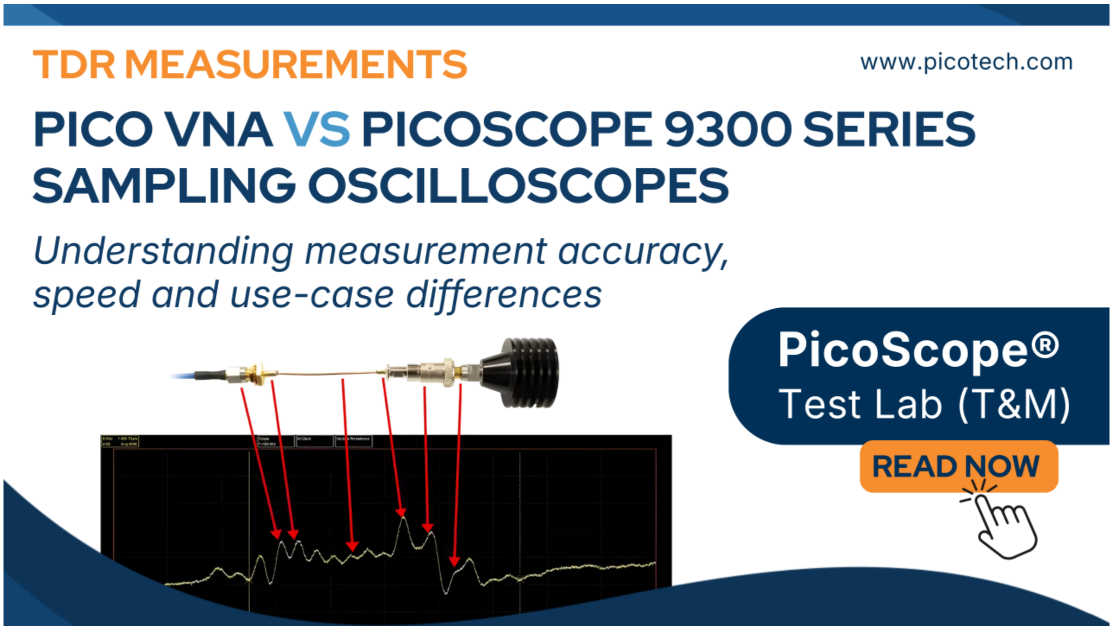


TDR Measurements: Pico VNA vs PicoScope 9300 Series Sampling Oscilloscopes

This article explores the comparative performance and methodology of Time Domain Reflectometry (TDR) using two distinct instrument classes: a [Vector Network Analyzer (PicoVNA)]() and a [PicoScope 9300 Series sampling oscilloscope]().

What you will learn:

- ***Instrument comparison:*** *The fundamental differences in how the PicoVNA and a PicoScope 9300 Series sampling oscilloscope approach TDR measurements.*
- ***Setup & configuration:*** *Practical steps for configuring both instruments to achieve accurate results.*
- ***Data interpretation:*** *How to read and analyze the resulting waveforms to identify faults and impedance mismatches.*
- ***Choosing the right tool:*** *Determine which instrument is best suited for specific signal integrity applications.*

What is Time Domain Reflectometry?

Time Domain Reflectometry (TDR) is a useful technique for measuring the impedance of transmission lines and determining the position of discontinuities caused by connectors or damage. An impedance mismatch from a discontinuity causes a reflection, the shape and scale of which gives clues about the type of mismatch.

Time Domain Transmission (TDT) is a similar technique that examines the signal after it has passed through the device under test (DUT). Both TDR and TDT measurements, as the names suggest, take place in the time domain. This is in contrast to a VNA (Vector Network Analyzer) that operates in the frequency domain. The vectors in the name VNA refer to the measured characteristics at a given frequency, comprising a magnitude and phase component, which together make a vector. A VNA can also perform scalar analysis when only the magnitude is measured.

The vector measurements from a VNA indicate the quality of the match between the source (the VNA) and the DUT; the goal is the same as when performing a TDR or TDT measurement. TDR/TDT analysis tends to be faster, while scalar and vector analyses tend to have more dynamic range. Results can be transformed between the time and frequency domains using techniques such as inverse Fourier transforms, providing flexibility in analysis.
Time-domain measurements are particularly effective at determining the physical location of a mismatch, fault or component. Physical distance is obtained simply by multiplying the timing of a reflection by its propagation velocity

(close to the speed of light, c). Vector quantities, such as S-parameters, can in principle be extracted using either technique, but this is not always the case. This article will discuss the benefits and drawbacks of each method.

Time Domain Measurements

System bandwidth or, more accurately, system transition time (that of the fast pulse, combined with that of the sampling oscilloscope and any interconnect) determines the time resolution and hence the physical distance that can be resolved. To determine the magnitude of a mismatch, complete rise and fall times are needed to cleanly define a pulse amplitude. When detecting the presence or location of a mismatch, distance resolution can be around five times better than this. The resolution quantities given below assume a typical PCB or coaxial propagation velocity of around 0.7 c.

