WHITE PAPER

Testing Time Synchronization in the Field

Myths, Challenges and Solutions

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The data for this article was acquired using VeEX's TX300S and/or RXT-1200 Test Platforms with GNSS and Atomic Clock options, and Multi-Service Test Modules. TE data is unfiltered and graphs were captured with VeEX Wander Analysis PC Software and/or built-in Clock Wander Analysis function.

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Introduction

Actual (absolute) Timing Error, or Phase Alignment, verification may not be as simple as commonly thought. It requires the right tools and knowledge to overcome the challenges associated with being in the field, at the very edge of the network and under conditions that are completely different from any lab environment. After all, that's where actual timing verification is required (e.g. PTP Slave Clocks, GPSDO, Base Stations, customer premises).

Most of the technical literature covering time or phase synchronization, standards included, is likely aimed at an audience of NEM R&D, network engineering and/or Network Operators'' Evaluation labs. We often come across 1588v2 PTP and GNSS articles based on pure mathematical hypothesis, lab simulations and network emulations, under tightly controlled conditions and assumptions. Very little has been published about real life testing, including actual on-site timing verification requirements and procedures for bringing remote sites into service or any of the challenges associated with it. To make matters worse, there seem to be some misinformation, assumptions and myths based on legacy frequency synchronization standards or legacy lab procedures, irrelevant to field Phase Alignment and Time Error testing. All of which contribute to setting wrong expectations.

We have come to a conclusion that just refreshing Wander concepts and training the target audience (end users) on Phase measurements may not be enough. An industry-wide discussion needs to be started, to come up with practical guidance and expectations. The main purpose of this paper is to get that conversation going, by bringing the current field test and measurement state-of-the-art into perspective and clarifying some common misunderstandings and assumptions, so that each communication service provider can identify their actual needs and define practical Frequency and Phase testing requirements, procedures and limits for the field deployment of phase synchronization. All within reasonable expectations.

Myths, Misconceptions and Extrapolations

Promoting Field Synchronization Testing, through training, seminars, discussions and actual field testing can be exhausting and sometimes feels like swimming upstream. Especially when it comes to discussing Phase or Timing Error concepts. It seems like one has to allocate plenty of time to bust a few myths and proof everything you are trying to say, before you can even engage in a meaningful conversation.

When discussing field test equipment, it is not unusual to hear requests like:

- ">24 hour phase holdover" – There are two problems: a) no time error limit is specified, b) may not be realistic.
- "Phase measurements with 1ns accuracy" – The accuracy depends on the reference clock being used. Within a lab, using the right instruments and reference, you may easily achieve relative accuracies of 1ns. But when point A and point B are geographically separated, then the absolute accuracy is most likely tied to the error of the GNSS Clocks being used as local references. People also confuse "display" and actual measurement resolution.
- "Non-intrusive pass-through mode" – When it comes to actual PTP links, it is difficult not to be intrusive (change the condition of the link as it would be in production). At the very least test equipment introduce delays and regenerate signals. Even adding a signal tap can be considered intrusive (unless it is meant to stay there when the link goes live). Port mirroring? It may not have the priority and packets may not be forwarded in real time. There are valid applications for pass-through (mainly in the lab) and it is important to understand how they work and what they do, to evaluate its value as a tool in the field.

Let's take a look at some of those important topics in more details.

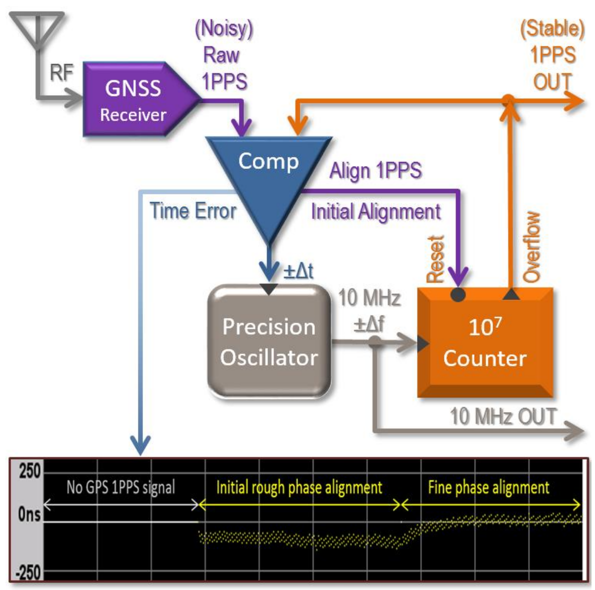
GNSS (Global Navigation Satellite Systems)

