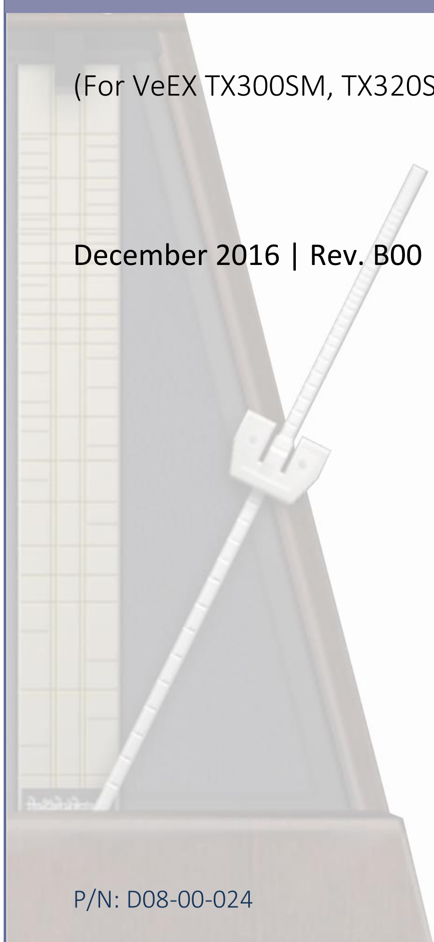
SYNC SERIES

1588/PTP Recovered Clock Wander Measurement

Using PTP Slave Emulation to Estimate Clock Stability and Accuracy



(For VeEX TX300SM, TX320SM, RXT-3000 and MTTplus-320)

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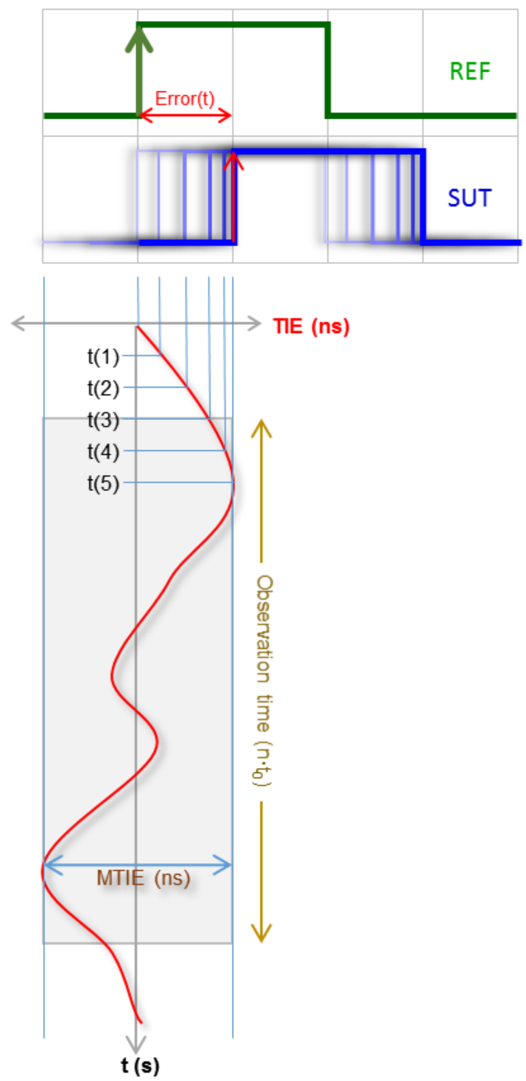
1588v2/PTP Recovered Clock Wander Measurement

Using PTP Slave Emulation to Estimate Clock Stability and Accuracy

Introduction to Wander

Wander or Time Interval Error (TIE) is a periodic relative phase error measurement used to evaluate the long-term stability and accuracy of a clock signal. The signal under test (SUT) can come from a reference oscillator, primary reference clock (PRC or PRTC) or a recovered clock from a network element (NE) acting as a slave. Wander is defined by ITU-T G.810 as "The long-term variations of the significant instants of a digital signal from their ideal position in time"



TIE measures the instantaneous phase variations on the signal under test (SUT), compared to a known and trusted frequency reference and it is plotted for long-term analysis. Different to Jitter, Wander focuses on the low frequency components of the phase noise, from 10Hz and below. This <10Hz doesn't refer to signal frequency variations, it refers to the rate at which the SUT's phase is changing with respect to the reference's. Clock wander may be caused by very small (parts per trillion) frequency differences between the clocks of two networks or network elements, due to misconfiguration, component quality, failure, by slow changes in the relative phase of two clock signals due to ambient temperature changes, or simply an active disciplining process, among other reasons.

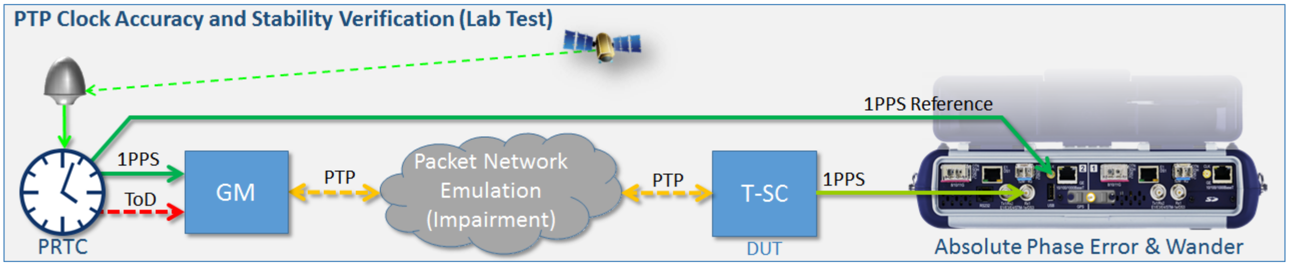
- **MTIE** (Maximum Time Interval Error): Is the peak-to-peak variation of TIE within defined observation intervals τ.
- **TDEV** (Time Deviation): Measures the spectral content of the wander graph. It's a function of observation interval τ.
- **Frequency Offset**: Indicates the degree to which the SUT's clock frequency deviates from its ideal value or standard.
- **Frequency Drift**: This rate measures how the SUT's frequency offset varies over time.

