Swedish-developed Wandermeter resolves synchronisation problems in the telecommunications network

Background

Today's telecommunication is digital. Our voices and the tones of fax machines and modems only exist as analogue signals from the subscriber up to the first switching station. After that the information is transported as digital ones and zeros, on copper wire or multiplexed up to 2.5 Gbits/s on optical fibres. Whether it be in a fixed telephone network or in the field of mobile telephony (with the new 3G systems), traffic in the network is constantly increasing. More and more information must be transported at higher and higher data speeds. Synchronisation of the traffic in the networks is becoming more and more important.

Reliable telecommunications is based on the data signals being synchronised and clocked using the same clock everywhere in the network. The basic clock in the European telecommunications networks (the SDH networks) is called E1, and it must be exactly 2.048 MHz. In an SDH (Synchronous Digital Hierarchy) network there is a caesium clock (2.048 MHz) as "master clock" or primary reference – PRC (Primary Reference Clock). This clock is distributed in the network with the data signals and regenerated in the network's nodes in "slave clocks". This clock regeneration is never completely perfect, but rather each regenerated clock will have variations in frequency and phase. The more nodes passed "en route" the less stabile the clock will be. This is illustrated in Figure 1.

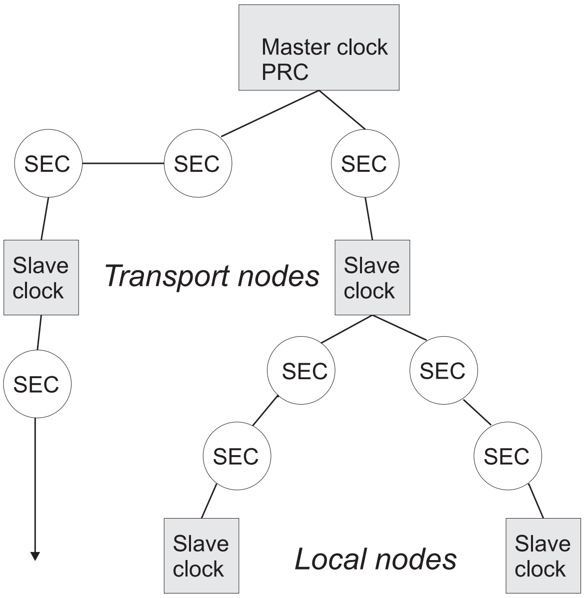


Figure 1. ***The clock in an SDH network is based on a caesium clock (PRC) which is distributed and regenerated in the network's nodes***

The clock's stability is characterised by two parameters: **jitter** and **wander**. Jitter is the fast phase variations and wander the slow ones. Phase variations with a frequency content above 10 Hz are jitter, and those with a frequency below 10 Hz are wander. It is wander which is the major culprit when it comes to incorrect synchronisation. If one looks at a jittery signal without wander on an oscilloscope, then the pulse edges are perceived as being fuzzy and "broadened". If one looks at a signal with a lot of wander but without jitter, then one perceives a "sharp" clock signal, which gradually "sways" to and fro. This is illustrated in Figure 2.

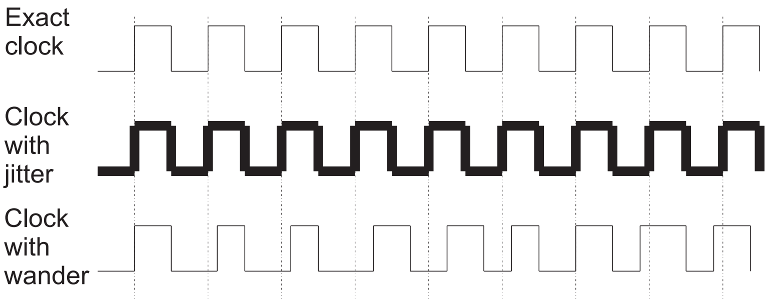


Figure 2. Jitter and wander

Measurement of wander in clock signal

Wander is the slow variations in the clock signal's phase position. Measurement of wander means making a phase comparison between the actual clock signal and the theoretically correct one. In order to be able to know when the "theoretically" correct signal arrives a Wandermeter must have a built-in clock with very high precision and stability. For this purpose only a rubidium- or caesium-type "atomic clock" will do. This phase comparison can in principle be made in two different ways. One method is to use a phase-voltage converter, which converts the difference in phase into a continuous, varying analogue voltage, which is then filtered, sampled (to get digital data) and signal-processed. See Figure 3.