It seems like GNSS (GPS) has two camps: Those who idealize it and those who demonize it. Well, it is a somewhere in between. Until someone comes up with a competitive alternative, this reliable and proven technology will continue to be the main source for timing and time (ToD). Here are some examples of the arguments given:

- GNSS can be jammed – Of course, that's a fact. Learn to live with it and engineer it to mitigate the effects.
- GNSS can be spoofed – That's currently unlikely for the communication infrastructure as there is doesn't cause catastrophic effects and there is little economic or political gain attached to such act. Perhaps things may be different for the power distribution industry, since someone could potentially figure out how to trip a substation by deliberately changing its phase.
- USA can turn GPS off at any time – The GPS encryption could indeed be turned on again. But that is very unlikely since there is too much at stake. The world has become GPS dependent. Anyways, if that day comes, you would probably be worrying about something else.
- GNSS Clocks are very accurate – This is true, but accuracy requires long time to acquire. Be aware that a properly engineered PRTC is allowed up to ±100ns error (ITU-T G.8272 clauses 6.1, 6.2). This uncertainty refers to a telecom-grade GNSS-disciplined clock reference, in locked mode with calibrated installation, no RF multipath, controlled interference, no jamming and no storms. Modern GPSDO can do better than 100ns, but don't assume.
- Portable time sources can be created by adding a battery to a GNSS Clock – Not so fast. Most timing-oriented GNSS clocks are configured for stationary applications and take very long time to survey their accurate position in order to calculate accurate time. Waiting for a week may not be an issue when the device is stationary for its whole lifespan. But it wouldn't work in nomad applications, unless allowed enough time to complete the survey every time it is moved. A laptop would be needed to configure and verify the status and readiness of the clock.

Understanding GNSS strengths and vulnerabilities is key to developing robust solutions for field testing. After all, GNSS is the standard (commercial) time distribution system.

Disciplining & Holdover



The original purpose of holdover is to bridge temporary synchronization outages by maintaining the last known frequency, while trying to keep accurate timing within the 1.1µs limit. But, since there is a lack of traceable references in the field, the obvious option for test and measurement is to use a clock in holdover mode as an alternate clock reference source. If taken out of context, the holdover capabilities could get stretched and idealized. That is the reason why one may be hearing or asking the question "How long is your holdover?" without any indication of what may constitute the end of a valid holdover period (how much phase drift is acceptable?).

Holdover is a good practical alternative to not having any reference clock at all. But it is important to be aware of its limitations. Oscillator, GNSS Clock and PTP NE manufacturers may advertise holdover >24h to ±1.1µs under controlled temperature conditions. Nevertheless, these figures can only be achieved with a lengthy internal process, learning the characteristics of the oscillator. Their specifications may include foot notes like "*7 days powered and 2 days locked to GNSS before entering holdover". That may be good enough for permanent always-on installations, but the same can't be extended to test and measurement.

Allowing test equipment phase references drift all the way to 1µs doesn't make much sense because the error (or uncertainty) would be equal to the upper limit of what you are trying to measure. Unfortunately there is no clear guidance of what is expected from the test gear. We can only assume that its error limit should be tighter (good enough for relatively short tests), but achieving >4 hours within 100ns, at variable temperatures, requires high-quality precision oscillators with <0.007ppb. That doesn't seem to stop people from asking for ">24-hour holdover".

Also, total holdover time is not as predictable or repeatable as commonly thought. During active 1PPS signal disciplining process, the oscillator's frequency is continuously changed to adjust its phase and keep it aligned to the timing reference coming from the GNSS receiver. Any small short-term frequency offset (in the order of parts per trillion) present at the moment the holdover is initiated affects the resulting phase behavior. Environmental conditions also play a role in the holdover behavior and the total usable holdover time.

Extreme Expectations

The field test and measurement industry has always suffered from the added complexity of tender specifications and requirements. Some of the extra requirements are inherited from lab environments, even though they may not serve any validation or troubleshooting purpose in the field. Others may come as copy-and-paste from the last conference or article read, without much thought given. The unintended consequences of these superfluous requirements may be unnecessary complexity.