Reference Clock is Required

Wander measurement requires access to the slave's recovered clock (SUT) and a traceable (or calibrated) frequency reference. A 1PPS timing reference traceable to the standard second would be required to evaluate absolute timing (phase) accuracy. In Lab, NOC or CO environments users may have access to a copy of the Primary Reference Time Clock (PRTC) or 1PPS from a GPS-disciplined oscillator (GPSDO). A trusted clock signal shall be used as the measurement reference. When no access to a PRC or PRTC are available, users must have access to an accurate 1PPS clock, aligned to the standard second and in sync (frequency and phase) with the PRTC driving the GM, such as the test set's built-in GPS-disciplined chip-scale (Cs) Atomic Clock option.

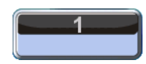
A. Measuring the Actual Phase Error and Wander at the T-SC's 1PPS Output

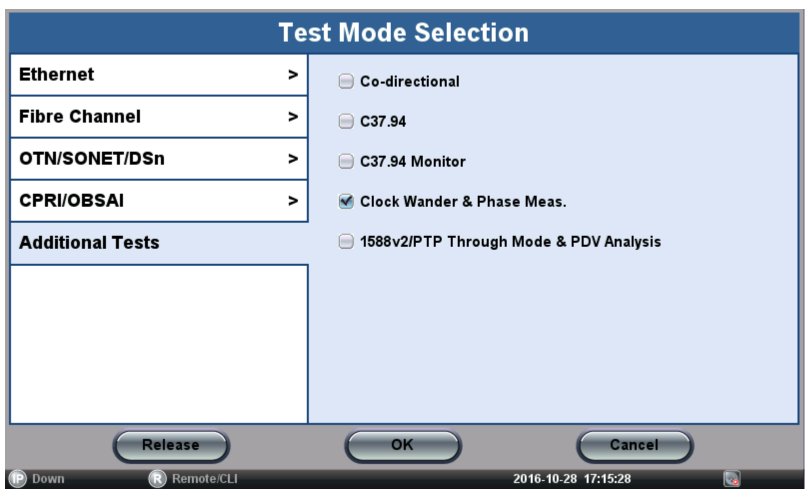
Measuring the Phase or Timing Error at the output of a GPS-disciplined Oscillator (GPSDO) or PTP Telecom Slave Clock (T-SC) is the best indicator of the actual system or link performance, under real or simulated network conditions. This is also referred as Physical Layer Clock measurement or Physical Clock measurement.

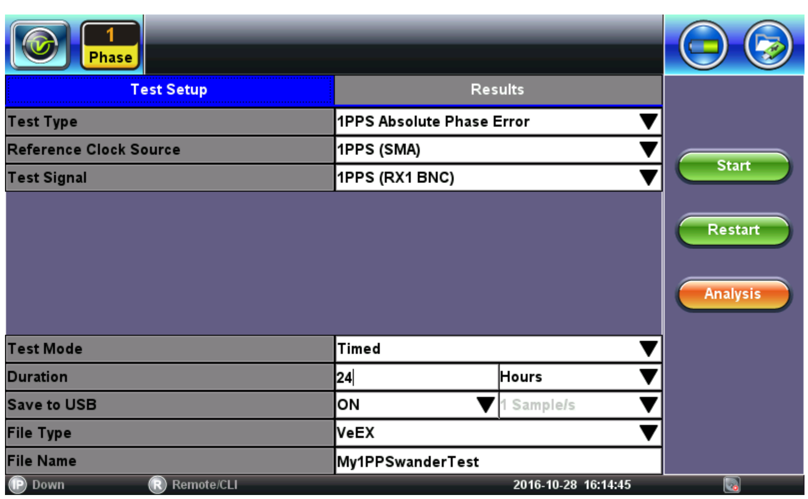


To measure the Wander or Phase Error at the Slave's physical clock output, use the **Clock Wander Measurement** test mode, which can be launched from >Additional Tests >Clock Wander & Phase Meas. In this case, you can connect the clock signal under test to RX1 (BNC) and the frequency or phase (1PPS) reference to the CLK (SMA) port or use the optional built-in precision timing and frequency references, if available.

1. Touch the application button, on the top-left side of the screen, to launch the >Additional Tests >Clock Wander & Phase Measurement test application and press OK.