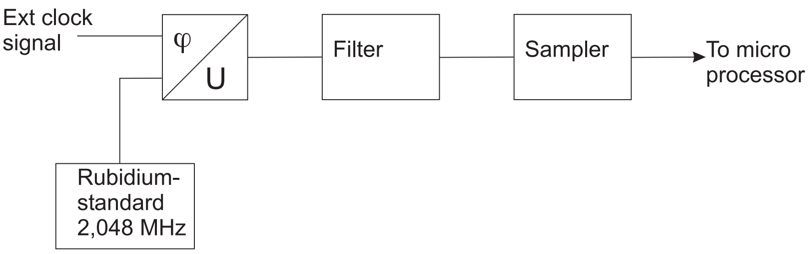


Figure 3. Wandermeter in accordance with the "phase-voltage converter method"

The other method is based on time-interval measurement in a digital electronic counter circuit, between the built-in clock and the external clock signal. See Figure 4.

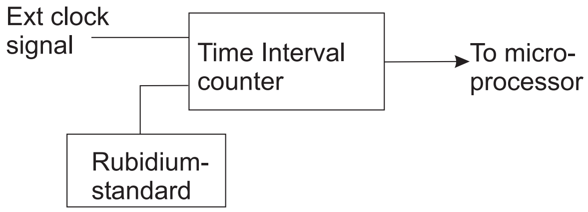


Figure 4. ***Wandermeter in accordance with the "time-interval measurement method"***

The advantage of the digital time-interval method is that it provides superior precision and resolution. A traditional time-interval counter, however, has a limitation. A phase change of over 180° (half a clock period) between two time-interval readings will be missed. An ordinary time-interval counter performs an instantaneous measurement and does not keep a check of the periods between the measurements. If the phase glides away by over ±½ clock pulse, then that is missed.

The WM-11 Wandermeter from Pendulum Instruments AB eliminates this limitation entirely. Thanks to modified time-interval measurement, which amounts to continuously counting and time-stamping the clock signal's pulse edges, the instrument keeps track of **all** clock pulses between the samplings, and does not miss any phase leaps.

Measurement of Wander in data signals

With measurements in a telecommunications exchange in the fixed telephone network one usually has access to the local regenerated 2 MHz clock. But often one also needs to measure the clock stability directly on the traffic signal (2 Mbits/s). With measurements on transmission networks to base stations in the mobile network, normally only data signals are available for measurement.

In contrast with the monotone clock the traffic signal is constantly changing, depending on the information transferred. A traffic signal of 2 Mbits/s is HDB3-coded, which means that the signal is bipolar and that a one is marked as a pulse which is alternately positive and negative. A zero is marked as absence of pulse. Furthermore, there are certain restrictions in the coding, for example the fact that there cannot be more than 3 pulse gaps in a row in the signal. See Figure 5.

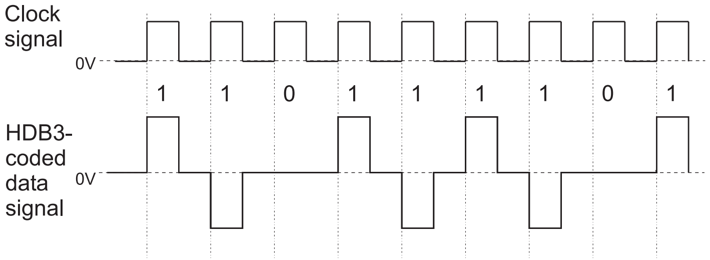
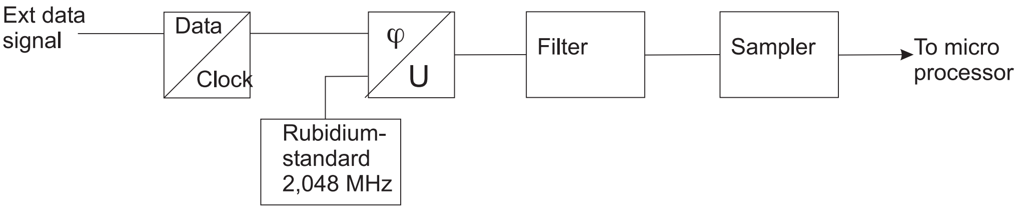
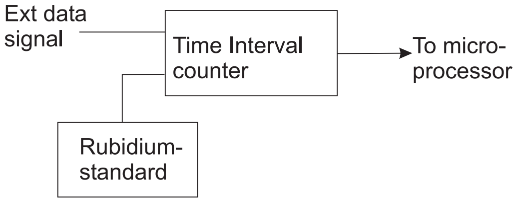


