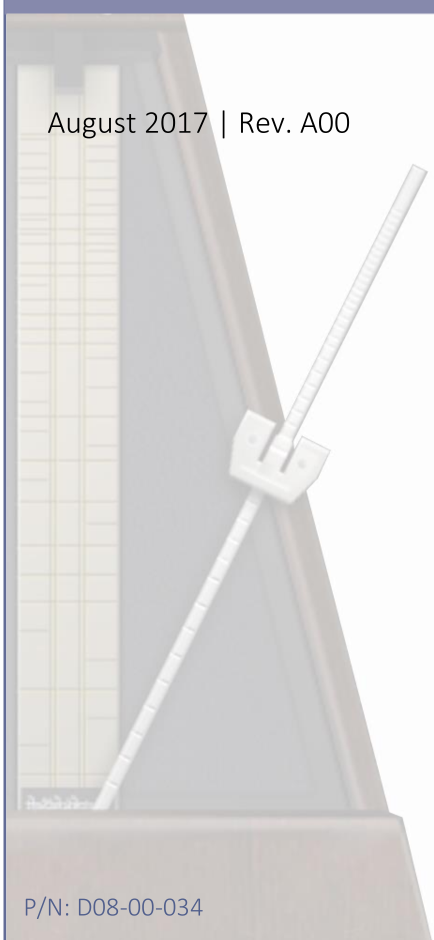
The Verification Experts

APPLICATION NOTE

How to Measure Actual Coaxial Cable Delay

Use Phase Measurements to Verify Cable Delay for Time Compensation (with VeEX TX300S)



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For assistance or questions related to this document and procedures, or to get a test set serviced by a VeEX or authorized service facility, please contact:

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How to Measure Actual Coaxial Cable Delay

Use of Phase Measurements to Verify Actual Cable Delay, with a TX300S

Introduction

Estimated, calculated or poorly-documented cable delays, including test cords, are often a significant source of Time Error (TE). Coaxial Time Domain Reflectometers (TDR) are the go-to tools to determine cable length. But, what if there is no calibrated TDR available on site and there is a need to verify the (electrical) length of coaxial cables being installed as GNSS antenna feed? How could you measure the cable's delay for timing compensation purposes?

Even if a TDR is available, they actually estimate the cable's physical length, based on the parameters configured by their users. At the end, a traditional TDR would give a distance reading that is as accurate as the velocity of propagation (VP%) entered by the user.

In precision timing applications, such as the installation of GNSS antenna feed for a PRTC, PTP Grandmaster or APTS, we are more interested in measuring the delay, to compensate it. If you take the length 'measured' by a TDR (in m or ft) and multiply it by the typical velocity of propagation (ns/m or ns/ft) printed on a datasheet, then you can get an estimated cable delay figure. That would count as a second approximation.

This document explains a simple alternative procedure that can be used to directly measure the actual delay induced by coaxial cables >10m (32.8 ft). It uses relative phase measurements to determine the pulses' time of flight. To measure shorter patch-cord cables for lab or field use, we recommend using devices with much better temporal resolution, such as dual-channel oscilloscopes, with a similar connection set up.

Requirements

Recommended Test Equipment

- A TX300S test set with two TX300SM modules.
- The Clock Wander & Phase Measurement and SyncE features. (The SyncE function is only used to generate the 1PPS signal, so no additional clock source is required.)