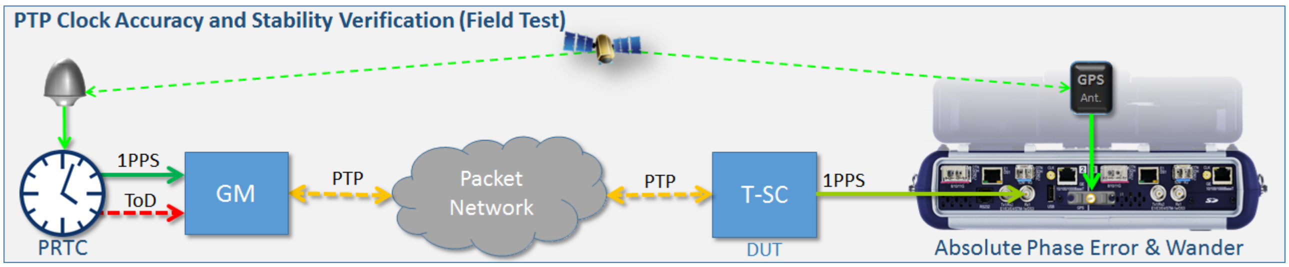




2. Select Clock Wander Measurement mode to monitor and evaluate the clock signal's Frequency Accuracy and Stability or select 1PPS Absolute Phase Error to monitor and measure the 1PPS clock Timing Error (compared to the standard second), or accuracy, and its long-term Stability.

3. Use the Reference Clock Source pull-down field to select the frequency or phase reference available, then connect the actual reference signal to the CLK (SMA) port. Use a flexible BNC-to-SMA adapter cable is necessary.

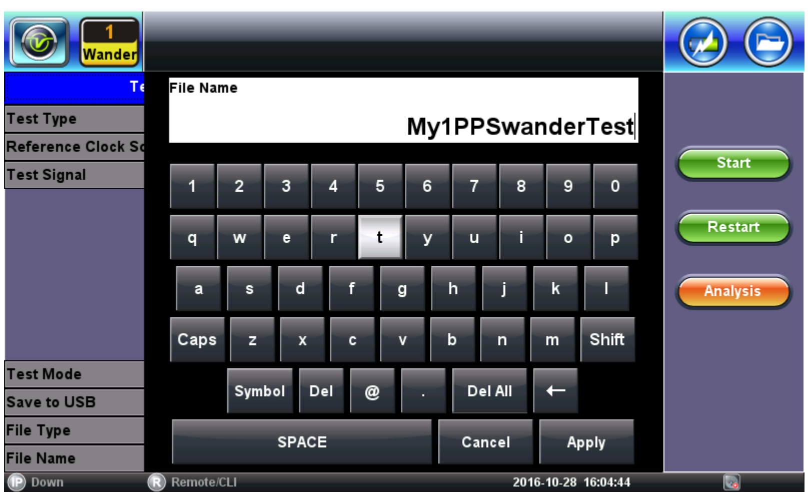
For actual timing verification in the field, the optional built-in Atomic 1PPS and Atomic 10MHz can be used as timing references, when disciplined by GNSS. If you plan to use this internal reference, then connect the SMA antenna cable to the GNSS receiver instead. Discipline the oscillator, to correct any small frequency offset, before starting the wander test.



4. Use the Test Signal pull-down to select the type of clock output coming out of the device under test, then connect the test signal from the DUT to the RX1 (BNC) port.

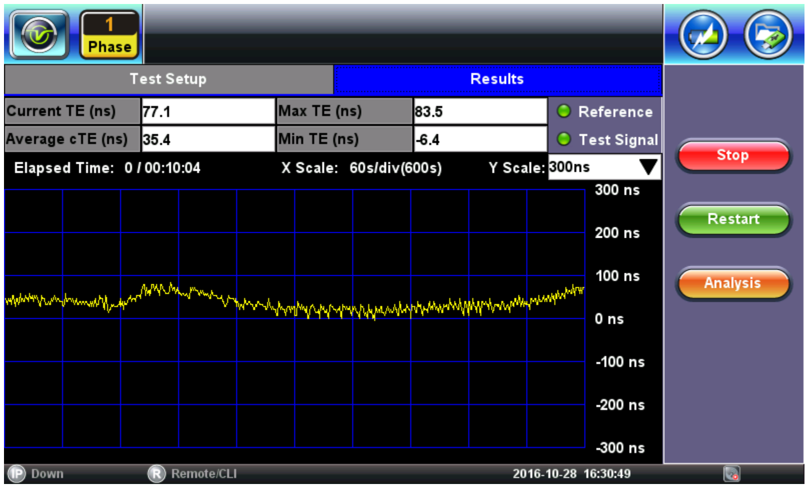
5. Set the Test Mode = Timed to program an exact length for the test, if desired.

6. Insert a FAT32 USB memory stick into a test set's USB port, wait until the icon appears on the top-right corner of the screen and Enable the Save TIE to USB. The sampling rate for 1PPS signals will be limited to one TE or TIE measurement per second. Enter the desired file name (no spaces) for the test results and press Apply. It is recommended to use meaningful file names, perhaps including the date for future reference (e.g. "ACME_Bank-1PPS-20161231")

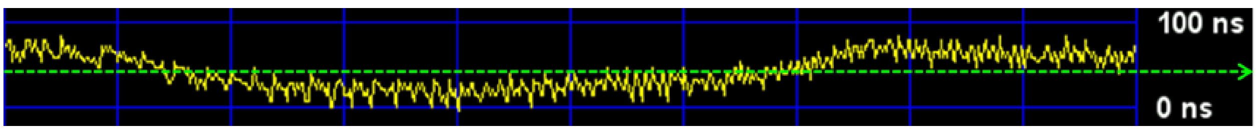


7. Press Start. The Wander measurement starts and all the samples are saved in real-time to the USB memory for future analysis. A 600-second monitoring graph shows the latest TIE or TE samples for users to evaluate the current status of the test and decide whether to continue, stop or abort the test (e.g. there is no point

on running a 72-hour test if you already know that something is not right). Use the Y-Scale to zoom-in (the real-time X-scale is fixed to a 60s/division sliding window).