Figure 5. "2 MHz" clock signal and "2 MBit/s" data signal

To carry out measurements on the data signal in accordance with the "phase-voltage method" a Wandermeter must contain a clock regenerator (a phase-locked loop) to regenerate a comparison clock from the data signal. Because of the time-stamping principle the WM-11 Wandermeter does not need this, but can perform measurements directly on the data flow. See Figure 6.



a) Wander measurement using phase-voltage principle



b) Wander measurement using time interval principle

Figure 6. Measurement of data signals

Information box

Wander parameters

TIE:

The basic measurement is called TIE (Time Interval Error) and is the time interval between the actual and the theoretically exact clock pulse edge. TIE is shown graphically as a value measured over the course of long and medium-long periods (minutes to days), and it is expressed in ns or μs. The clock regenerator contains a local 2.048 MHz oscillator which is synchronised with and phase-locked to incoming data signals. Because of the properties of the phase-locked loop the long-term average value of the frequency will be very exact, whilst on the other hand short-term variations on account of the locking mechanism will arise. One can often see a periodicity in the TIE value, which is a result of the time constant in the loop. Furthermore, sudden leaps can occur, for example when switching data.

MTIE:

MTIE stands for "Maximum TIE" and is calculated from the TIE curve measured. It expresses the "worst conceivable TIE change" for different observation periods τ (tau). Assume we have measured a TIE curve with a TIE value every second. Our smallest period of observation τ is then a second, and covers two adjacent points of measurement. Let us imagine a window with a "breadth" of 1s, which scans the total body of data, from the first measurement to the last. The maximum difference between two TIE values is saved, and becomes the MTIE value for $\tau = 1$ s. Let us now increase the breadth of the window to 10 s and again scan the entire body of data. Within each position of the 10 s window the difference is noted between the largest and the smallest TIE value. When the entire body of data has been scanned, the maximum difference is saved as the MTIE value for $\tau = 10$ s, etc.

An MTIE curve thus shows the maximum TIE difference over the periods of observation (τ). MTIE is expressed precisely as TIE in ns or μs and is a monotonely growing curve (MTIE for a greater τ value cannot possibly be less than for a smaller τ value).

TDEV:

TDEV stands for Time Deviation and is also calculated from the TIE curve measured. It expresses the "rms variations in TIE" for different observation intervals τ. Clear periodicities in the TIE curve will show up as "bulges" in the TDEV curve. For example a 10 s periodicity in the TIE curve will show as a peak in the TDEV curve for $\tau = 10$ s.

Examples of measurements

The TIE graphs below show measurements made with the WM-11 on outgoing and incoming traffic for a telecommunications exchange at the highest node level (PRC level). Outgoing data traffic is controlled by a very stable clock in the exchange, close to the PRC clock, whilst the same clock has passed 5 nodes before it comes back in the incoming traffic. See Figure 7.