Here are some simple questions to think about before adding new requirements to the mix:

- Does such test suit or requirement really apply to the field?
- Does the function or feature provide meaningful insights to help identify or isolate the source of a problem?
- Would the test equipment connection preserve the integrity of the link or network as it is intended to be in production? E.g. intrusive pass-through settings, temporary signal taps, etc.
- Would the intended end user (not the lab expert writing the requirements) have the knowledge required to handle such test, interpret the results and take appropriate actions?

Many standards, recommendations and test cases are oriented to R&D verification and network engineering. They are often used by Carriers to benchmark different PTP network elements and identify the one with the best performance/cost benefit. Once those transparent clocks, boundary clocks, slave clocks, radio links,… are deployed, the task for field test equipment is to verify that the whole solution work in real-life conditions, within defined performance limits, as well as offering diagnostics/troubleshooting tools in case something is not right.

Challenges

When we first visit (potential) customers or go through an evaluation process, we usually deal with "the Lab". Often we have to overcome a list wishful expectations before we can get into a productive conversation. After those lengthy discussions, the conversation turns into actual needs and becomes quite fluid. The other major hurdles are usually related to "extreme" expectations or assumptions applied to field test and measurement equipment. Some of them are related to extending previous frequency experience directly into phase or borrowed from the lab equipment they have been using in the initial technology and network elements evaluation process.

On the other hand, dealing with actual end users and their ever-changing environments is a different story. Many technicians don't have previous experience with synchronization. PTP and phase measurements are new items to add to the long list of tests they are expected to perform. Close attention should be payed to those users and their environments should be taken into account, because practical solutions go beyond technicalities.

By "Field" we mean: Away from the cozy controlled labs where all sort of calibrated equipment and traceable reference are always available. Testing Phase/Timing synchronization at the edges of the network can be full of surprises. Every site has its nuances and some of them may prevent you from running the required tests.

- It is not possible to know the actual accuracy of the time reference at any given time. Selecting the right test equipment (one that provides a much status information as possible) may help in minimizing that uncertainty.
- In certain sites, the GNSS Clocks were installed out of the box, using the default configuration. They may be missing the cable delay compensation and information may not be available (this wasn't an issue for frequency testing). End users may not be familiar with GNSS or disciplining parameters such as the Time Constant.
- There is often a lack of formal guidance, reference material or practical expectations.
- There is often a lack of experience, knowledge and many misconceptions/myths.
- There are challenges associated being in the field and constantly moving (quicker geo-location surveys?).
- There is a lack of traceable clock references on site.
- No GNSS coverage (due to indoors location, interference or "urban canyons").
- No physical access to the recovered clock signal to be verified (no clock output or non-standard connector).
- Legacy test gear may not support 1PPS or phase measurements.
- Long term tests are required, but there may not be room in the site to secure multiple test gear overnight or a way to get the GNSS antenna cable out of the enclosure.
- GNSS RF feed may be available, but without proper documentation (e.g. unknown cable length and delay).
- There may be no access to power (AC or DC).
- The environments in which field tests are performed is not controlled (e.g. variable temperature).
- There could be disconnects between theoretical and lab expectations vs. practical approaches and field needs.
- Bringing field crews up to speed with regards to phase/time synchronization could be challenging.
- Available or expected test time. Wander and phase measurements require long term tests, but field technicians may be used to perform quick service tests.

Thou Shalt Never Go Beyond ±1100ns

When bringing new phase synchronization links into service and taking time error measurements to validate them, being below 1.1µs may not necessarily mean getting a PASS verdict.

- Never is a very long time. What does a relatively short measurement done one day mean in the long term?
- Keep in mind that GNSS references are affected by atmospheric and ionospheric conditions. It is not unusual to see them wandering between day and night times.
- Don't forget that the GNSS Clock reference being used to perform the "absolute" time error measurement has a time error of its own. (Technically, it should be ≤100ns. But, you would want it to be <<100ns.)
- With PTP, the phase error can be affected by link traffic conditions, so it may vary over time.

It would be safe to assume that practical PASS/FAIL limits should include some room for all the uncertainties. Carriers may end up specifying lower pass/fail limits on their test procedures (e.g. ≤800ns) to leave some room for long-term uncertainties. In the absence of formal guidance, carriers must use field experiences to dictate limits that fit their network architecture, environment, test gear and their actual needs.