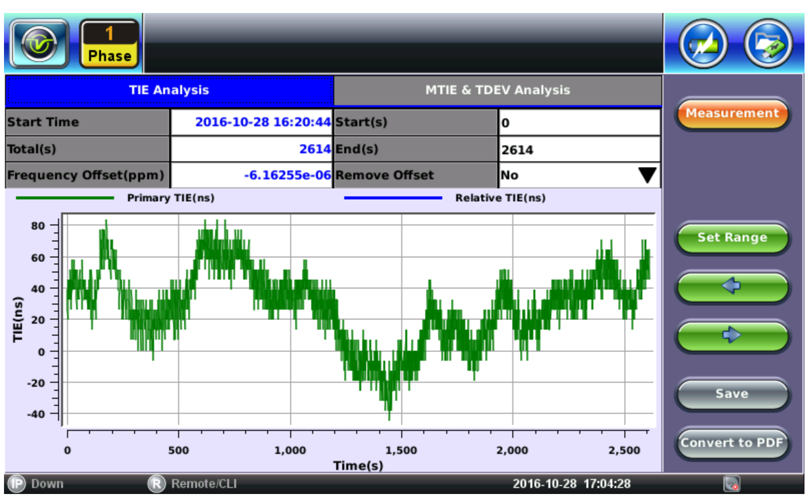
The TIE samples will always vary (wander) over time, but in a well-synchronized DUT it will slowly vary around 0ns and it shall not diverge, neither in a positive nor negative direction. (A noisy DUT/SUT was selected on purpose for this example, for better illustrative purposes.)



In the case of 1PPS, you want to see the Time Error tightly wandering up and down across an imaginary horizontal straight line (mean TE) with no upward or downward trend (e.g. ramp). A horizontal (flat) trend indicates accurate frequency lock, while ramps indicate frequency inaccuracies (offset).

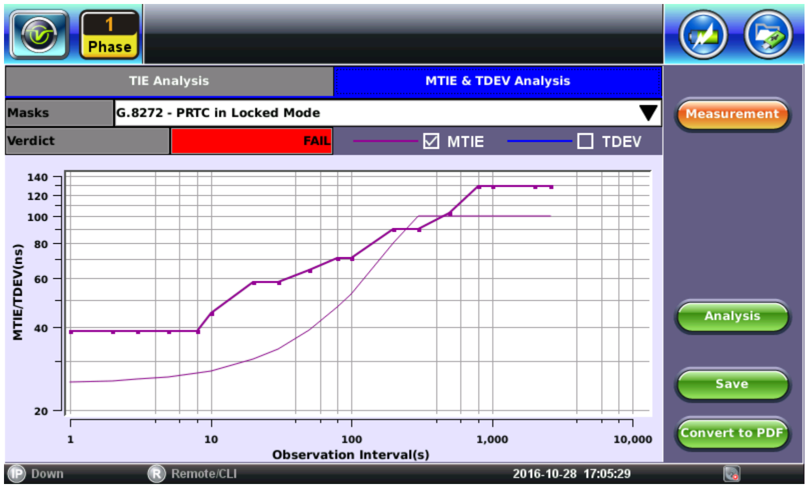
8. Press the Analysis button to run a partial (run-time) or final TIE/TE/MTIE/TDEV analysis.

   For long-term tests, users can zoom in or limit the analysis to isolate a specific time windows. To do this, enter the desired beginning time in the Start (s) field, enter the finish time in the End (s) field and press the Set Range button to apply. Use the Analysis button in the MTIE & TDEV tab to recalculate the values based only in the selected time window.



Users can also tap on the TIE graph to position a cursor, then use the ⇦ ⇨ arrow buttons to adjust the position to the desired sample.

9. Now you can click on the MTIE & TDEV Analysis, tab to select the appropriate Mask, run the Analysis and generate reports. Uncheck the ☐ TDEV box if you are only interested in MTIE.



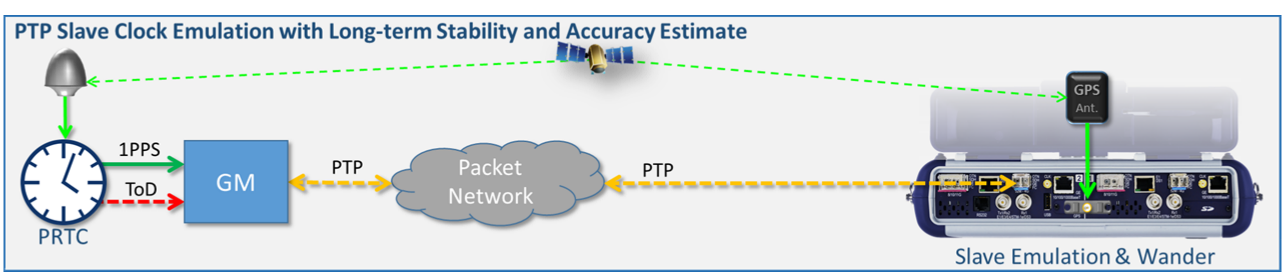
- The Save button saves the current MTIE, TDEV and Mask results into a CSV file, directly to the USB memory.
- The Convert to PDF button saves a PDF report, of the current measurement, directly to the USB memory.
- Use the Measurement button to go back to the Wander Measurement screen, where you can run another test.

You can also use the VeEX Wander Analysis PC software to run the same analysis and generate reports

B. Using Quasi-Slave Emulation to Recover the Raw Clock and Measure its Wander

It is always recommended to measure the Wander and Phase (or Timing) Error at the physical output of the Slave device, as described in the previous section. It represents the true performance of the entire link or network, including all network elements, traffic and environment. But, in certain occasions it may be necessary to quickly verify the link's readiness before installing the T-SC, T-BC or for troubleshooting purposes.