Or

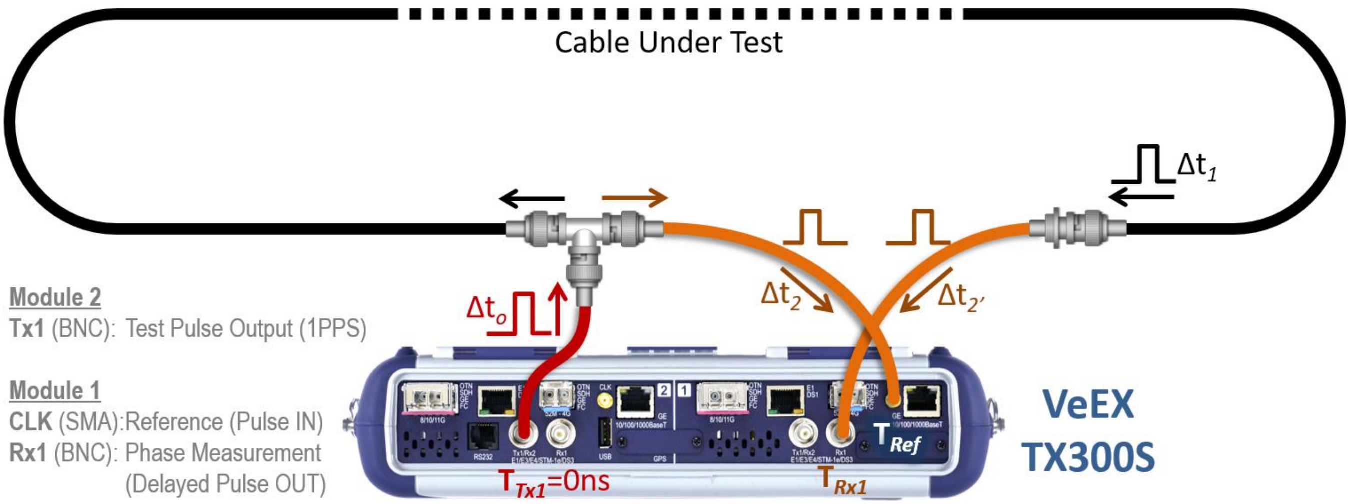
- A TX300S with one TX320SM module, MTTplus with MTTplus-320 module or RXT-1200 with RXT-3000 module.
- The Clock Wander & Phase Measurement feature.
- One external 1PPS clock source. (The absolute phase accuracy of the 1PPS is not important in this case, because this is a relative measurement.)

Cable Under Test

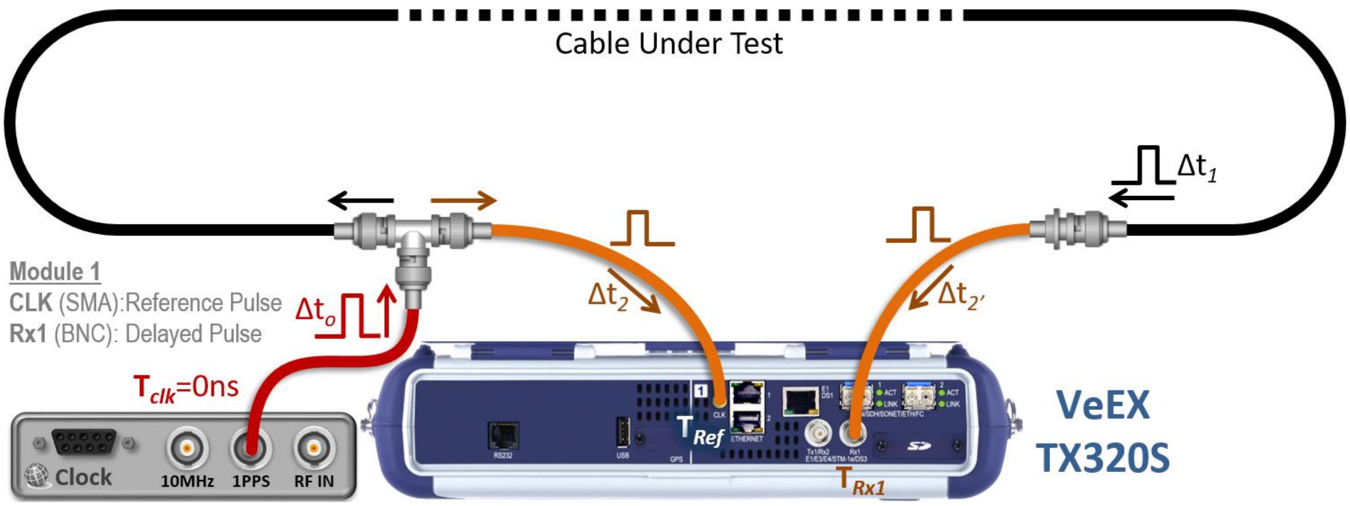
To verify the cable delay, for time compensation purposes, we recommend:

- Access to both ends of the coaxial cable that needs to be measured (device under test).
- Any necessary connector adapters to fit the cable and the test set (e.g. between TNC, BNC, SMA, etc.). Short adapter cables are recommended, especially when measuring thick rigid coaxial cables. Make sure to use the same type of adapters and same short length (one at each end of the cable), so their effects cancel each other (refer to simple math theory).
- Some people recommend extending the cable, instead of leaving it in a coil, to ensure its internal diameter is the same as a when installed (mostly a straight cable).

Connections



Or



Technically speaking, the use of T-splitters and double terminations are never recommended for live measurements. However, for the sake of a practical field solution, and since only passive elements are being used, in this case the potential reward outweighs the 'shame' of not being technically correct. It is recommended that the red and orange adapter cables be very short, <15cm (0.5ft), to minimize the effects of reflections due and impedance mismatch.

Basic Data & Calculations

In theory

Speed of light in vacuum (C): 299,792,458 m/s
Light's Propagation (Delay): 3.335641 ns/m 1.0167 ns/ft

Pulses' Delay: $T_{Ref} = \Delta t_0 + \Delta t_2$ $T_{Rx1} = \Delta t_0 + \Delta t_1 + \Delta t_{2'}$ $\Delta t_2 = \Delta t_{2'}$ (same adapter cables)

Phase Delay Measurement $= T_{Rx1} - T_{Ref}$

$= \Delta t_0 + \Delta t_1 + \Delta t_{2'} - \Delta t_0 - \Delta t_2$

$= \Delta t_1$ = Cable Under Test's Delay

On Paper

A Belden® 1189A gas-filled FPE 75 Ohm Coaxial cable with TNC connectors, ordered to be 75ft (22.86m) long, was used as an example. The following values are extracted from the manufacturer's datasheet:

i. Nominal Propagation Delay: 3.9372 ns/m (1.2 ns/ft)
ii. Velocity of Propagation: 83%

If we rely on those numbers, do the math and use the results to program the antenna cable delay compensation into a GPS clock, this is what one would expect:

a) $Delay_i$ = 22.86m x 3.9372 ns/m = 90.00 ns

b) $Delay_{ii}$ = 22.86m / (0.83 x 299,792,458 m/s) = 91.87 ns

This is just simple math and we are already seeing some trouble, two values to choose form, with 2.08% difference.

In Practice

- Even though coax cables can be ordered to specific lengths, the resulting physical length of the cable may not be exact. If a 'calibrated' cable has been ordered, please refer to the certificate from the cable house and not to the generic datasheet.
- Values on datasheets are just typical values. We have seen significant deviations with actual cables in the field.
- The 300,000,000 m/s speed of light approximation is often used, because it is easier to remember.

Those are just some of the uncertainties we have to deal with in real life. So, making direct cable delay measurement is always recommended. You can use the phase measurement method described here or a trustworthy coax TDR that provides direct time of flight (delay) measurements.

Procedure

- Make all the necessary connections. following the diagrams shown in the Connections section.
- Turn the test set ON.

Note: The mini coax cables were only coiled to organize them to fit neatly in the picture.