Available pulse amplitude and pulse amplitude variability can both be considerations, but not as significant as you might think. In practice, the usable pulse amplitude is limited to the oscilloscope's full-scale voltage. The benefit of a large amplitude at the source is that the test system source match can be improved by using an attenuator.

Variable amplitude allows optimizing signal level and thus dynamic range in any time-domain measurement, and possibly reducing amplitude to keep within the device-under-test limits. Pulse distortions or aberrations at the pulse source or at the receiving oscilloscope and interconnect are not of primary importance in a TDR/TDT application because they are corrected by system port calibration to known short, open, and load conditions.

Method 1: Using a PicoScope 9311-20

The **PicoScope 9300 Series** is a range of sampling oscilloscopes that operate up to 30 GHz. The input voltage is 1 V peak from an open-circuit reflection or unimpeded transmission path. The 9311's signal generator can produce up to 7 V, and so an attenuator can be used to improve the match.

An oscilloscope typically only records scalar quantities, so S-parameters cannot be extracted from the measurement.

To demonstrate TDR measurements with Pico test equipment, we measured a cable from a defense company. They wanted to understand where a mismatch in their cable was occurring to improve reliability and avoid failures.

With the cable under test connected to the 9311, the following results were obtained, as Figure 1 below illustrates:

Figure 1 – *TDR test results with the cable connected. Pin 49 yellow/grey to blue/black grounding, terminated to 50 Ω.*

Method 2: Using a PicoVNA 108

The rise time of an impulse used for TDR effectively determines the frequency of the measurement – a faster rise time corresponds to a higher test frequency.

The **PicoVNA 108** can determine the time-domain response to a step input from a broadband frequency sweep at harmonically related frequencies. An Inverse Discrete Fourier Transform (IDFT) is performed on the reflected vector data (S11) to give the impulse response in the time domain. The impulse response can then be integrated to give the step response.

Several methods are available for extracting time domain information from the frequency domain. The main methods are lowpass and bandpass.PicoVNA 5 software uses the lowpass method.

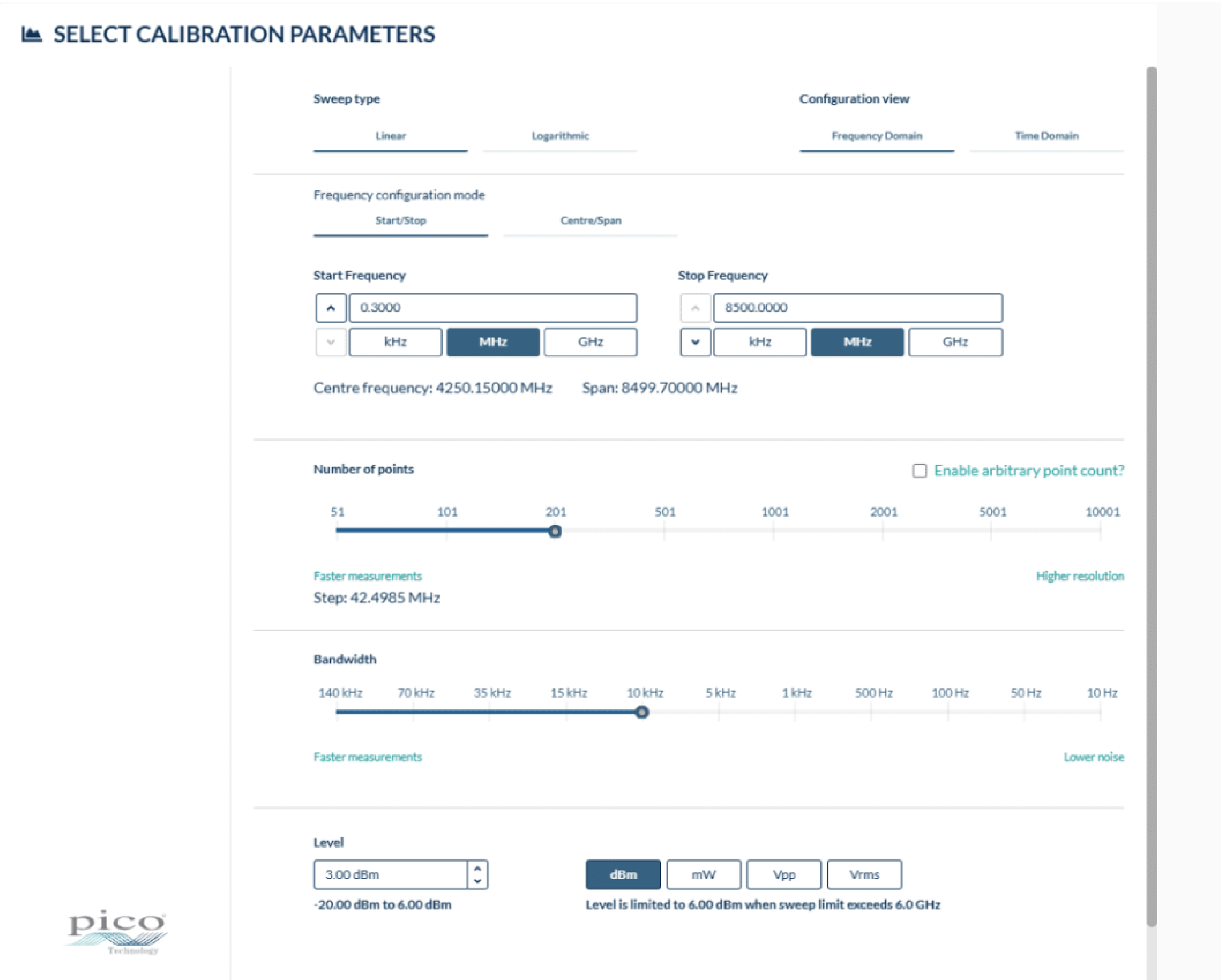
The IDFT directly computes the DUT's impulse response, which PicoVNA 5 then integrates to determine the step response. In the step response mode, the trace is similar to that of a traditional TDR measurement, except there is no step at t = 0. This is because, when the time-domain response is derived from frequency information, the value at t = 0 corresponds to the impedance of the transmission line or load immediately following the calibration plane. The value is referenced to 50 Ω, the system's characteristic impedance.

