Technical Note

Understanding Wander in Transport Networks

CMA5000

XTA module (e**X**tended **T**ransport **A**nalysis)

Introduction

Synchronous SDH/SONET networks are the powerhouse of modern long haul backbones. As their name implies, they are supposed to run on synchronous clocks, that is to say, clocks that all derive from a common source and supposedly fairly identical.

While this requirement is, to some extent, indeed respected in most cases, these networks have to handle occasional losses of perfect synchronization. SDH & SONET indeed have enough internal provision to do that but the impact of bad synchronization must be appreciated at the payload level. This is because transported tributaries within synchronous streams may sometimes be badly hit in such cases while everything looks fine at SDH/SONET level. This can lead to loss of frames at tributary level and therefore create a serious degradation of the services carried by these circuits.

Synchronization problems mean low frequency phase fluctuations at clock and signal level and are commonly called Wander. The object of wander analysis is therefore to characterize these clocking fluctuations. This application note addresses this issue, explaining first what wander is, presenting the classical background behind it and the techniques used to characterize it.

What is Wander, its causes and consequences

As mentioned above wander is the generic term for the slow and very slow timing fluctuations affecting transmission networks. Transmission streams are supposed to arrive at exchange nodes regularly, but what if they don't?

If one or several incoming streams accumulate important (many µs) phase differences (wander) between one another we may get problems: signals are bufferized before processing and the node processes them with a common clock. If the wander gets too large, buffers will either loose a whole frame (buffer overflow) or repeat one twice (buffer underflow) in order to keep control. This is called a "controlled frame slip". In all cases the internal data carried within these streams will be corrupted, resulting in a quality of service degradation. The only service that would not suffer from a frame slip is the case of uncompressed voice transmission. In all other cases (data, video, signalling, etc...) excessive wander is a real threat.

But why should this happen in the first place, anyway? Basically, if all network clocks were perfectly stable (no clock noise) and fully synchronized, this would never happen. Unfortunately clocks, even if they are driven by a nice synchronization source, add up some internal wander of their own. Their intrinsic wander amplitude may individually exceed 100 ns over a few hours.

Clocks within a network are usually all driven from a common source called a Primary Reference (PRC or PRS) but we have to consider that interconnected networks may run on different PRCs that will show relative wander to one another. Each PRC may build a wander of 1 µs per day. Then, due to micro interruptions or change of reference clocking source (consecutive to a failure) at the input of PLL circuits, clocking signals in Network Elements experience random phase changes.

In the end, especially in the unfavourable cases of PDH / T-carrier streams travelling along several SDH/SONET networks, there exists the possibility of large wander accumulations that may lead to several frame slips per day.

Additionally, SDH & SONET networks add their own peculiar contribution to this issue. Their equipments “transparently” accommodate synchronization differences with what is called pointer adjustments. A 2Mbit/s trunk line crossing SDH networks with serious timing problems would actually travel in a TU12 container with frequent pointer movements. It turns out that each occurrence of these movements induces a non negligible jitter on the extracted 2M line. If this “pointer-induced” jitter is not well smoothed out (by a circuit called desynchronizer) this impairment may well “knock off” the terminating equipment, say, a PABX or a mobile base station, in the sense that the equipment may then temporarily loose synchronization and data.

Normally pointer movements are scarce but they occur when a failure in the synchronization distribution forces a node to run on its internal clock or when a dc offset in the PLL clock circuitry causes a clock drift.

Figure 1 sums up these issues.