Configure the 1PPS Generator Side

If using one side of the TX300S as a pulse generator:

A. Tap on the Test Application button 2 to select Module 2 (left side of the connector panel).

B. In the Test App 2-Test Mode Selection menu, select Ethernet.

C. Check ☑ 1G Ethernet Testing and tap on OK.

D. After the 1GE application launches, tap on Setup.

E. On the Port tab, tap on the ▶ button to go to Page 2 of the Port configuration menu.

F. Set Synchronous Ethernet = Enabled.

G. Set Emulator Mode = Master.

H. Set TX Clock Source = Internal or Atomic 1PPS or Atomic 10MHz.

The precision of the source selection is not crucial in this scenario. This test is a relative measurement focused on the pulses' actual time of flight.

I. Set Recovered Clock Output = 1PPS.

J. Leave the Offset(ns) = 0.

K. Tap on Apply.

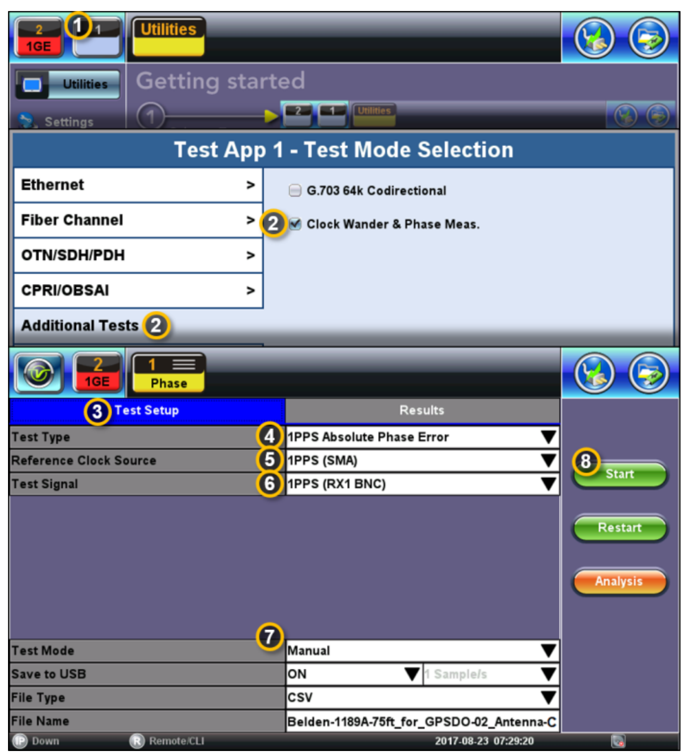
L. After a short configuration, the 1PPS clock output signal will be available in Module 2, Tx1 BNC port.

If an external 1PPS signal source is used, please follow its manufacturer's instructions.

Configure the Phase Measurement Side

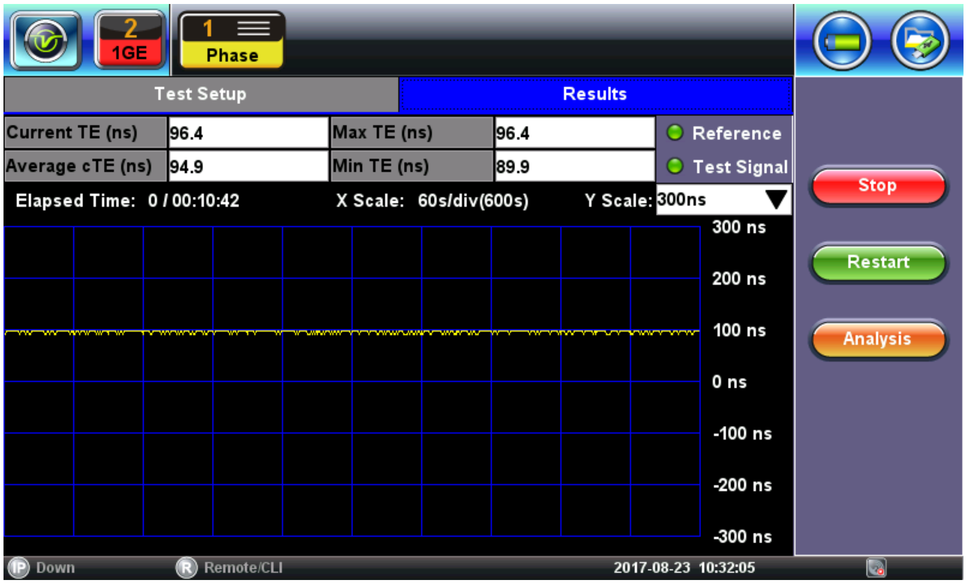
Using the TX300S (TX320S, MTTplus-320 or RXT-3000) to measure the Phase difference (delay):