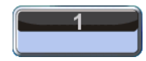
For this application, the test set offers a limited Slave Emulation function in which it acts as like a T-SC terminal to verify that the GM(s) is reachable, the 1588v2 PTP protocol can perform all the necessary handshakes and that basic synchronization can be attained. In that process, the test set can recover the raw clock (not filtered by any precision oscillator) so users can run a wander measurement to check overall frequency accuracy and long-term stability. Since this physical recovered clock is a direct representation of what's happening at the packet level, it will be noisier than usual and may fail some of the masks due to its limited short-term stability. Nonetheless, it won't mask (filter) any impairments or behavior present in the link under test.

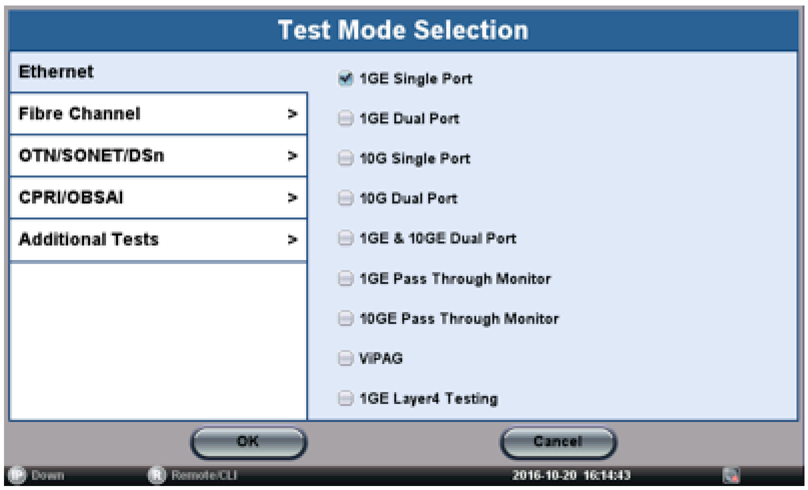


Note that the clock recovery, conditioning and stabilization processes are not defined by any standards. They are proprietary to each T-SC/BC vendor and based on their own expertize. So, the final clock recovery performance depends on the actual T-SC installed, its settings and purchased options (e.g. oscillator grade and cost). In that sense, the test set's slave emulation's clock recovery should not be expected to match or predict the performance of any true T-SC or T-BC, since they are all different.

If you still want to use the test set to terminate the link, emulate the Slave, recover the raw 1PPS clock and get a rough idea of the long-term stability (wander) and overall accuracy, then here is how to do it:

1. Touch the application button, on the top-left side of the screen, to launch the >Ethernet >1GE Single Port or 1G Ethernet Testing test application and press OK.





2. In the Setup menu, select the matching Base-T or Base-X interface, connect test set to the test interface, turn the Laser ON (if necessary) and verify the yellow Link Status box at the bottom-left corner of the screen (e.g. 1000Base-T Full Duplex).

3. Go to >Advanced Tools >1588v2/PTP.

4. Configure the test set as a Slave and select whether it is a Layer 2 or Layer 3 UDP PTP environment.

If Layer 3 is used, go to the IP function in the Main Menu to stablish and IP connection, before configuring the slave emulation. Then go back to configure the protocol Transfer Mode as Unicast or Multicast, and any other applicable settings to match the network.

5. Click on the Clock Settings tab and select the Measurement Clock Reference to be used for Wander and other timing measurements. Connect that physical clock to the CLK (SMA) port.

   The optional built-in Atomic 1PPS and Atomic 10MHz can also be used as a timing reference, if it is disciplined by GNSS. If you plan to use this internal reference, then connect the SMA antenna cable to the GNSS receiver instead. Discipline the oscillator, to correct any small frequency or phase error, before starting the wander test.

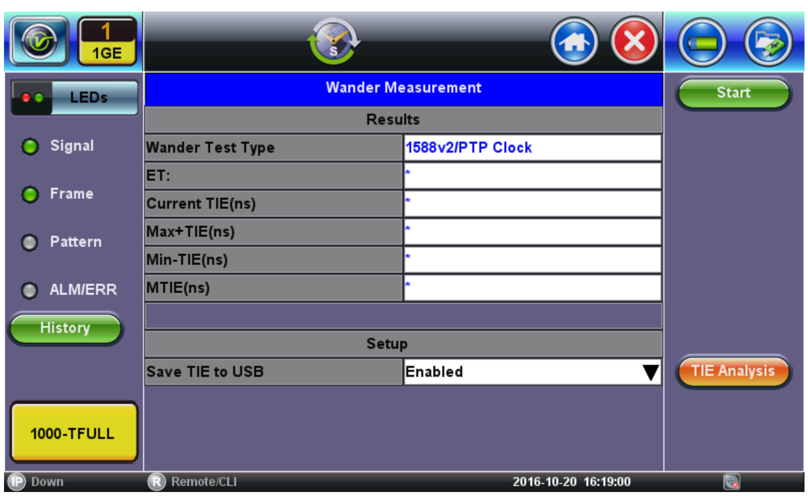
   In this example, the test set is also configured to output a copy of its recovered clock on the TX1 (BNC) port.

6. Press Start to get the PTP session started and wait until the chasing-arrow (S) icon on the top bar turns green, to indicate that the test set has successfully stablished a PTP session with the Grandmaster.

7. Go to the Results tab to monitor the Sync PDV to make sure it has stabilized into a low value (e.g. <100ns). This is to verify that the slave is in sync.