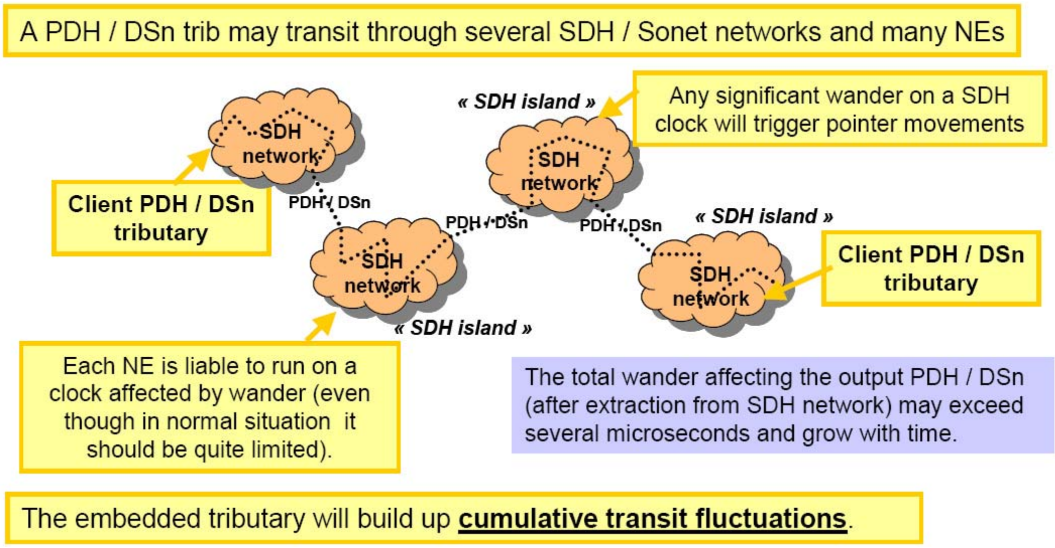

Figure 1. Why wander may accumulate?

Synchronization and wander

Network synchronization is very important. Synchronization is commonly distributed in a chain through different clock units with different levels of quality, as illustrated in Figure 2. It also shows the difference in terminology in SDH and SONET worlds.

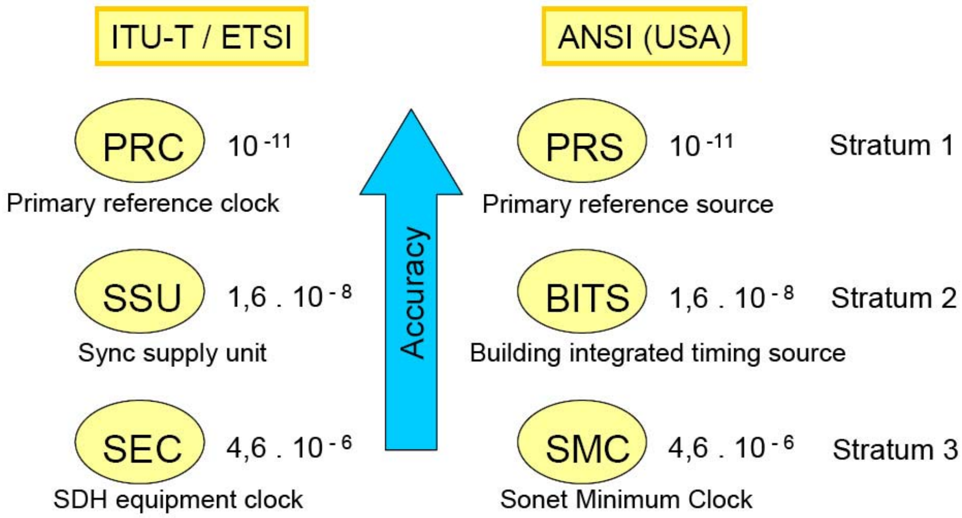

Figure 2. Two clocks hierarchies in the synchronous world

Stratum 1 clocks are by definition clocks with the best long term accuracy. For instance Cesium beam oscillators are Stratum 1. Stratum 2 and 3 refer to the next levels below Stratum 1, with long term accuracy decreasing from Stratum 1 to Stratum 2 and finally Stratum 3. Stratum 3E (enhanced) is a particular case whose quality is intermediary between Stratum 2 and 3.

In ITU-T parlance the highest level is called PRC or Primary Reference Clock. The second level is the SSU or Synchronization Supply Unit and the third one is the SEC or SDH equipment clock. One difference between SSU and SEC is that SSUs have a narrower bandwidth and different intrinsic wander limit specifications.

Similar terms are used in SONET and the corresponding long term accuracy is listed in Fig. 2. Most common PRC units use GPS satellite timing signals as a synchronization source, whenever reception conditions are correct, but switch to alternative sources like a Rubidium clock if GPS reception is not satisfactory. On the other hand, SEC clocks are typically made with quartz crystal oscillators.

The job of a SSU is to select one of several available timing sources and distribute it locally to the different SEC units. But in general we may encounter the distribution chain shown in Figure 3 (see also Fig. 8 for more details).

One way to appraise the quality difference between clocks is to look at Table 1. It displays their maximum number of (125 µs) frame slip occurrences assuming they run in free mode after having lost their normal reference. However these figures do not include the impact of their own intrinsic wander and of clock distribution. They are just an illustration.

