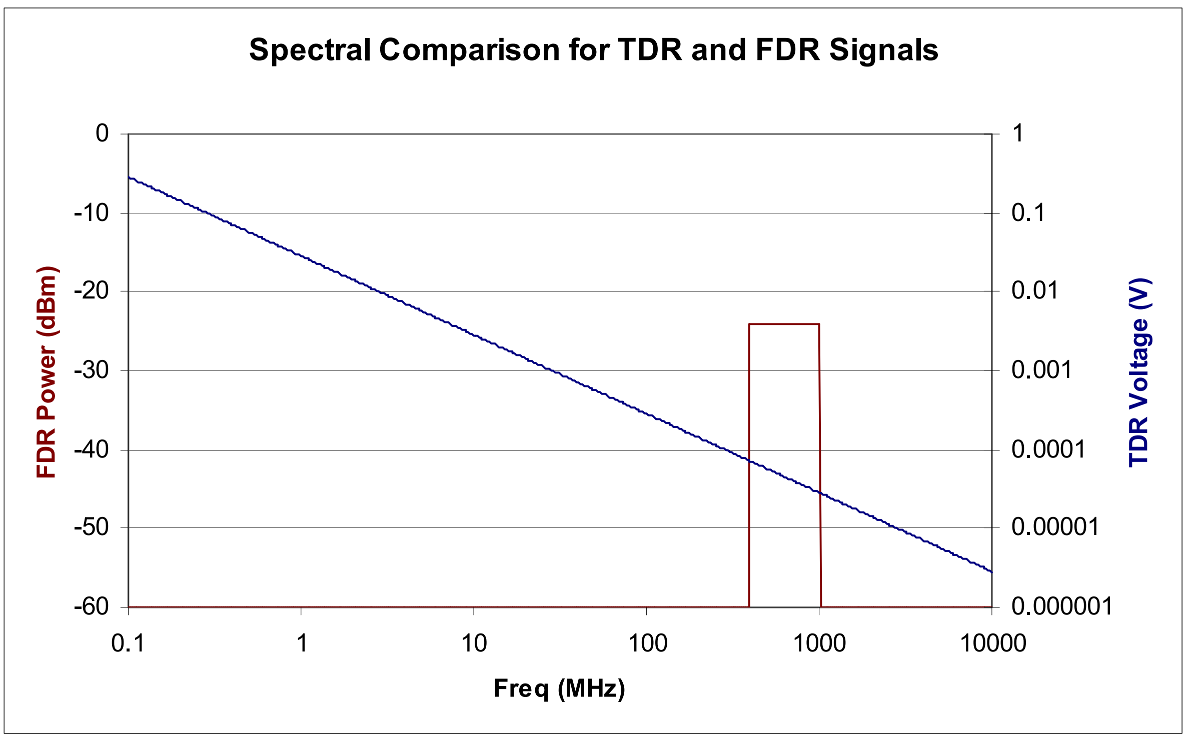


A lossy (resistive) connector could also produce this type of plot. By inspection and measuring at the connector, one can determine which condition exists. Another method would be to look at the cable from the other end; a resistive connection will always raise the impedance reading of the cable after the connector. If the connector is good, the cables will read the same impedances as before (but in opposite order). The FDR does not give any additional information by measuring the cable from the other end.

While the FDR and TDR plots show similar results (connector and antenna distances) for the same feedline, the TDR plot also shows mismatch direction and absolute impedance level.