1. Tap on the Test Application button 1 to select Module 1 (right side of the connector panel).
2. In the Test App 1-Test Mode Selection menu, select Additional Tests, Clock Wander & Phase Measurements and tap on OK.
3. After the Clock Wander & Phase test application launches, tap on Test Setup tab.
4. Set Test Type = 1PPS Absolute Phase Error.
5. Set Reference Clock Source = 1PPS (SMA).
6. Set Test Signal = 1PPS (BNC).
7. If you want to record the data, insert a FAT32 USB memory stick, set Save to USB = ON, select File Type = CSV, and enter a meaningful file name in the File Name field, for each individual test.
8. Press the Start button to initiate the phase measurement.



Measure the Cable's Time of Flight (Pluses' Phase Delay)

Once the test bed is all setup and connected, press the Start button and let the test run for about 10 minutes, to gather enough samples to make a meaningful Mean Value (Average TE). The result obtained with this method was a total pulse delay of **94.9 ns** (mean value)



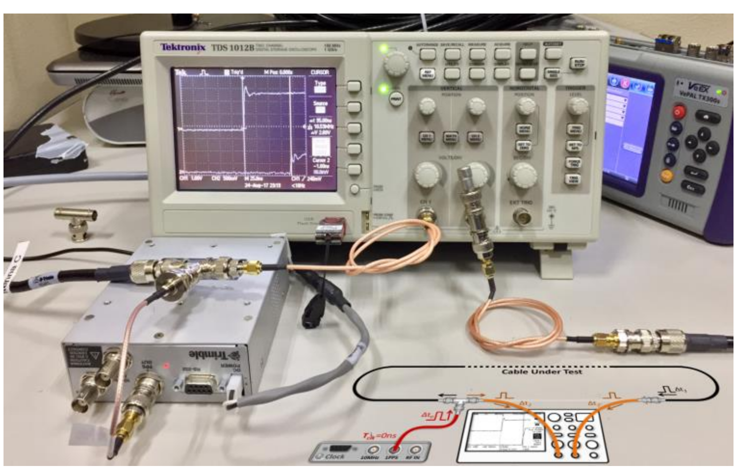
Notice that there is a 3 to 5 ns discrepancy with the values calculated from the datasheet. Either the cable is longer than the 75 ft ordered or the two typical velocity of propagation values reported on the manufacturer's datasheet are not the exact values for this particular piece of cable.

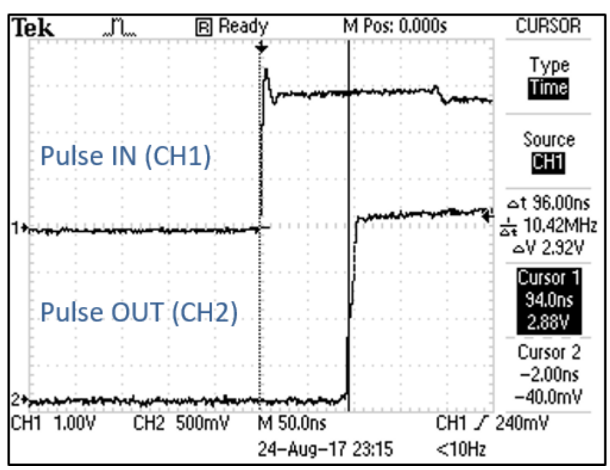
Alternative Methods to Confirm the Results

Oscilloscope

For a more visual approach to demonstrating how this technique works, we also measured the cable delay using a dual-channel oscilloscope (with Ch1 as the trigger, or reference, and Ch2 as the phase measurement port), a free-running GNSS-Clock as the 1PPS source and the same cable set up. Similar to the TX300S, Ch1 captures the pulse as it enters the cable under test and Ch2 captures the same pulse as it exits the cable.