When transforming from the frequency to the time domain, the calculation requires a window to taper the frequency data to zero at the edges. In specific terms, the windowing function is applied to the finite set of frequency-domain S-parameter data before the Inverse Fast Fourier Transform (IFFT) is performed.

The PicoVNA 5 software allows you to choose between:

- NoWindow, also known as a rectangular window, is the default.
- Hanning window, also known as a raised-cosine window.
- Kaiser-Bessel window. The order of the Kaiser-Bessel window is configurable.

The VNA was calibrated as shown:



SELECT CALIBRATION PARAMETERS

Sweep type: Linear

Configuration view: Frequency Domain

Frequency configuration mode: Start/Stop

Start Frequency: 0.3000 MHz

Stop Frequency: 8500.0000 MHz

Centre frequency: 4250.15000 MHz Span: 8499.70000 MHz

Number of points: 201

☐ Enable arbitrary point count?

Step: 42.4985 MHz

Bandwidth: 10 kHz

Level: 3.00 dBm

-20.00 dBm to 6.00 dBm

Level is limited to 6.00 dBm when sweep limit exceeds 6.0 GHz

Figure 2 – PicoVNA calibration parameter setting dialog.

There are the results from the PicoVNA 108, testing the same cable as before, can be seen in Figure 3, below:

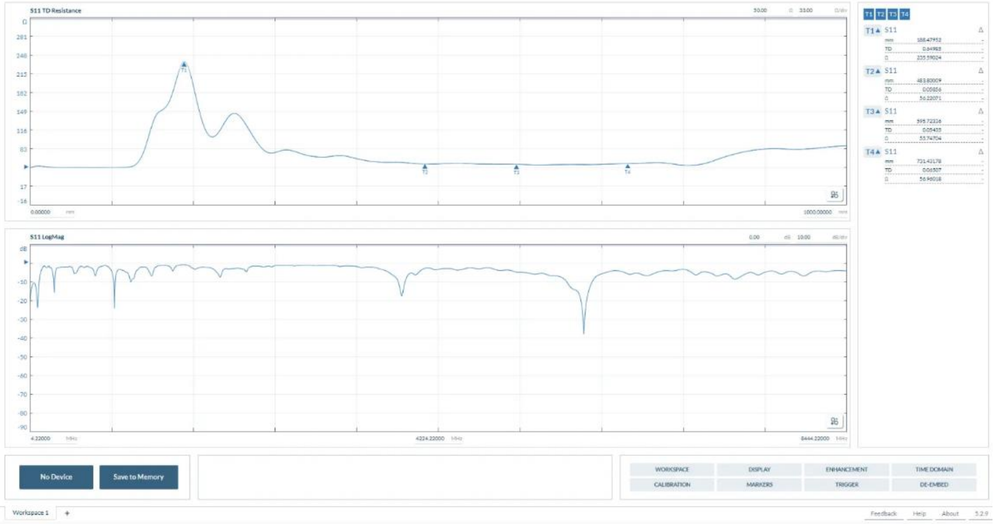


Figure 3 – Cable test using the PicoVNA, indicating the time resolution of 59 ps and the distance resolution of 19.5 mm.

The following table (Figure 4) shows how varying the VNA's frequency-sweep settings affects resolution and range. Changing the number of frequency steps (N) has no effect on the resolution but changes the range over which you can measure. Increasing the maximum frequency improves resolution but decreases the range:

f_L (MHz)	f_H (MHz)	N	Range (ns)	Range (m)	Resolution (ps)
0.3	8 500	201	11.8	3.52	58.8
0.3	6 000	201	16.7	5.00	83.3
0.3	8 500	10 001	588	176	58.8
0.3	6 000	10 001	833	250	83.3
0.3	1 000	201	100	30.0	500
0.3	1 000	10 001	5000	1500	500

Figure 4 – This table demonstrates how frequency and sweep settings affect resolution and range.