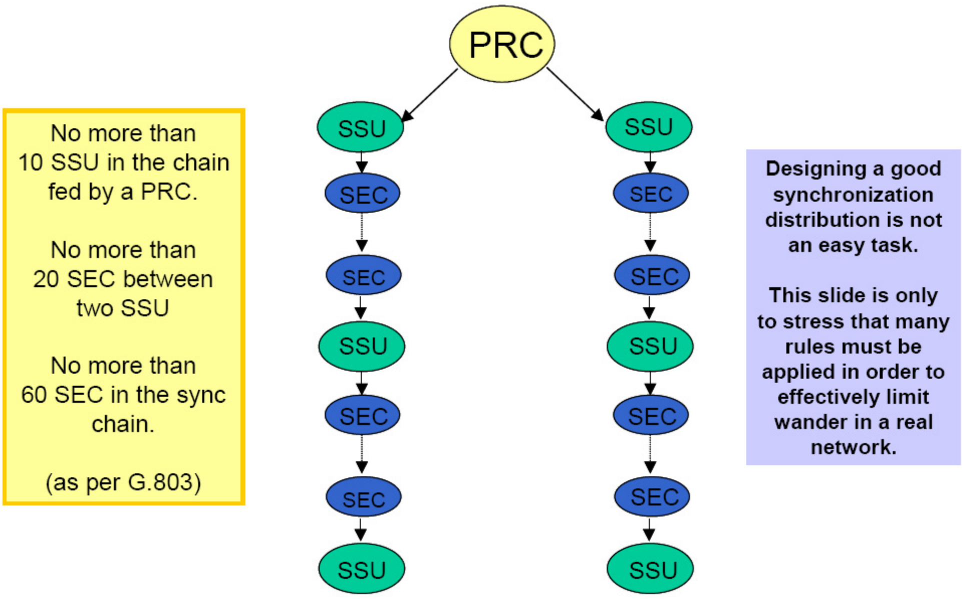

Figure 3. Synchronization distribution in SDH terms (Master – Slave type)

Stratum level	Free run accuracy	Holdover accuracy (first day)	Number of 125 µs periods
1	10^{-11}	NA	<1 slip in 72 days
2	$1.6 \cdot 10^{-8}$	$1 \cdot 10^{-10}$	<1 slip in 13 days
3E	$4.6 \cdot 10^{-6}$	$1 \cdot 10^{-8}$	<7 slips in 1st day
3	$4.6 \cdot 10^{-6}$	$3.7 \cdot 10^{-7}$	<255 slips in 1st day

Table 1. Quality differences between clocks (in free mode)

The wander recommendations (eg. ITU-T G.810, 811, 812, 813, 822, 823 and Telcordia GR-253, 1244) have been conceived to constrain wander to reasonable limits even in the case of information streams crossing many synchronous networks and assuming worst case situations. These standard limits come in the form of templates that measurements must not exceed, but we must first explain what these measurements are.

Wander measurements

Figures 4 and 5 show two important cases:

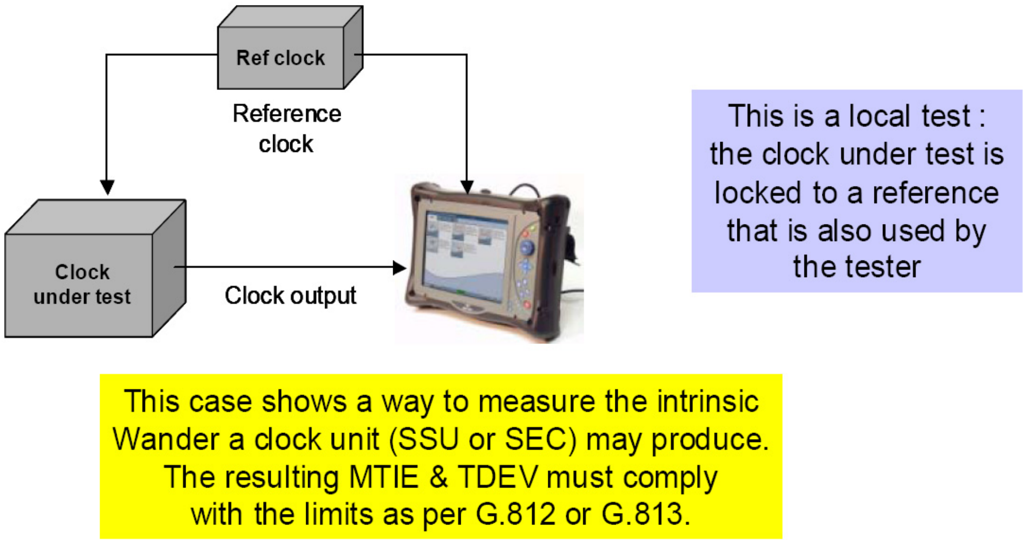

Figure 4. Example of intrinsic wander measurement

As discussed above, any clock contributes to wander accumulation with its own intrinsic low frequency phase variations. With the test shown in Fig 4 this intrinsic wander may be gauged. This test is called “locked mode” or “synchronized clock” wander measurement. The analysis of the wander data must comply with the relevant standard. If clock quality were not strictly bounded intrinsic wander could be a serious cause of wander accumulation in networks.

Figure 5 is more focused directly on measuring a network wander. In this case wander at point of measure (a clock unit or a data line) depends on the whole chain of synchronization, that is to say, it is not a local test. Since the outcome may involve a broad wander accumulation (imagine you are actually measuring a 2M trunk line that went through several SDH sub networks) the standard limits on maximum tolerable wander in networks are more relaxed, as will be seen later. This test is called “independent clock” wander measurement.

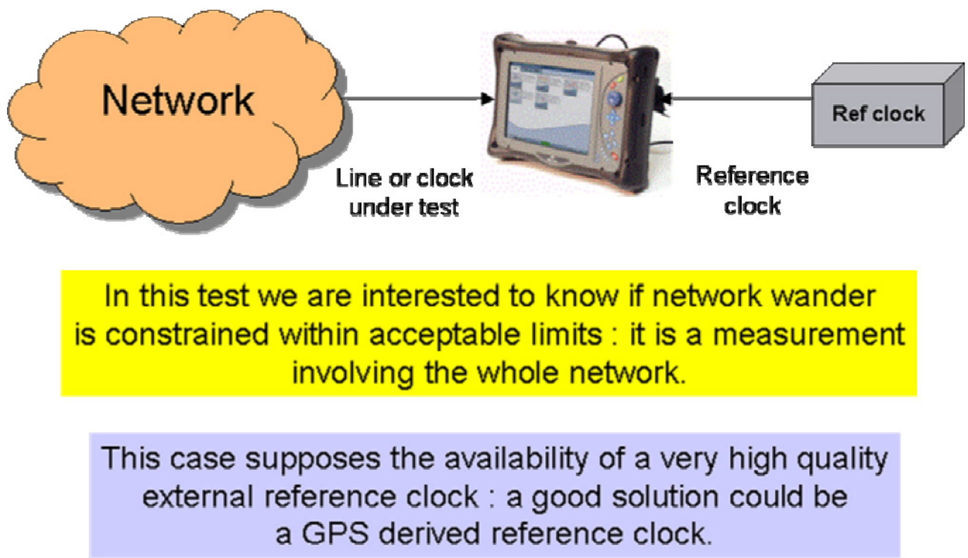

Figure 5. Network wander measurement

But what does the tester record during a wander measurement and how long should it last? The tester periodically measures the phase difference between the reference and the signal under test and stores the data. These data are called Time Interval Error or TIE and are usually displayed in ns.

TIE sampling periodicity is user-settable but depends on the application, and the same applies to the total wander measurement time. Table 2 shows a list of application examples. If one wants to, say, observe the wander induced by pointer movements the total observation time is short (less than 10s) but in order to track quick phase variations it is best to have 30 or 100 TIE samples per second.

On the other hand, if one wants to characterize a network wander long term fluctuations it is advisable to run the test during several days. This is because wander build-up in networks may not be seen with a simple 24 hrs run. In such cases it is most advisable to lower the sampling rate to 1 per second or 1 every 10s. A one week run with 0.1 TIE per second would already collect a bit more than 60.000 TIE.

Figure 6 shows a TIE recording done with the CMA5000 XTA application, with the horizontal scale in seconds and the TIE vertical scale in ns. It shows a TIE wander of 10 µs peak-to-peak fluctuation, first with a period of 100s (10 mHz) then a period of 50s (20 mHz).