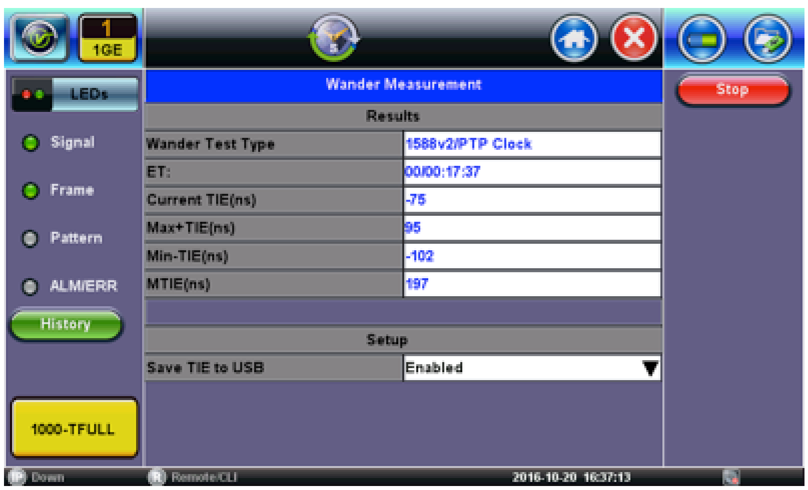
8. Go to the Wander Measurement function.

9. Insert a FAT32 USB memory stick in a USB port, wait until the icon appears on the top-right corner of the screen and Enable the Save TIE to USB. The sampling rate may be limited to one TIE measurement per second.



10. Press Start, enter the desired file name (no spaces) for the test result and press Apply. It is recommended to use meaningful file names, perhaps including the date for future reference (e.g. “ACME_Bank-20161231”)

11. The Wander measurement starts and all the samples are saved in the USB memory for future analysis. The TIE from the recovered raw 1PPS clock will vary, but in a well-synchronized slave it will vary (wander) around 0ns and not diverge in positive or negative direction. Of course, this all depends on the network under test.

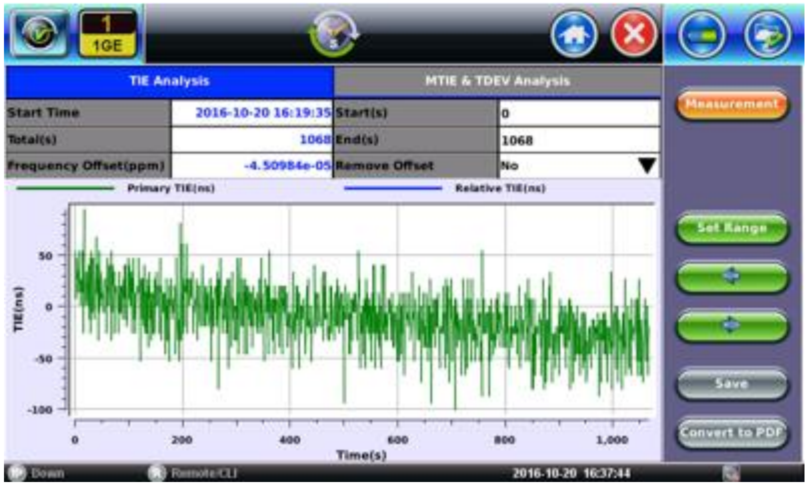


If you need to check the up-to-the-moment TIE results while the test is still running, you can use the Open Files procedure described later on in the “Built-in Post Analysis” section.

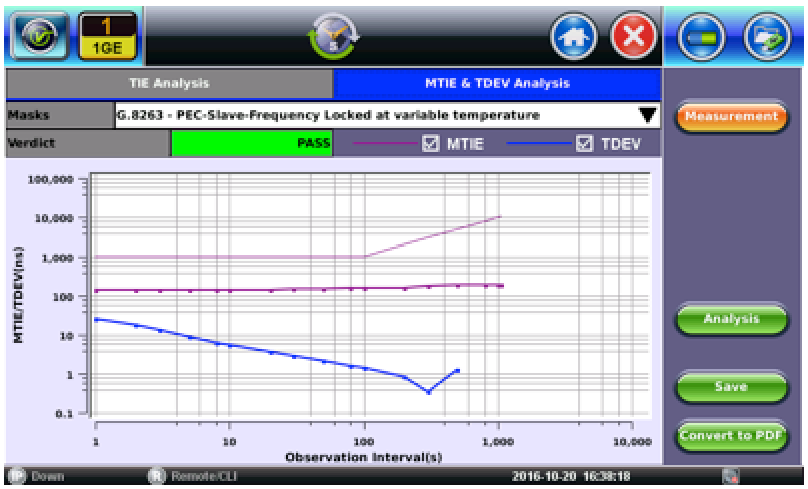
12. Once enough samples have been taken, you can press Stop. At this point a TIE Analysis button should appear on the action bar. Press this button to view all the TIE samples in a graphical format and perform the MTIE/TDEV masks analysis.

For long-term tests, users can zoom in or limit the analysis to a specific time window (segment). To do this, enter the desired beginning time in the Start(s) field, enter the finish time in the End(s) field and press the Set Range button to apply. Use the Analysis button in the MTIE & TDEV tab to recalculate based in the selected window.

Users can also tap on the TIE graph to position a cursor, then use the ⇦ and ⇨ arrow keys to adjust the cursor position to the desired sample.



13. Now you can click on the MTIE & TDEV Analysis tab to select the appropriate Mask, run the analysis and generate reports. Uncheck the ☐ TDEV box if you are only interested in MTIE.