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The range calculation assumes that the propagation speed is equal to the speed of light, so ranges in practical transmission lines will be lower.

Comparing the PicoScope 9311 and the PicoVNA 108

The PicoScope 9300 Series TDR and PG900 resolution capabilities provide TDR resolution for accurate impedance measurement (Figure 6):

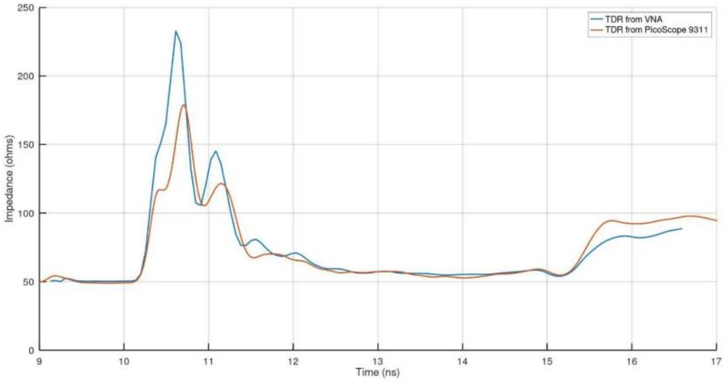

Figure 5 – Graph showing the difference in TDR test results from the PicoScope 9311 (blue) and the PicoVNA 108 (red).

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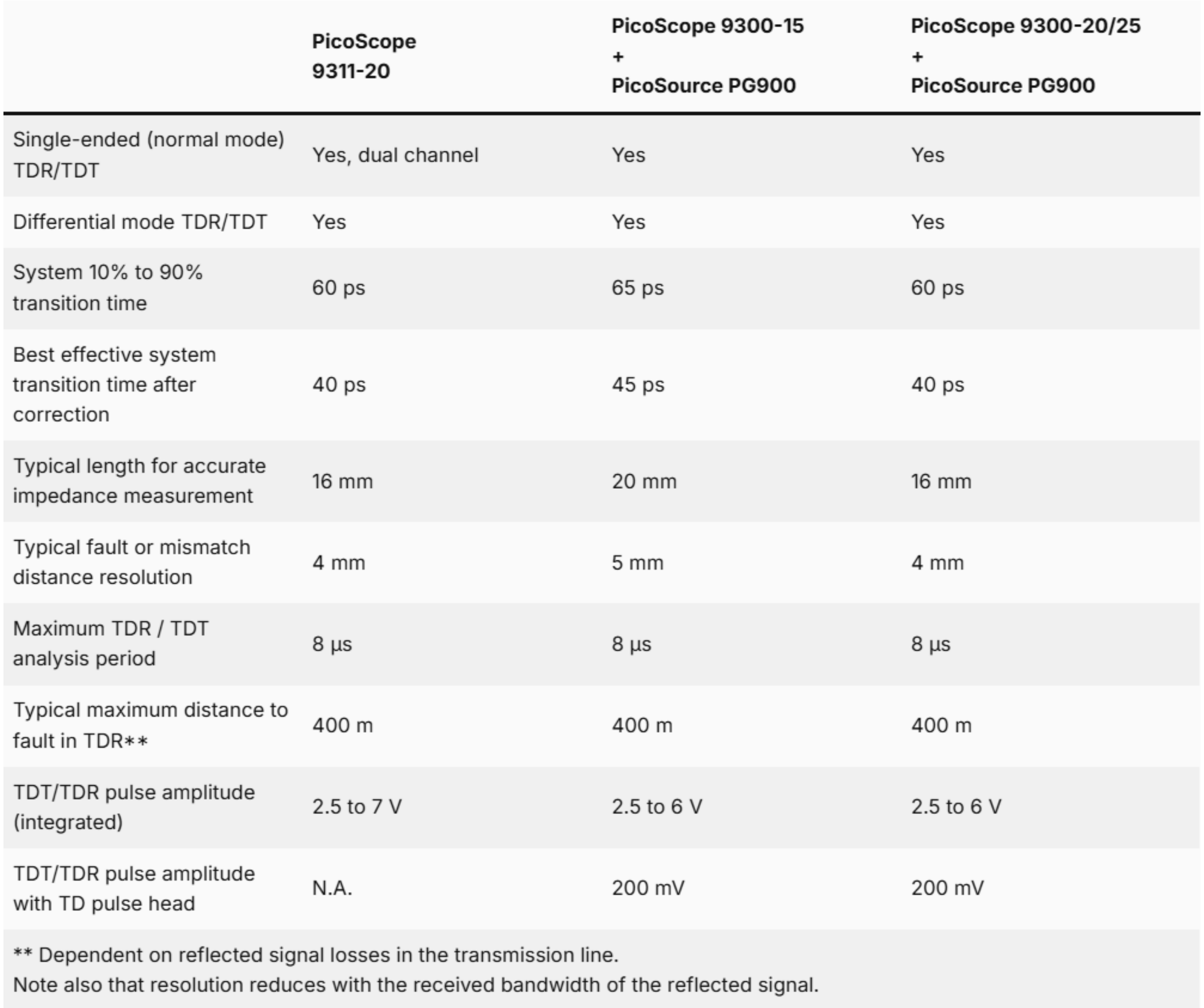