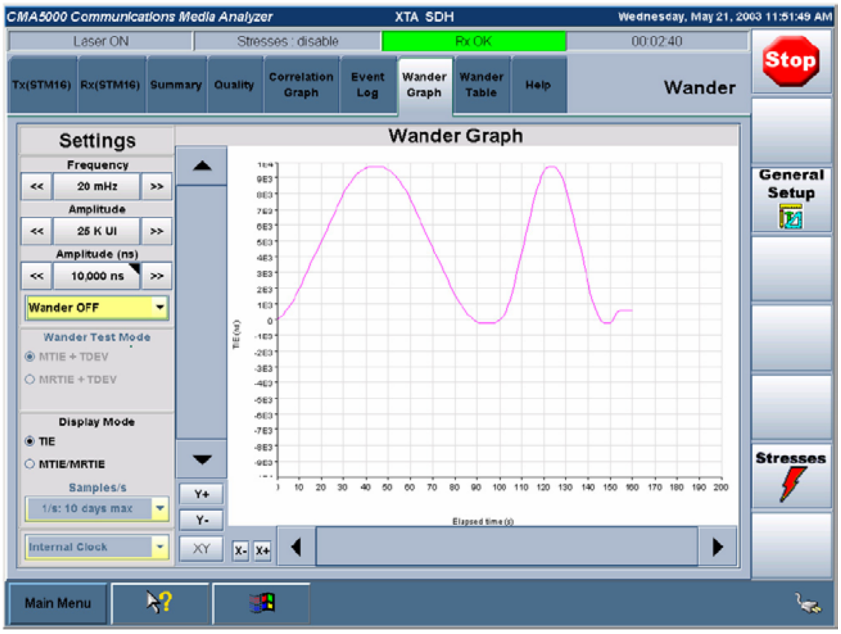

Figure 6. Time Interval Error (TIE) measurement with CMA5000 XTA

In long wander measurements, setting a fast sampling rate is unnecessary since we are then mainly interested in tracking very low frequency phase fluctuations. Setting, say, the rate to one TIE every 10s (100 mHz) basically prohibits any wander analysis on frequencies above 50 mHz but is perfectly fine to focus on the 10 µHz – 10 mHz wander range.

In other words, if you run a one week test with 10 TIE / second you will end up with 6 million TIEs (that is, if the tester can handle that). Better do that at 0.1 TIE / second: you get only 60.000 data but that's more than you need.

Then, if one wants to focus later on higher frequencies it is a simple matter to rerun the test with a faster sampling rate and a much smaller measurement time.

Rec	Type	Analysis	Observ. window	Freq.	Measurement time
G.783	Impact of pointer sequences on DS1 & DS3	MTIE	Up to 10 s	x	10 s
G.812	Transient analysis on clocks at 2M and STM-n level	MTIE	Up to 240 s	x	4 min
G.823	Network limits for PDH signals (section 5.2)	MRTIE	Up to 1000 s	x	20 min
G.823	Network limits (absolute meas. with PRC ref clock)	TDEV	42,000 sec	10 µHz	5,8 days

Table 2. Examples of wander measurement types with associated measurement time

Wander terminology

Most templates defining wander limits refer to the terms MTIE and TDEV. They both characterize the nature of the raw TIE wander data. To analyse wander you normally don't want to see the TIEs. They are only a lot of raw data and we need to extract from them something that really allows network engineers to decide quickly if they are in a Pass or a Fail situation.

What is MTIE? Imagine you find in the TIE sequence a TIE transition of 0.5 µs between measurement times t = 20s and t = 30s, that is to say, during a 10s interval. Imagine that nowhere else in the TIE sequence can you find a larger transition (500 ns) occurring during **any** 10s interval (you slide a 10s window along the whole TIE record). Then you have found the MTIE (10s) value of your wander measurement.

You then do that for other intervals like 1s, 2s, 5s, 10s, 20s, 50s, 100s and so on and you end up with values like : MTIE (1s) , MTIE (2s) , MTIE (5s) , MTIE (10s) , MTIE (20s) , MTIE (50s) , MTIE (100s) , etc… This is the essence of MTIE analysis. The parameter (here the sliding window width) is often called "observation window".

MTIE is very useful to pinpoint peak-to-peak wander phase fluctuations or identifying a shift in frequency.