Based on marker positions, the result was **94 ns**.

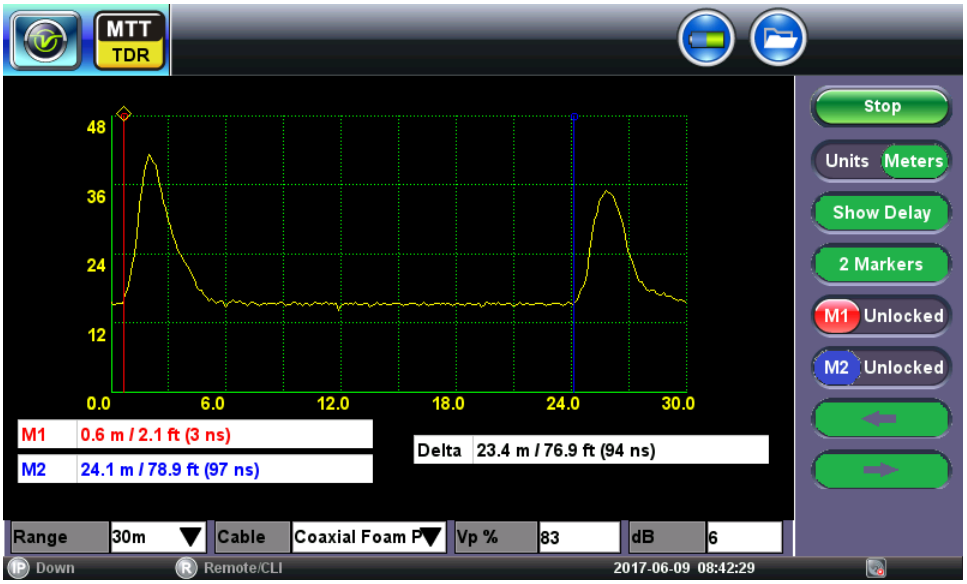




Coaxial Time Domain Reflectometer

A more traditional approach is to measure the cable using a TDR. In this case, we selected a timing-oriented coax TDR, which offers direct time-of-flight measurements (not a calculation).

Based on marker positions, the result was also **94 ns**.



Contrary to common perception and their traditional use case, TDRs measure Time, not Distance, as clearly stated in their name. They estimate distance based on the VP% entered or selected by their users. So, their distance readings are as accurate as the VP% value entered. That is why a TDR with direct time measurement display (independent from the VP% entered) is recommended for accurate cable delay compensation.

Another issue with TDRs is that their results still depend on proper marker positions. Whether they are placed by the user of by an internal algorithm, place those markers one pixel to the left of right and the measurement changes. The technique shown here does not have such dependency.

Conclusion

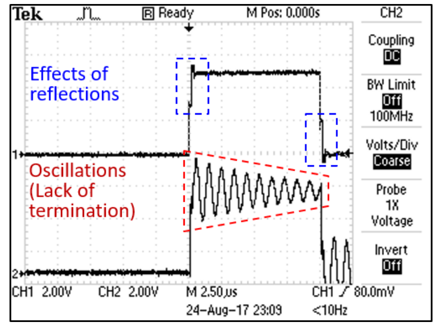
With just 1% error (compared to the Oscilloscope or TDR), the phase delay measurement is a reliable alternative method that can be used to accurately confirm and record the actual propagation delay of coaxial cables. It can be used to measure a sample segment of the target cable, then use the result to correct the actual VP% on the TDR being used. This would guarantee that delay and length measurements, of already installed cables, are accurate.