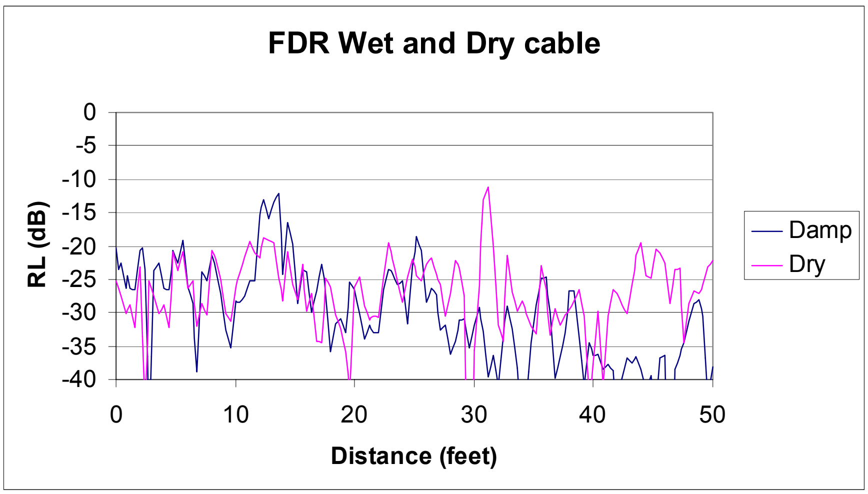
Signal Energy

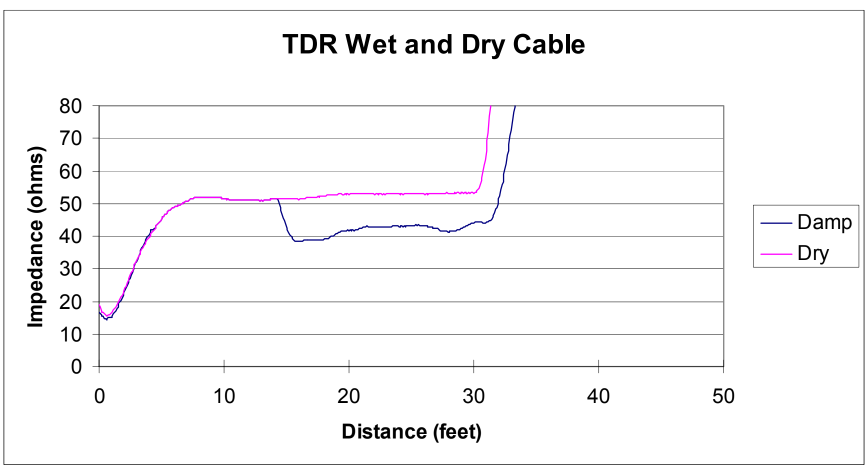
In order to make the TDR seem inferior, the competition shows a graph comparing the spectral distribution of the FDR vs. TDR. The sin(x)/x curve for the TDR shows that a pulse type TDR, not a step TDR, was used for their graph. Our graph compares the *step* TDR vs. an FDR. Since the step TDR processes reflected voltage while the FDR processes reflected power (return loss) comparision of the TDR vs. FDR signal *power* spectrums becomes misleading. To better reflect how the two units detect, process, and display the signal, the plot below shows the FDR frequency sweep power distribution vs. the voltage distribution of the TDR step waveform. The FDR sweep divides the power evenly amongst the 250, 500, or 1000 points of its sweep; we show the 250 points case in this plot (1000 points would be 30 dB down). This plot compares two units with the same output level (0dBm) with the FDR set to a 700 MHz center frequency and a 600 MHz wide sweep. Note that the FDR signal has limited frequency range, while the TDR has a steady drop in amplitude as frequency increases. A step TDR actually covers a wider range of frequencies than an FDR, but the FDR can concentrate its energy in a narrower band. This difference will give the FDR an advantage when a frequency selective component or interfering signal is on the line being measured.



Water Faults

Some faults are caused when water leaks into the coaxial feedline. The FDR and TDR plots for a damp cable are shown here. Each graph compares the faulty cable plot with the same cable prior to the fault. With a TDR, the water fault has its distinct signature, a drop in impedance from the start of the wet cable to the end of the cable or end of the water. If there is standing water inside the cable, the plot will drop to zero and the end of the cable will not be detected. Note that the plot shown here shows that the cable is longer with the water fault, this is because the VF in the wet section has dropped and slowed the pulse down. Distance measurements in and beyond the wet section are distorted and can not be relied upon (for either TDR or FDR). Finding the length of the wet section requires a measurement from each end of the cable, then subtract these readings from the total length. The FDR plot shows the water fault, but one really can't be sure its a fault or the end of the cable unless they know that the cable is longer than the 12 foot reading shown on the graph. Once the FDR user has determined there is a fault, they have no indication as to the nature of the fault until the visual examination discovers it. Since the water entry point could be a long distance beyond the detected fault distance indicated by the TDR/FDR, being able to clearly distinguish a water fault from other fault types gives the TDR user an important advantage.