Some propose adding Synchronization Monitoring Systems to make sure the remote clock never exceeds the limit. But if one had the capability to continuously monitor (measure) time error accurately, that would mean that the remote probe is considered always accurate. If that is the case, why would you even need that other clock you are trying to measure in the first place?

Although the Absolute Time Error allowance seems a bit fuzzy (basically a flat 1100ns mask that extends forever), the required MTIE wander limits still apply (depending on interface being tested). Wander masks shall still be used to help better define the required test time and tighten the phase behavior criteria for Pass/Fail evaluations.

Phase is Different

In the past (and still today) synchronization crews where very small groups of highly specialized individuals who worked for the carrier, NEM or system integrator. They travel across their territory making frequency accuracy and stability measurements in a select number of central offices. Mainly at very important points of presence. Not only they have good understanding of frequency sync, but they carry a lot of delicate test gear, including portable rubidium references and even not-so-portable Cesium clocks for their wander measurements. This is simply not scalable when we are talking about the larger geographical coverage required by a massive deployment of timing synchronization (via PTP and GNSS) all the way to the very edges of the network.

Portable Rb and transportable Cs frequency references can be "calibrated" regularly at a central location by comparing their frequency against a traceable reference (e.g. PRC, SSU), recording the frequency error (offset) and writing the corresponding steering correction into memory. They can be turned off and on, and after warm up they will output fairly accurate and repeatable frequency. Although frequency accuracy is very important, this kind of "weekly or monthly calibration" can't be done to Phase.

- First of all, the oscillator and time counter must remain powered after its 1PPS has been aligned to GPS timing, to maintain phase synchronization.
- Second, the phase will start to drift as soon as it is disconnected from the reference, so the time error (TE) uncertainty increases as time goes by. How fast or how slow, would depend on the oscillator frequency offset at the moment of disconnection. If the offset is known, the drift rate could be estimated as Xppb = Xns/s.
- Many of the older portable frequency references currently being used don't support 1PPS, Phase or Time, and may be in need to be replaced. They may also require external power, which may not be available at all sites.
- Although certain locations have well engineered GNSS RF feeds to the equipment rooms (with power feeder, amplifiers, power blockers, splitters), they may not be usable for phase. Missing the antenna cable length and delay documentation is not uncommon. That may have been OK for frequency, but it is not for phase.
- Distribution cables' length! It was not an issue for local frequency distribution. But, at 5 ns/m (1.5 ns/ft), cable delay could certainly be a significant source of phase error. Keep in mind that, even at small sites, cable runs could easily reach 100m (500ns) since they follow cable trays. Even the test cables used to connect the reference clock and the signals under test to the test set must be of equal length (at least differences are accounted for).

The places where frequency and phase accuracy and stability are being measured today are quite different. They are actually in the field. Some are literally out in the open and full of surprises (customer premises, containers/cabinets, base station controllers, base stations, small cell sites, microwave sites, rooftops, basements, etc.). The test gear must be all-inclusive, highly portable and capable of dealing with most scenarios.

Reference Oscillators

It should not come as a surprise that test equipment reference oscillators play a crucial role in the quality of synchronization testing, verification and troubleshooting. This becomes even more important when performing field measurements at the edge of the network, due to the lack of other traceable references.

Older test equipment used bulky external calibrated frequency references for wander measurements, but with the introduction of Phase/Timing, it is more important than ever to maintain the reference timing signal integrity (low delays, impedance matching, avoiding adapters, etc.). Test equipment has to be designed to handle timing signals. That should not come as an afterthought via firmware updates or adding some piggyback adapters. Fully-integrated packaged designs are desired for field applications, where mobility and minimizing human errors are crucial.

The Need for Precision Oscillators

Precision oscillators refer to the high stability and accuracy required by the main internal oscillator being used as a reference by the test equipment. There are certain characteristics that should be important when considering portable test equipment for field use:

- Frequency Accuracy: In many applications the test set's internal reference is used in free-running mode and the closer it is to the ideal frequency the better. A highly accurate frequency source will also help in maintaining phase holdover for longer time. The <4ppm crystal oscillators (XO) often used for OTN, SDH or ISDN testing will not cut it. Even a 1ppb (1E-9) oven-controlled oscillator would produce a 1ns/s phase (or time) drift, reaching 1µs error in just 00:16:40 (1000s). Free-run frequency accuracies of <0.1ppb (1E-10) are highly desired.
- Frequency Stability: The use of phase (time) holdover is starting to play important role as alternative reference for field testing, so having stable and predictable frequency source helps in extending the usable holdover time.
- Temperature Compensation: Not being in a controlled lab environment puts portable test equipment at the mercy of the environment, with quite rapid changes in temperatures from the outside, or a vehicle, to the common 20°C inside of equipment rooms. In many cases the whole test happens outside and the test set must be able to deal with constant ambient temperature changes.
- Power Consumption: When talking about battery-operated test gear, the autonomy is as important as any of the previous specifications. The best quartz oscillators tend to consume more power since they use double oven (DOCXO) or single oven (OCXO). This is similar for Rb-based oscillators. Their power consumption is even higher during the warm up process and in colder days. Component size is also an issue for handheld test equipment and DOCXO are also bigger. The newer chip-scale atomic clock technology (Cs based) seems to be the closest to offering the power, size and performance required, in a double-insulated temperature compensated package.

The Need for Disciplining

The oscillator package should also offer built-in Frequency (e.g. 10 MHz) and Phase (1PPS) disciplining, so they are tightly controlled within its sealed environment. The most common disciplining source for field operations would be a UTC-aligned 1PPS signal from GNSS (e.g. GPS clock). Which is used to precisely align the oscillator's 1PPS output and constantly correct (steer) its frequency to maintain accurate phase alignment.

Phase disciplining is a bit different than traditional Frequency disciplining or calibration. The emphasis here is in maintaining the output phase tightly aligned to the UTC reference, provided by the GNSS receiver, so the frequency is constantly changed to adjust the phase of the 1PPS signal. At the end, higher phase and frequency accuracies are both achieved. It is important to keep in mind that the oscillator's frequency always contains a very small correction factor (steer), in the order of parts per trillion. That comes into play in the uncertainty of the total phase holdover time that can be achieved, depending on the steer state when the GNSS signal is removed. Any small offset creates a slow phase drift ramp that defines the total usable holdover time.

In the lab, frequency and phase can be monitored and measured to identify when the discipline process has stabilized and reached the required accuracy. This can be used to identify the perfect moment to disconnect the GNSS and initiate a controlled holdover. That would not be possible in the field. Users rely on relative information gathered and provided by the instrument itself. There are no other points of reference to assess its readiness.

Unexpected Connectors

When participating in field tests, evaluations or field demonstrations, it is quite common to find network elements with unexpected connectors being used for recovered clock outputs. It is not uncommon to find USB-A, USB-B, mini-USB, HDMI, MDR14, RJ45 in all sort of pin-out arrangements, or even no clock output at all. In many cases it seems like the clock output could have been an afterthought. That could certainly ruin the day for the technician.

Finding the pin-out, signal format and impedances is not always a simple task. Sourcing the matching connector in the local market, to make an adapter, may not be as easy either. Fortunately, this problem affects mostly visitors, since local technicians would probably make the necessary adapter for the few types of odd interfaces found in equipment deployed within their territory. One can only hope that they are built correctly, to preserve impedance matching and the clock signal integrity.

Solutions

As mentioned earlier, very high expectations are currently imposed to field synchronization test equipment and its users, so T&M manufacturers need to continue evolving to keep up with the state-of-the-art and use all those challenges found in the field as motivation to continue bringing practical and creative solutions to the field.

Most field T&M equipment requirements are still defined and evaluated by the customers' lab. But, it can't be assumed that actual end users would have even similar level of experience, knowledge or understanding. So the complete user-tester interaction becomes critical to minimize human error, as field users also become part of the "uncontrolled environment". Here user interface goes beyond screen, buttons and menus, into actual usability. Being simple to transport, setup, connect and use are key. Reducing the number of required devices, connections, adapters and configurations help a lot. So, having as many of the required functions integrated into a single portable device would be a highly desirable approach.

It is also important that the test gear offers all, or most, of the tools required to compete the job (e.g. Installation, fine tuning, verification, bringing-into-service, troubleshooting, etc.). Including provisions for unexpected scenarios.

Minimum Test & Measurement Requirements

For the targeted end users it is all about user friendliness (even to those who don't know or are not expected to learn sync), making the equipment automate as much as the process as possible, provide lots of status information and be able to deal with the environment. Having the same test set they use for day-to-day testing to do sync makes it easier to them, busting confidence due to familiarity and, in turn, reduce invalid tests or repeat visits.