	PicoScope 9311-20	PicoScope 9300-15 + PicoSource PG900	PicoScope 9300-20/25 + PicoSource PG900
Single-ended (normal mode) TDR/TDT	Yes, dual channel	Yes	Yes
Differential mode TDR/TDT	Yes	Yes	Yes
System 10% to 90% transition time	60 ps	65 ps	60 ps
Best effective system transition time after correction	40 ps	45 ps	40 ps
Typical length for accurate impedance measurement	16 mm	20 mm	16 mm
Typical fault or mismatch distance resolution	4 mm	5 mm	4 mm
Maximum TDR / TDT analysis period	8 µs	8 µs	8 µs
Typical maximum distance to fault in TDR**	400 m	400 m	400 m
TDT/TDR pulse amplitude (integrated)	2.5 to 7 V	2.5 to 6 V	2.5 to 6 V
TDT/TDR pulse amplitude with TD pulse head	N.A.	200 mV	200 mV

** Dependent on reflected signal losses in the transmission line.
Note also that resolution reduces with the received bandwidth of the reflected signal.

Understanding Cables and Connector Measurements in TDR

This article previously showed that both the PicoScope 9311 and PicoVNA 108 are capable of accurate TDR measurements and produce similar results. But how do the results from the TDR measurement actually help diagnose cable connection problems? To demonstrate, we measured a cable used in a Pico test jig.

The cable (see Figure 7 below) is an SMA connector with a ferrule attached to some rigid coaxial cable. At the far end is a BNC connector with a ferrule for connecting to the coax. This cable is hand-made, and the ferrules make it very hard to tell if the connection is good. We can perform a TDT measurement to find out.

For the TDT measurement, we will use Time Domain Transmission (TDT) instead of Time Domain Reflectometry (TDR) in this case because of two chief concerns:

1. The quality of transmission through the cable, not reflections:
    - TDT measures how well a signal is transmitted from one end of the cable to the other.
    - In this case, the SMA-to-BNC cable is fully assembled, and you are interested in ensuring the signal passes cleanly through the entire cable — especially through the hand-assembled ferrule connections.
2. TDR only tells you about impedance discontinuities from one side:
    - While **TDR** can detect reflections due to impedance mismatches (e.g., a poorly crimped ferrule), it only shows these from the perspective of the launch point.
    - **TDT**, on the other hand, reveals **insertion loss**, transmission degradation, and discontinuities **as they affect the full signal path** end-to-end, which is more aligned with your goal of verifying overall signal integrity.
3. TDT is more sensitive to losses and transmission degradation:
    - Imperfect ferrule connections may not cause strong reflections (and so may be missed by TDR), but they can cause signal loss or phase distortion, which TDT will pick up more clearly.

To make the measurement, we connect the cable and the VNA as shown. below in Figures 7 and 8. The probe holder keeps the cable secure during testing, preventing both strain on the BNC connector (which is only a push-fit) and bending of the rigid coax.

Figure 7 – The test cable in situ, ready to make the TDR measurement.