- The Save button saves the current MTIE, TDEV and Mask results into a CSV file, directly to the USB memory.
- The Convert to PDF button saves a PDF report, of the current measurement, directly to the USB memory.
- Use the Measurement button to go back to the Wander Measurement screen, to run other tests.

Keep in mind that the test set is not a full/true PTP Slave Clock, so don't expect the same performance and robustness of purpose-built OCXO, DOCXO or Rb stabilized T-SC deployed in the production network. The normal Slave mode doesn't filter incoming 1588 messages or use a precision oscillator for filtering the effects of incoming packet jitter or to smooth out the clock recovered from the PTP protocol. This is done for two reasons: (a) Using a high-quality oscillator to stabilize (filter) the timing signal would hide anything that happens at the line, packet and PTP levels, so users would be blind as measurements could go undisturbed even if the link is completely lost and (b) clock recovery and conditioning is the proprietary part in which each vendor gets to work out their magic, so there is no point in comparing. Therefore, it is strongly recommended to measure the recovered clock at the physical output of the NE.

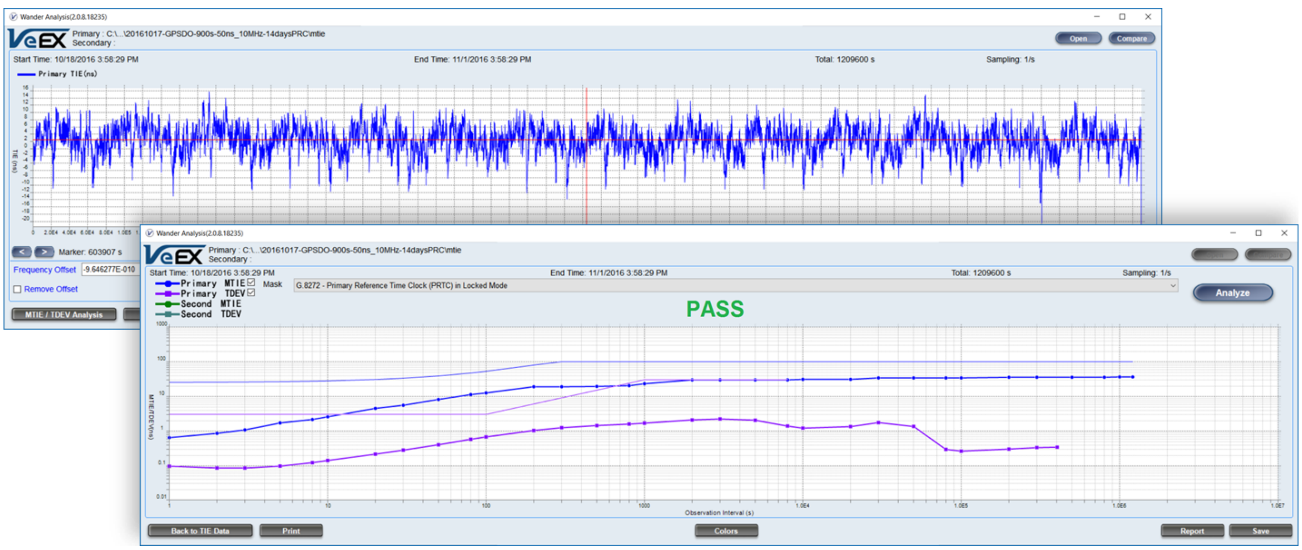
The Quasi-slave Mode (with packet filtering)

Since real network slaves implement proprietary mechanism to filter out 1588 messages with excessive jitter, the test set may also offer a **Quasi-slave Mode** option. The Quasi-slave Emulation feature adds filtering to incoming 1588 packets, following the filter definitions of the ITU-T G.8260 standard. For example, users can set the Min (minimum) filter, to only use PTP packets with the lowest time error (the fastest or lucky packets) and ignore the others. With packet filtering, the Quasi-slave recovered clock becomes less sensitive to network jitter and the resulting recovered clock is more stable (less wander). Although the clock recovery performance should be better at the packet/protocol, it should not be directly compared to a real network slave (each vendor has their proprietary method and perform further filtering at the physical clock level). The Quasi-slave mode can only give an estimation of the achievable performance of a network slave.

Post Analysis (Offset, MTIE and TDEV)

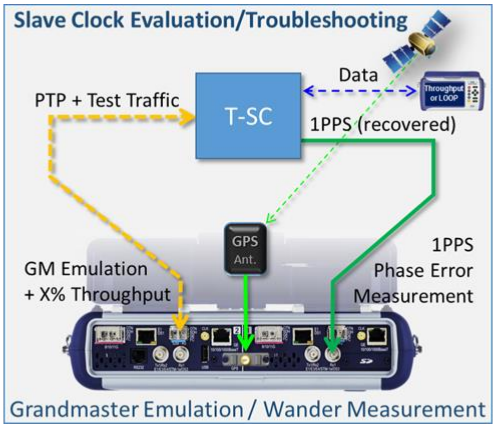
Built-in Post-Analysis: If you want to reanalyze previous tests stored in the USB memory, insert the memory stick containing the TIE or TE samples into the test set and go to >Utilities >Files >USB. Open the folder with the name you gave the test of interest (e.g. My1PPSwanderTest), select the mtie or phase file and press the Open button at the bottom-right corner of the screen. The same post-analysis interface explained before would come up and you will be able to select the sections (time window) to analyze, as well as the different masks.