Full disclosure: VeEX is a T&M manufacturer, so take the following recommendations at their face value and apply your own judgement. Nevertheless, the list below comes from feedback gathered from customers and field tests around the world.

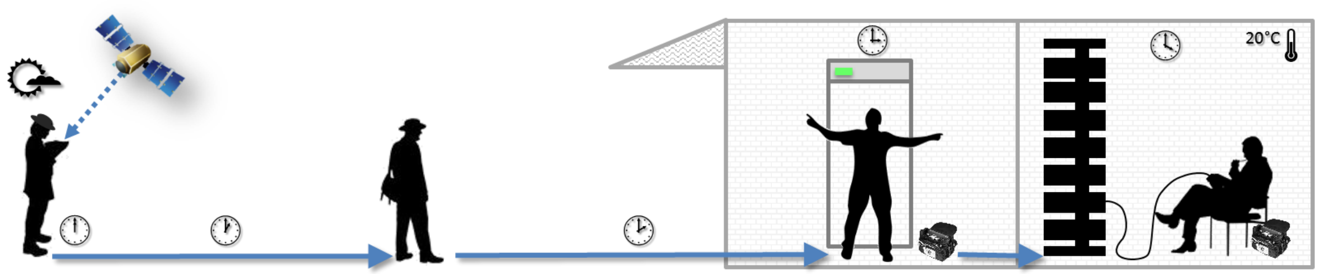
- Compact highly-integrated solution suitable for field use. Ideally techs should carry only one test gear.
- Field-replaceable high capacity Li-ion or Li-Po battery pack with >2 hours of autonomy running clock wander and absolute phase error measurements.
- Accurate and stable internal frequency and phase source (oscillator) with 10MHz and 1PPS support. Ideally with free-run frequency accuracy better than 0.1ppb (1E-10).
- Built-in GNSS receiver to discipline the oscillator and align the 1PPS pulse, with accuracy better than 30ns.
- External reference clock inputs supporting common clock formats and levels, such as sine, square and bits. Minimum requirements: 1PPS, 1.544 Mbit/s, 2.048 Mbit/s, 2.048 MHz, 10 MHz. Some sinusoidal clocks have low levels (<1Vpp), so sensitivity is also important.
- Clock inputs and output ports with common industry-standard locking connectors, such as BNC or SMA.
- Measure Wander (TIE) and perform MTIE/TDEV analysis with standard masks for T1, E1, STM-1, SyncE links, as well as common 1PPS, 1.544 Mbit/s, 2.048 Mbit/s, 2.048 MHz, 10 MHz recovered clock formats.
- Measure Phase or absolute Time Error (TE) and perform run-time MTIE/TDEV analysis with standard masks for 1PPS recovered clock.

- Capable of recording and analyzing at least 72 hours (one weekend) of wander or phase measurements, at up to 30 samples/s. A post-analysis (PC) tool should also be available for longer tests and higher screen resolution.
- Minimum T1/E1, 10M to 10G Ethernet, SyncE Master/Slave, 1588v2 PTP Master/Slave service testing capabilities. SDH/SONET testing capabilities are also desirable.
- SSM clock Quality Level (QL) generation and monitoring for E1/T1, SDH/SONET, SyncE and PTP.
- PTP Quasi-Slave emulation with packet delay variation (PDV) monitoring. Mainly used to check new links, when Slave Clocks have not yet been installed, to make sure the provisioning was done correctly, Grandmasters are reachable, protocol handshaking takes place and that synchronization is attainable. That way, when another vendor or contractor comes to install the actual Slave Clock, it should be expected to work. Grandmaster emulation could also come handy when troubleshooting Slave Clocks or trying to isolate/segment problems.
- Flexible multi-stream traffic generation, with enough randomness to simulate live traffic to stress PTP links.
- GNSS-assisted one way delay (OWD) measurement to identify link asymmetry.