After extending and measuring the physical length of the cable (22.96m / 75.33 ft), the 94 ns cable delay value was used to confirm that its actual VP = 4.0938 ns/m or VP% = 81.48.

Limitations & Recommendations

We are not positioning this technique as the recommended method to accurately verify, document and compensate delay for all cables. The purpose of this article is to show an alternative technique that can be used to accurately measure and document cable delay, if no other accurate application-specific instruments are available.

- Wander measurements (TIE) can't be used with this technique, since it measures phase variations relative to the first sample. It would always measure 0ns ± Quantization Error. Absolute phase measurement (TE) is required.
- The coaxial cable must have connectors at both ends.



- All end-point connections must be properly terminated, to reduce the effects of reflections and avoid oscillation in the cable. This may not be an issue when using a TX300S, but it could be significant when using Hi-Z oscilloscope ports. By the way, if using an oscilloscope, connect the cables directly to its BNC input ports, do not use probes.
- Long cables could be an issue. due to attenuation, which depends on the type of cable under test. The TX300S Tx1 (BNC) port outputs a 4µs 1PPS with 2.0 Vp @ 50 Ohm (which is split in half). For longer cables you could use a source with TTL level, or 5.0 Vp, 1PPS output.
- This technique requires access to both ends of the cable, so it is not suitable for the verification of cables that are already installed (e.g. existing antenna feeds). In those cases, use a coax TDR that can provide direct delay measurements (not delay calculations or estimates based on typical pre-loaded VP% tables or datasheets). If a sample of the cable is available, the technique can be used to stablish the cable's true propagation delay and use it to "calibrate" the VP% in the TDR.

Acronyms and Abbreviations

1PPS	One Pulse Per Second timing signal
APTS	(GNSS-) Assisted Partial Timing Support in PTP
BNC	Bayonet Neill–Concelman (coaxial connector)
C	Speed of light in vacuum (299,792,458 m/s)
Ch	Channel
Coax	Coaxial Cable
CSV	Comma Separated Values (file format)
ft	foot or feet (unit of measure, 0.3048m)
GM	PTP Grandmaster clock
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
Hi-Z	High Impedance
m	meter or metre (unit of measure, 3.2808 ft)
MTT	Modular Test Toolkit (a modular test and measurement equipment)
N	Type N (coaxial connector)
ns	nanosecond (10^{-9}s or 1.0E-9s)
PRC	Primary Reference Clock
PRTC	Primary Reference Time Clock
PTP	Precision Timing Protocol (IEEE 1588v2)
Rx	Receiver
SMA	SubMiniature version A (coaxial connector)
SyncE	Synchronous Ethernet
TDR	Time Domain Reflectometer
TE	Time Error (also known as Phase Error)
TIE	Time Interval Error
TNC	Threaded Neill–Concelman (coaxial connector)
TTL	Transistor-Transistor Logic chips
Tx	Transmitter
T&M	Test and Measurement
Vp	Peak Voltage
VP	Velocity of Propagation
Δ	Delta (relative difference)

Notes

About VeEX Inc.

Founded in 2006 by test and measurement industry veterans and strategically headquartered in the heart of Silicon Valley, VeEX Inc. provides innovative Test and Measurement solutions for next generation networks, services and communication equipment.

With a blend of advanced technologies and vast technical expertise, VeEX's products diligently address all stages of network design, verification, deployment, maintenance, field service turn-up, troubleshooting and integrate legacy and modern service verification features across DSL, Fiber Optics, WDM, CATV/DOCSIS, Mobile backhaul and fronthaul/DAS (CPRI/OBSAI), next generation Core & Transport Network, Fibre Channel SAN, Carrier & Metro Ethernet technologies and Synchronization.

The VeEX team brings simplicity to verifying tomorrow's networks.

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