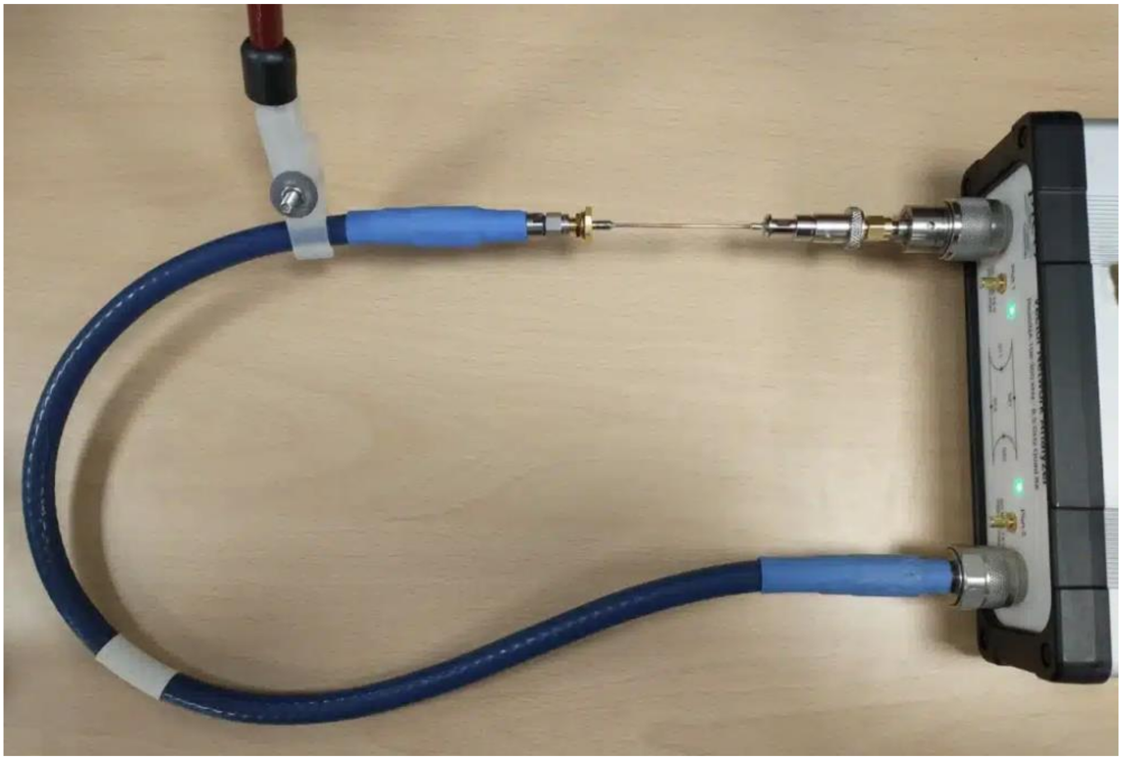

Figure 8 – The complete test setup with the test cable and the connections between ports 1 and 2 on the PicoVNA.

Figures 9 and 10 (below) show the results from the TDT measurement plotted in PicoVNA 5 software. We've highlighted with arrows the features on the plot corresponding to positions on the test cable DUT. Note that the cable shown above (Figure 8) and the cable in Figure 9 are rotated 180 degrees to align with features on the plot:

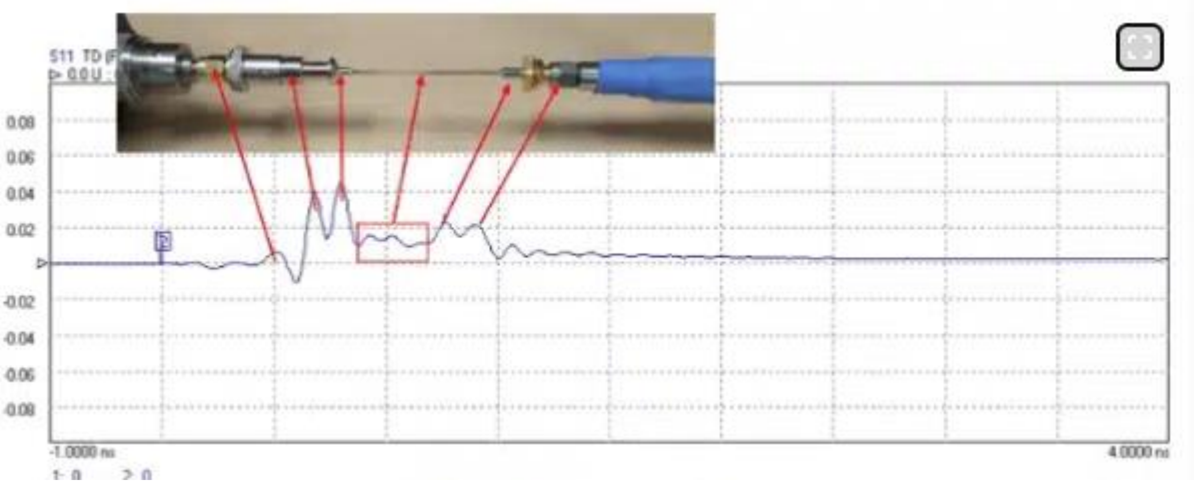

Figure 9 – TDT measurement result, plotted in PicoVNA software – test section highlighted in red