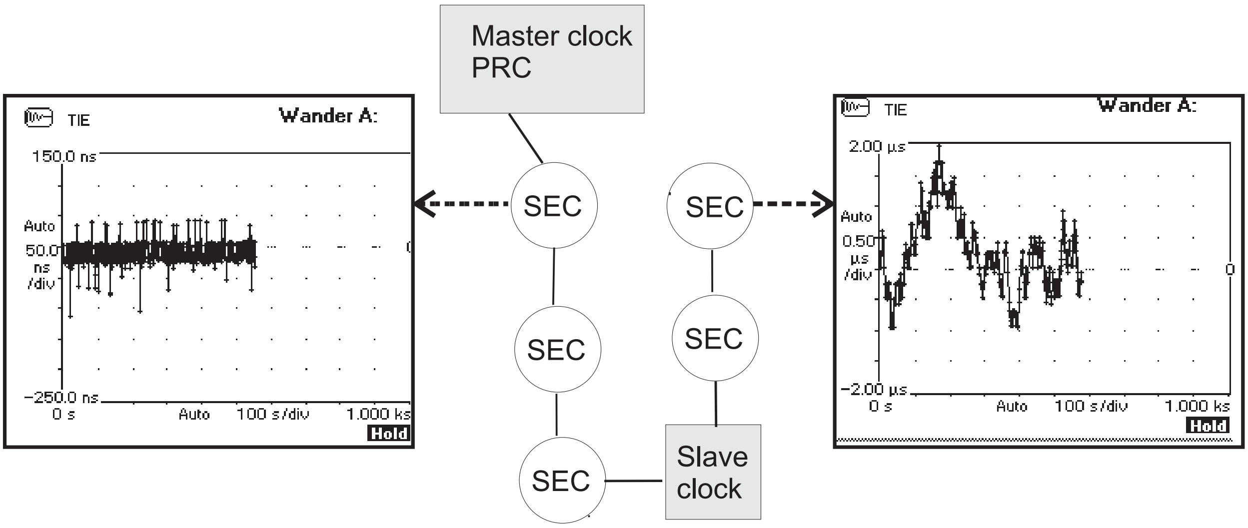


Figure 7. ***The clock gets greater wander the further into the network one goes (seen from PRC)***

As we see from the figure, the clock varies much more "on the way back" (max. MTIE is around 3 µs) than "on the way out" (around 150 ns), because the PRC clock has had to be regenerated in several nodes. Note that a clock-pulse period is 488 ns, so the accumulated phase drift in the clock is several clock periods (Unit Intervals, UI) measured "on the way home".

The MTIE curve for the regenerated clock "on the way home" can be seen in Figure 8.

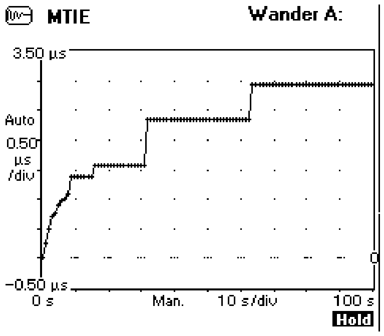


Figure 8. ***The MTIE curve for the clock with the longest transport route in accordance with Figure 7***

Conclusions

A Wandermeter such as the WM-11 from Pendulum Instruments is an excellent tool for assessing the clock's quality in SDH networks. By performing measurements in successive nodes one can follow the way the quality changes via the TIE and MTIE curves. By making comparisons with standardised ETSI masks one can get a black-and-white picture as to whether or not an item of synchronisation equipment (SSU or SEC) meets the demands in accordance with ITU and ETSI. The WM-11 in Figure 9 is an easy-to-use portable Wandermeter which through its built-in display provides clear feedback of the quality of the synchronisation clock.

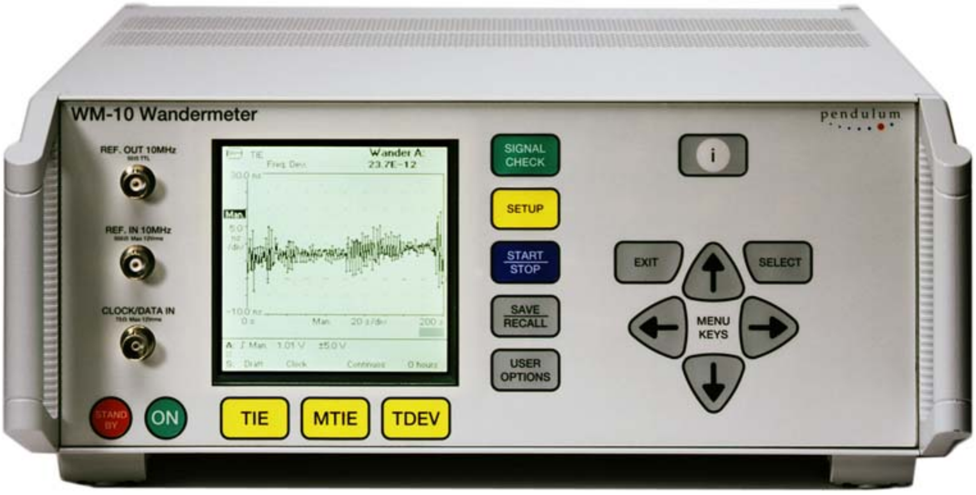


Figure 9. The WM-11 Wandermeter from Pendulum Instruments AB

The instrument is easy to calibrate and adjust. You just need to connect it up to a frequency reference with a GPS-controlled rubidium oscillator and leave the instrument overnight, then the built-in rubidium clock will automatically have set itself precisely.