What is TDEV now? TDEV is used to characterize more precisely the "randomness" or the degree of phase instability present in the TIEs. For instance it is not affected by any rate shift (unlike MTIE). It is more like a spectral density analysis.

What is basically done to compute TDEV (10s) when TIE rate is 1 per second? The TIE data are band pass filtered and roughly speaking the frequency content around 20 mHz and 70 mHz is extracted. Then the root mean square (rms) of these filtered data is computed. That is exactly TDEV (10s).

Similar computations are done to get the other TDEVs: the parameter is also called "observation window". To compute TDEV (τ) the band pass filtering is about centred around 0,42 / τ . That's why TDEV is a spectral analysis. Table 3 gives the correspondence between the observation window and the central frequency. The larger τ the smaller the frequency band analysed by TDEV (τ).

τ	1s	10s	100s	1,000s	10,000s	100,000s
Frequency	420 mHz	42 mHz	4 mHz	420 µHz	42 µHz	4 µHz

Table 3. Correspondence between TDEV observation windows (τ) and central frequency of band pass filter

MTIE and TDEV analysis is very useful: it gives a good synthesis of the recorded TIE data. Once they are computed MTIE and TDEV data are displayed in ns unit vertically with the observation window parameter on the horizontal scale in second unit. Figure 7 shows such a MTIE / TDEV analysis window. In this figure MTIE template and data are shown in red while TDEV template and data are in green.

What is fundamental in MTIE / TDEV wander analysis is that the computed curves are generally compared to the relevant templates. All points must be below the template in order to be in a PASS situation.

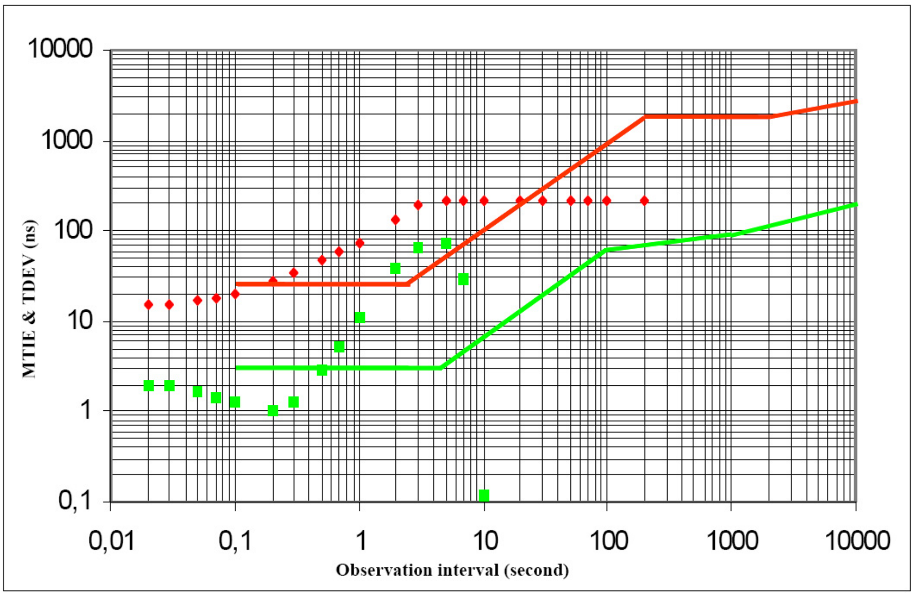

Figure 7. MTIE/TDEV data compared to corresponding templates for PASS/FAIL results

Note: there is a useful relationship between the minimum τmin parameter one wants to investigate and the TIE sampling rate (see ETSI EN 300-462-3 Annex A.2) : **(TIE rate) x (τmin) ≥ 3**

In order to avoid aliasing problems this in turn normally requires that the TIE data be first low-pass filtered with a cut-off frequency around: $(\tau min)^{-1}$.

For example, if one plans to do a long measurement and is basically interested in τ values above 30s one may set the TIE rate to at least: 3 / 30s = 0.1 TIE/s (one every 10s). But then the data must have been first processed by a low pass filter of cut-off frequency around 33 mHz (through hardware and/or software).

Standard limits on wander

Once MTIE / TDEV analysis is through we must display the relevant templates. There are many templates corresponding to very different situations and standard bodies (ITU-T, ETSI, ANSI and Bellcore). Table 4 mentions but a few, applying to networks built on the European hierarchy.