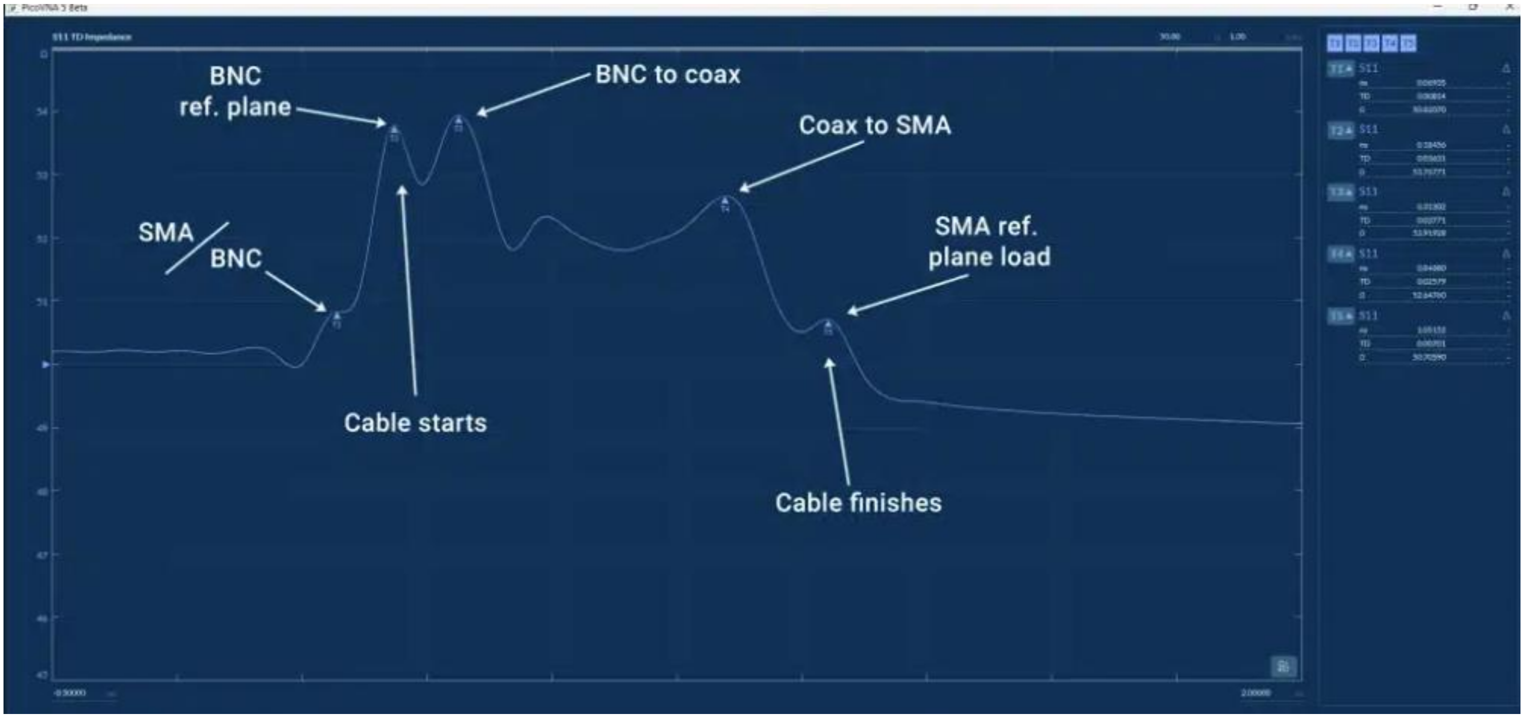

Figure 10 – PicoVNA 5 plot with annotations indicating corresponding positions on the test cable.

The initial transition from the PicoVNA 108 to the SMA to BNC adaptor is slightly inductive and so the resistance is low. The BNC-BNC connection is also not perfect, and there is a capacitive element – the line increases. The third feature is the transition from the BNC ferrule to the coax. Using a marker shows the peak reaches 55 Ω, which meets the specification for this cable.

There is a relatively flat portion of the graph that is not exactly 50 Ω. This corresponds to the cable.

At the far end of the cable, there is a second ferrule and the SMA-SMA transition. The soldering on this joint was a bit better, and so the bump is smaller. This is also a nice demonstration of how SMA is better for high-frequency systems than BNC – the peak for the SMA-SMA transition is much smaller than the BNC-BNC transition.

Using the PicoScope 9311 Sampling Scope with TDR Capability

The PicoScope 9311 oscilloscopes feature built-in step generators for time-domain reflectometry and transmission measurements. The 9311-20 features deskewable rising- and falling-step generators suited to single-ended and differential measurements. These features can be used to characterize transmission lines, printed circuit traces, connectors and cables with 16 mm resolution for impedance measurements and 4 mm resolution for fault detection.

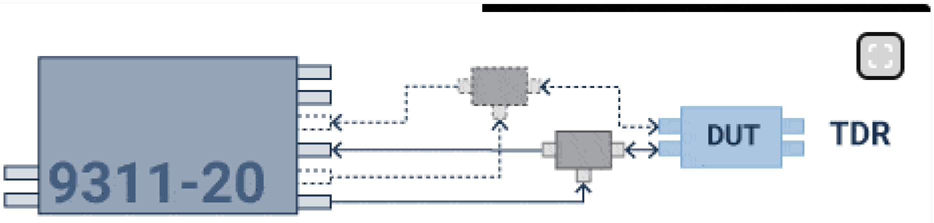

Figure 11 – Schematic of a typical cable test setup using the PicoScope 9311 sampling scope with TDR capability.

The PicoScope 9311-20 generates 2.5 to 7 V steps with a 60 ps rise time from built-in step-recovery diodes. It is supplied with a comprehensive set of calibrated accessories to support your TDR/TDT measurements, including cables, signal dividers, adaptors, attenuator and reference load and short.

The PicoScope 9311-20 TDR/TDT model includes source deskew with 1 ps resolution and comprehensive calibration, reference plane and measurement functions. Voltage, impedance, or reflection coefficient (ρ) can be plotted against time or distance.

An alternative approach to TDR/TDT capability is to pair any 9300 Series scope with a standalone PG900 pulse generator. These instruments include similar differential step recovery diode step generators and also offer an option of 40 ps tunnel diode step generation. This brings extra flexibility and the ability to remotely position the pulse source.