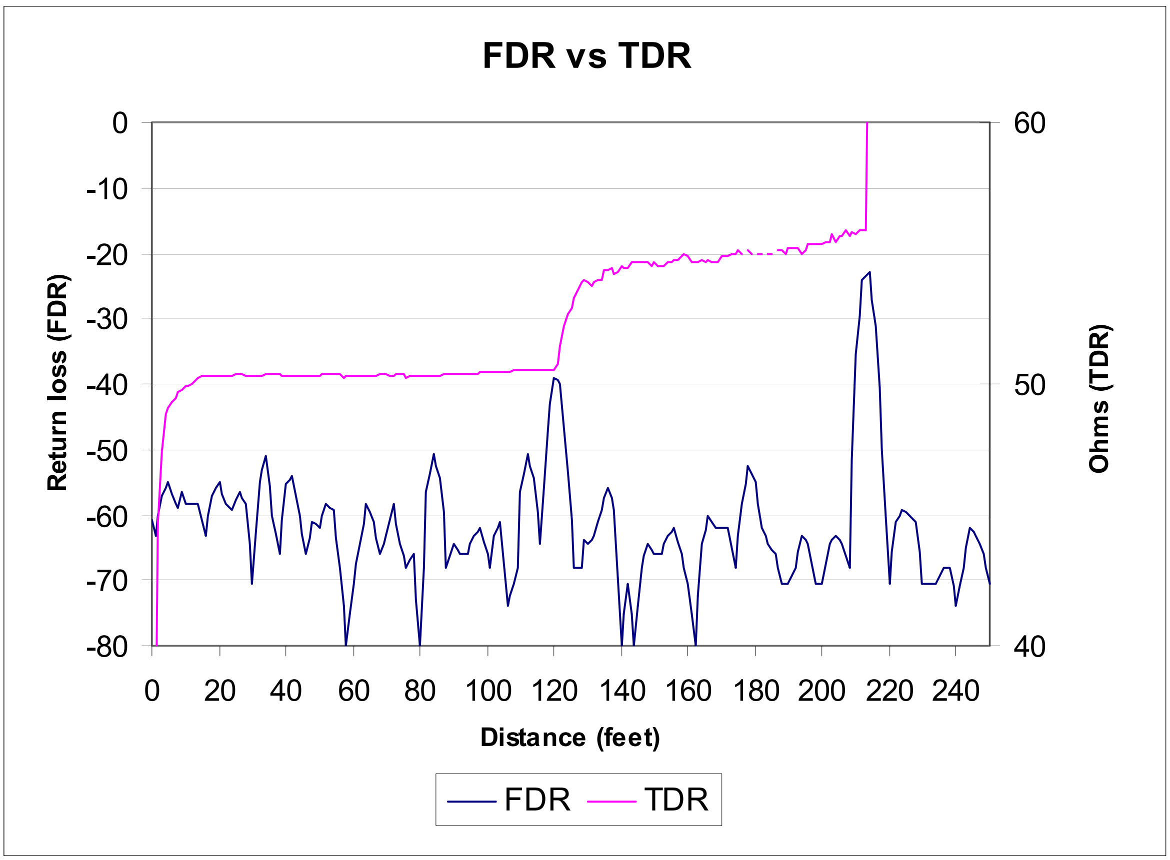




Displayed Information

While both types of reflectometers show the distance to a fault, that is where the similarity ends. The units of display on a step TDR are Ohms, not the dB scale that FDRs use. A step TDR displays conductor/connector resistances as they accumulate over the length of the cable. The step TDR also displays the measured Z_0 of the cable. An FDR shows neither of these important characteristics.

The example plot here shows a 120 foot length of quality, low loss cable followed by a 90 foot length of low quality cable. Note how the TDR shows the Z0 for each section, plus the flat slope of the first section indicates low loss coax while the steep slope of the second section indicates a lossier coax. There is no information on the FDR trace to indicate the Z0 or the quality of each section, only the distances to the connection and to the end are clearly shown.



Another quirk of FDR's cause oddball distance increments on the horizontal scale. The finite synthesizer step size (typically 10 KHz or worse in FDRs) combined with the cable velocity factor and the sweep bandwidth to produce an inflexible and usually irregular step size (e.g. 9.7 inches per step). The FDR will label the horizontal axis with a round number, but this merely masks the irregularity of the actual distance increments. The 20/20 TDR uses an internal resolution much finer than the displayed resolution, so the TDR sweeps cables with any velocity factor using even, customary step sizes (e.g. 1.0 inch per step, with <0.2% full scale error).

Since the return loss information, used by the FDR, is scalar, the user does not know the direction of the mismatches, only their magnitudes. Step TDRs display the mismatch direction, thus you can distinguish a high Z fault from a low Z fault. This additional information, provided by the step TDR, improves fault analysis, because a series loss shows differently than a shunt loss. On the other hand, an FDR does not distinguish between these conditions. Thus the impedance display of a step TDR shows far more information than the return loss display of an FDR.

Preventative Maintenance

The AEA 20/20 TDR includes the TDR PC Vision™ software that allows one to expand on the TDR's capabilities. Data can be saved in the unit and transferred to the desktop PC in your office (or to a laptop PC anywhere). Data can be stored on the hard disk to create historical files. By comparing readings of a particular site from one time to the next, preventative maintenance can be practiced by replacing/repairing only the cables that have degraded, while leaving the non-degraded cables intact. Data in TDR PC Vision can be exported to spreadsheets so that customized calculations, comparisons, or plots can be performed. There are no licenses required to use TDR PC Vision™ which enables coworkers and customers to examine and use any TDR files you send to them.