Measurement type	Reference	Level
Locked mode	ITU G.812 / ETSI EN 300-462-4	SSU type I
Locked mode	ITU G.813 / ETSI EN 300-462-5	SEC option 1
Network limit	ITU G.823 / ETSI EN 300-462-3	SSU clock output
Network limit	ITU G.823 / ETSI EN 300-462-3	SEC clock output
Network limit	ITU G.823 / ETSI EN 300-462-3	PDH clock output
Transient response	ITU G.812	SSU type I at E1
Transient response	ITU G.812	SSU type I at STM-n
Transient response	ITU G.812	SSU type I - phase discontinuity

Table 4. Examples of ITU-T recommendations containing MTIE/TDEV templates

Figure 9 shows the MTIE templates that define the maximum permissible limit on networks This supposes however that the network is not running in an abnormal way (for instance with one or several clocks in holdover) but on the contrary with all clocks deriving their synchronization from a common master clock.

Figure 8 reminds the condition under which we are running such a test. A master PRC is used at the start of the synchronization distribution chain in the network. Suppose we want to know if some SSU output in the network is complying with the standard. This SSU output is then fed into the wander tester (using another PRC as tester reference since usually it is not possible to use the network master PRC at point of measure). The MTIE obtained must lie below the SSU limit of figure 9. Figure 8 shows for all 4 levels (PRC, SSU, SEC, PDH) where the tests should be applied.

Why consider here PDH? This is because PDH interfaces may be used for synchronization distribution. In such case a 2M path is used to carry sync to the next SSU. In this case the point of measure is the PDH line fed into the SSU clock. The most relevant cases in Fig. 8 / 9 / 10 however are for SSU and SEC output (SDH regular clock feeding).

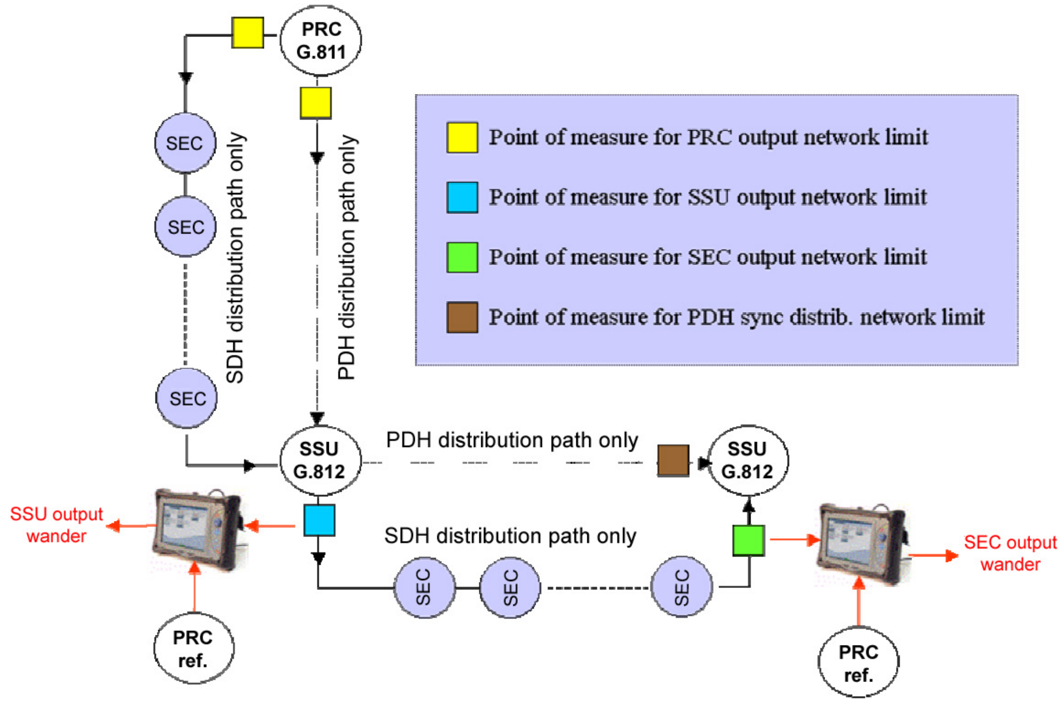

Figure 8. Points of test to measure the maximum permissible MTIE limit on a network