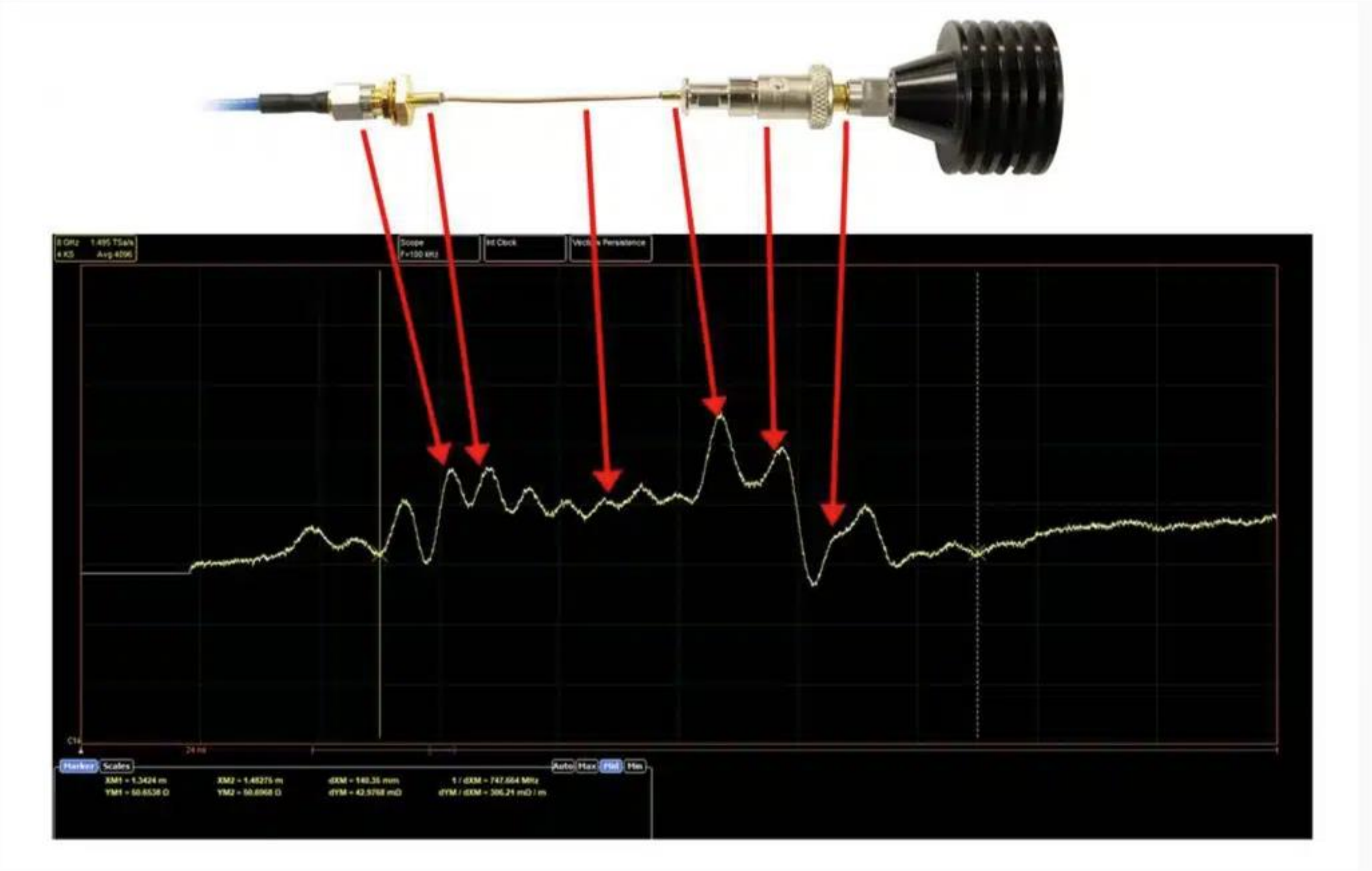

Figure 12 – PicoScope 9311 sampling scope with TDR capability – cable test result plot showing parts of the test cable and their corresponding influence on its reflective properties.

Conclusion

This article has explored the complementary use of time-domain and frequency-domain techniques for characterizing transmission lines using the PicoScope 9311 sampling oscilloscope and the PicoVNA 108 vector network analyzer. TDR and TDT measurements using the 9311 provide high time resolution and are particularly well-suited for pinpointing physical discontinuities in cables and connectors. In contrast, the VNA offers detailed frequency-domain analysis and, through transformations such as the Inverse Discrete Fourier Transform, enables effective time-domain visualization as well—albeit with some trade-offs in dynamic range and resolution depending on the sweep settings.

By comparing measurements of the same cable across both systems, we demonstrated that, while each tool has its strengths, both can produce comparable, reliable results when properly configured and calibrated. The TDR example further illustrated how these measurements translate into actionable diagnostics – revealing impedance mismatches due to inductive or capacitive transitions at connector joints, which can be traced to specific soldering or assembly issues.

Ultimately, the choice between using an oscilloscope or a VNA depends on the specific diagnostic goals. When the physical location and nature of a fault are key concerns, time-domain analysis offers direct insight, and an oscilloscope meets all the requirements and gives results more quickly.

However, for broader spectral characterization or in frequency-sensitive applications, VNAs offer more features than purely time-domain oscilloscopes. Used together, these tools provide a comprehensive view of signal integrity in modern high-frequency systems.