Measurement Artifacts

The inverse FFT process used by an FDR possesses an artifact known as “aliasing”. It is beyond the scope of this paper to provide a tutorial on aliasing; there are plenty of papers written on the subject. The result of aliasing is that you must choose your FDR sweep to measure the ***entire*** length of the cable. In practice you will have to set the sweep to measure ***beyond*** the end of the cable to be certain that there is no aliasing. Improperly setting the FDR frequency sweep causes aliasing, which results in incorrect distance information. This requirement that the entire cable be swept, along with the finite number of display points, combine to limit your resolution on longer feedlines. On the other hand, quality step TDRs do not alias so these limitations do not apply. A step TDR can look at any segment of the cable (i.e. you can zoom in on a fault). Displaying a portion of the cable with the step TDR does not introduce any false readings. Thus the cable length and number of displayed points do not limit the displayed resolution. The 20/20 TDR can always display its finest resolution over some segment of the cable (sometimes over the entire length). For the 20/20 TDR this corresponds to 1 inch or 2cm for any 160 foot (25 meter) segment.

If the TDR or FDR does not exactly match the Z_0 of the cable under test, the reflectometer sends secondary and tertiary reflections down the cable. These extra reflections cause “ghosts” of the cable beyond the actual end of the cable. The 20/20 TDR always displays these ghosts at distances beyond the end of the cable, while the inherent aliasing of the FDR may cause these ghosts to appear at distances before the end of the cable, displaying false events.

Performance Summary

Measurement property	20/20 TDR (step TDR)	FDR	Quality Pulse TDR	Cheap TDR
Distance to Fault	Y	Y	Y	Note 1
Z sensitivity	0.1 ohms	0.1 ohms, Note 2	N/A	N/A
Z_0	Y	No, Note 3	N	N
Conductor resistance	Y	N	N	N
Series vs. shunt fault	Y	N	Y	N
Display Cable Ohms	Y	N	N	N
Display Cable Return Loss	Y Note 4	Y	N	N
Display Cable SWR	Y Note 4	Y	N	N
Zoom in to any cable segment	Y	N	Y	N
Control of distance increment (resolution)	Y	N Note 5	Y	N
Measure delay match between cable pairs	Y	N	Y	N
Immune to false readings due to aliasing	Y	N	Y	Y
Cost	$$$	$$$$$$$$$$$$	$$$	$
Remove test lead from display	Y	Y	Y	N
Measure at Frequency	N	Y, Note 6	N	N
Measure cable with Diplexer in line	N	Y	N	N
Higher interference immunity	N	Y	N	N

Notes:

1. Can only measure faults that are opens or shorts.
2. This 0.1 ohms is implied when directivity is better than 55dB.
3. The FDR can express how close the cable Z is to the ideal Z_0, but can not distinguish lower Z from higher Z. This cable Z to ideal Z_0 ratio is expressed in terms of return loss or SWR.
4. Converting from ohms to return loss or SWR is just a calculation. See Application Note http://www.aeatechnology.com/html/AN_Html/AN103.htm for details of these calculations. The 20/20 TDR always displays the cable impedance but the PC Vision software can display the cable in any of these formats.
5. Distance resolution is some odd value that results from the combination of sweep width (forced by feedline length) and velocity factor.
6. The length of the feedline limits the frequency sweep settings and the sweep may exceed the frequency band of interest.

Conclusion

What is the advantage of using an FDR instead of a TDR? Let's use a Swiss army knife analogy. If a saw blade is added to the knife, it has increased utility. The saw blade could save your hide in a pinch. However, if you want to cut a bolt, a hacksaw would be a better choice. It would cut cleaner and faster, with fewer scraped knuckles to boot. To extend this analogy to reflectometers: The FDR increases the utility of a network analyzer, and may come in handy should the user not want to climb down the tower to grab the TDR from the truck. However, if measuring cable is a routine requirement, a quality step TDR, such as the AEA Technology's 20/20 TDR, will often be a more useful tool than an FDR. It should become standard equipment on the technician's tool belt.

How to chose between an FDR or a TDR? Use the performance comparison chart above to decide which type of reflectometer meets the necessary requirements. A few cases need an FDR instead of the 20/20 TDR. Unless you do testing through diplexer type components or are in high interference environments, an FDR will probably not be required

Reflectometry may be accomplished using two methods, FDR and TDR. Low quality TDRs are worse than FDRs, but <u>a quality step TDR will outperform any FDR on the market in all but a few categories.</u> If one measures cable regularly, they should add the 20/20 TDR to their tool belt and experience the increased productivity that will be obtained from the ability to distinguish series faults from shunt faults, easy to track step size, and alias free readings.