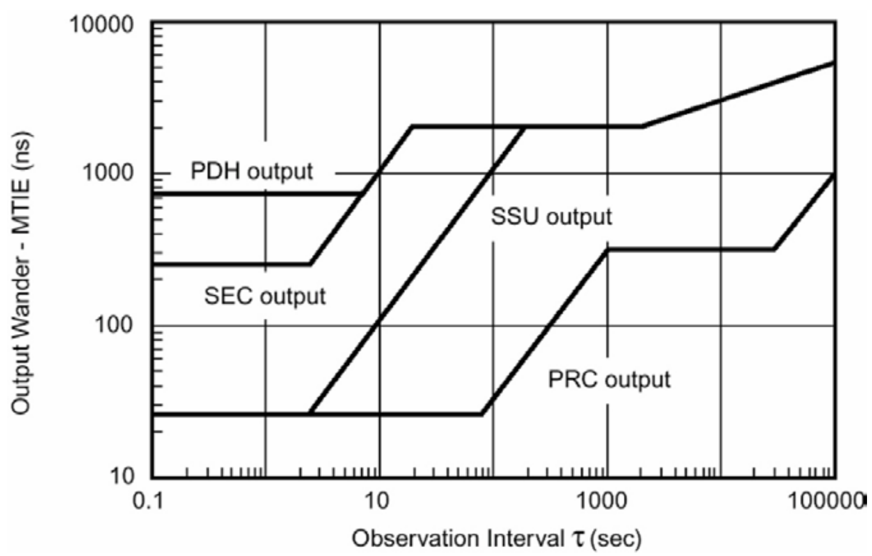

Figure 9. MTIE templates for PRC, SSU, SEC and PDH levels

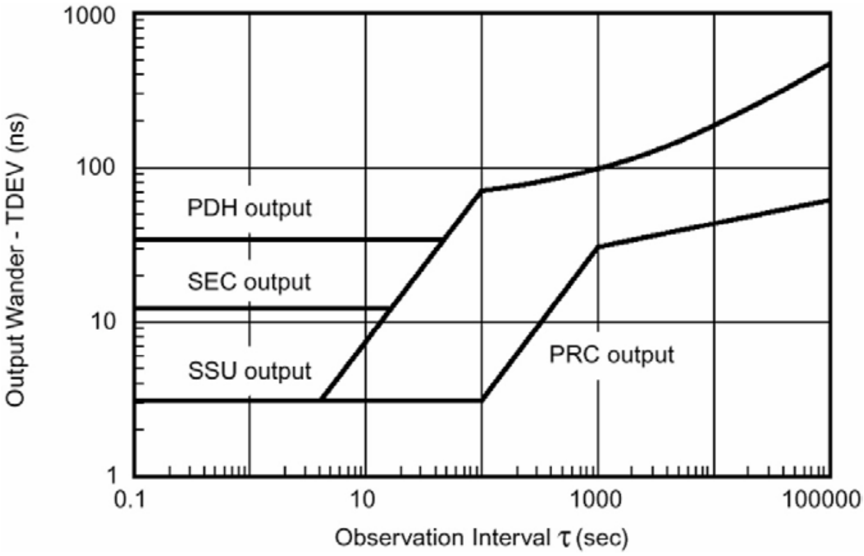

Figure 10. MTIE templates for PRC, SSU, SEC and PDH levels

Figure 10 displays the corresponding TDEV limits. As may be seen from these graphs the MTIE and TDEV limits are more relaxed when you move from PRC to SSU to SEC then to PDH. The important thing here is that the corresponding wander test is simple: you run the data recording, get the MTIE/TDEV curves and compare them to these templates. Any situation where the templates would be exceeded would be a serious source of concern and would require a serious synchronization distribution checking.

Conclusion

This note gave some background on the problematic of wander and network synchronization distribution and monitoring. It also illustrated these issues with the XTA application's GUI windows. Wander measurements are very important. If a clock unit (SSU or SEC) stops working in an adequate way, gets out of control and no warning is available at the network monitoring system level, a serious wander case may be triggered, which could lead to frame slip occurrences and/or large pointer movement activity.

In order to avoid potentially disastrous quality degradation, it is good practice to run wander tests at least at the SSU and SEC clock output level (as illustrated in Fig. 8) as a preventive action. These tests can be carried in an unobtrusive way whenever a clock output monitoring point and a good Stratum 1 reference clock are available.

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