Stand-by (Sleep) Mode

The ability to slow down the processor(s) and turn off all other circuits in the test set, with the exception of the reference oscillator, has been requested by customers, for the following reasons:

- Reduce the power consumption and heat dissipation, so the test set can be temporarily stored in its carrying case, safely, without overheating. Then it can be transported from outside (where GNSS synchronization took place) to indoors. In some cases pass through security checkpoints.
- Maintain 1PPS phase synchronization during transportation as described above.
- Keep the internal precision oscillator in top condition during overnight or long-term storage. Test sets are often left in the vehicle overnight (even in winter) and somehow expected to be ready to perform measurements in the morning. Since we can't expect end users to have temperature controlled chambers, the oven controlled oscillator in the test set can be used to take good care of itself by maintaining its own optimum temperature at all times and be ready next day (sleep mode autonomy >16 hours on full battery).



The Importance of Having Access to Status Information

One advantage of the all-in-one approach is that test sets have direct access to all their built-in components and their respective status. In the field, there are no other references that can be used to confirm whether the test equipment and its references are ready or valid (e.g. GPS status, disciplining process, internal phase alignment and holdover). Users rely on the information provided by the individual components and the system in general to make the best assessment possible about readiness and validity.

For example, having easy access to the GPS receiver status, such as number of satellites in view, their individual SNR and geo-location survey status, are important to identify the best antenna position and confirm whether its temporary installation is good or not (interference, obscured RF, multi-path). Same goes for the internal oscillator disciplining process, Ethernet connectivity, PTP synchronization process, PDV behavior and convergence, etc. The test equipment itself should give users the confidence to make valid measurements.

The Swiss Army Knife Approach

Besides offering all the required Phase and Frequency synchronization test features, with excellent performance and accuracy, we have to take into account that with the rapid increase of timing distribution via SyncE, IEEE 1588v2 PTP and GNSS, the responsibility of verifying accuracy and stability starts to fall on a larger geographic footprint and in the hands of more field techs, who are not necessarily sync experts and have to deal with many other services and technologies. That means field test sets would also have to offer a test suite supporting complementary technologies, to be used during construction/installation, bringing-into-service (BIS), troubleshooting, verification, acceptance and maintenance. For example:

- NEMs, system integrators and construction crews deploying new links for LTE-A/TTD base stations with PTP and/or SyncE, may also require Ethernet, CPRI/OBSAI and Fiber Optics testing capabilities.
- Communication service providers' field crews may have to carry new SyncE, PTP, Wander and Phase synchronization tests, on top of the regular jobs they currently do. That may include ISDN, PDH/DSn, SDH/SONET, OTN, Ethernet, Fibre Channel, FTTx… to name a few.
- Utilities may also need to test telemetry, teleprotection and supervisory control and data acquisition interfaces, such as 64k codirectional and IEEE C37.94.

Conclusion

There are no formal practical guidance on how to verify phase accuracy and stability in the field, but that doesn't mean it is not possible. Test procedures must be written around the existing absolute time error limit and the applicable wander masks, factoring in the available test time, uncertainty allowances and the local environment. Here are a few things to keep in mind:

- Field testing is very different than lab evaluations.
- Phase/Timing accuracy measurements are more complex and sensitive than frequency measurements.
- Unlike in lab environments, you can't control the test environment in the field, so the test equipment and its internal components should to be able to deal with it. For example, the use of highly-integrated GNSS-disciplined time and frequency atomic oscillators allow better internal measurements and control of the disciplining and holdover process, since they are encapsulated in the same sealed package. (Better than solutions using separate/independent oscillator and disciplining control systems.)
- Consider battery operation and its implication in disciplining, test and holdover time, as well as portability.
- Training is indeed required but this may not be easily scalable, so clear procedures, guidance and limits must be provided to end users.
- Consider all the testing needs your field crews have and select the test gear that fits all those applications.
- Be practical, realistic and know/understand your end users' capabilities and limitations. Make procedures as simple as possible to reduce errors (e.g. less choices/decisions, less devices, less adapters, less connections, more visual aids and guides, etc.).
- Each carrier may need to stablish their own Time Error Pass/Fail criteria applicable to field measurements, based on their own environment, experiences and network architecture of choice (e.g. full/partial/no on-path support, APTS, GNSS, fiber and/or microwave, number of allowed hops, etc.).
- The industry in general should come up with more field test guidance to set the right expectations and harmonize the way phase/timing are being verified.

Portable Time Error test equipment are indeed available today, in different sizes, weights and forms. Nonetheless, users must be aware of the limitations and caveats of all technologies involved, to factor them into their field testing requirements, procedures and guidelines. The goal is to get the most reliable measurement results possible that you can rely on for field environments.

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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