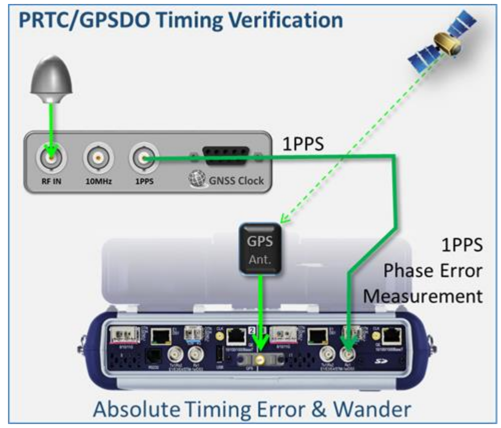
PC Post-Analysis: You can also use VeEX's Wander Analysis PC software to run the MTIE and TDEV analysis and generate reports. This Windows® program doesn't require installation and can be kept in the same USB memory stick with the TIE files, for greater portability (i.e. run the analysis from any PC or laptop). The PC application can be downloaded, free of charge, from www.veexinc.com/SecureFile/VeEX_Wander_Analysis.zip



The 14-day TE example shows the long-term accuracy and stability of a TX320S test set with built-in GPS-disciplined Atomic Clock in locked condition and in a variable temperature environment. For this case TE = ±16 ns, or Max|TE| = 16ns, and it passes the G.8272 PRTC MTIE and TDEV masks.

Troubleshooting a T-SC or GPSDO





T-SC Wrap-around Test: Advanced users may also use a dual-port test set, the PTP Master Emulation and internal or external precision clock reference to evaluate, fine-tune or troubleshoot a T-SC. Both Master Emulation and Wander Measurement sides must use a common clock reference, whether it is the internal Atomic 1PPS or and external 1PPS from a PRTC. This test can be ran using arbitrary time stamps (floating test environment) or by aligning the test sets time and timing to UTC/GPS, using the disciplined Atomic 1PPS clock source for Master and Wander reference. To align the test set's time, go to >Utilities >Settings >More >Precision Clock Source >GNSS and tap on the Sync ToD button. The Throughput test function in some test sets could also be used to generate different amount of test traffic to stress the PTP link and T-SC during the test.

PRTC/GPSDO Verification: The Clock Wander Analysis 1PPS Phase Measurement can also be used to verify GPS clock installations, timing, frequency accuracy and holdover response. Use an external 1PPS from a time standard, a traceable frequency standard or the built-in disciplined atomic clock (with external roof antenna) to assure maximum accuracy.

Other Considerations

Avoid using passive T-splitters for wander and phase measurement applications. They introduce reflections, impedance mismatch and other impairments that distort the pulses. Connecting or disconnecting other equipment attached to a T-splitter will affect any ongoing tests.

The 1588v2 PTP, SyncE, Wander Measurement, MTIE/TDEV Analysis and other features described in this document require software licenses. The built in GNSS receiver and chip-scale atomic clock are hardware options and may not be available for all products.

Acronyms & Abbreviations

1GE	1 Gigabit/s Ethernet (1000Base-T or 1000Base-X)
1PPS	One Pulse Per Second (clock signal aligned to the standard second)
BNC	Bayonet Neill–Concelman (popular unbalanced coaxial connector)
CLK	Clock Signal
CO	Central Office
Cs	Cesium or Caesium (oscillator)
CSAC	Chip-Scale Atomic Clock
CSV	Comma Separated Value file format (compatible with spreadsheets)
cTE	“Constant” Time Error (mean TE)
DOCXO	Double Oven Controlled quartz Crystal (Xtal) Oscillator
dTE	Dynamic Time Error
DUT	Device Under Test
FAT32	32-bit File Allocation Table (format commonly used in USB memory sticks)
GNSS	Global Navigation Satellite Systems
GM	GrandMaster Clock (PTP)
GPS	Global Positioning System (GNSS provided by the USA Department of Defense)
GPSDO	GPS (GNSS) Disciplined Oscillator
IP	Internet Protocol (e.g. IP address 192.168.0.100)
ITU-T	International Telecommunication Union - Telecommunication standardization sector
Lab	Laboratory (evaluation, conformance or development)
MAC	Media Access Control address (e.g. 00:18:63:01:23:45 or 00-18-63-01-23-45)
MTIE	Maximum Time Interval Error
NE	Network Element
NOC	Network Operations Center
ns	nanosecond (1E-9 s, 1/1,000,000,000th of a second)
OCXO	Oven Controlled quartz Crystal (Xtal) Oscillator
PDF	Portable Document Format
ppb	Parts-per-billion (1E-9 or $1x10^{-9}$)
ppm	Parts-per-million (1E-6 or $1x10^{-6}$)
ppt	Parts-per-trillion (1E-12 or $1x10^{-12}$)
PRC	Primary Reference Clock (a calibrated and traceable frequency standard)
PRTC	Primary Reference Time Clock (a clock that provides timing and time, aligned to the UTC standard)
PSN	Packet Switched Network
PTP	Precision Time Protocol (e.g. IEEE 1588-2008 or 1588v2)
Rb	Rubidium (oscillator)
REF	Reference
RX	Receiver port
SMA	SubMiniature version A (unbalanced coaxial connector). Don’t confuse with reverse-polarity SMA-RP.
Sync	Synchronous, Synchronization, Synchronized
SyncE	Synchronous Ethernet
SUT	Signal Under Test
T-BC	Telecom Boundary Clock (PTP)
T-SC	Telecom Slave Clock (PTP)
T-TC	Telecom Transparent Clock (PTP)
TDEV	Time Deviation
TE	Time Error
TIE	Time Interval Error
ToD	Time of Day
UDP	User Datagram Protocol
UTC	Coordinated Universal Time (the primary time standard)

Notes

About VeEX®

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 (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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