Appendix J: Telecom Technology

Basic SDH Signal

The basic format of an SDH signal allows it to carry many different services in its Virtual Container (VC) because it is bandwidth flex-ible. This capability will allow for such things as the transmission of high speed, packet switched services, ATM, contribution video and distribution video. However, SDH still permits transport and networking at the 2 Mbit/s, 34 Mbit/s and 140 Mbit/s levels, accommodating the existing digital hierarchy signals. In addition, SDH supports the transport of signals based on the 1.5 Mbit/s hierarchy.

CTS850 Test Set, SDH/PDH

Transmission hierarchies

The following tables compare the Non synchronous and Synchronous transmission hierarchies.

Table J 1. Non Synchronous Hierarchy

Signal	Digital Bit Rate	Channels
64 kbit/s	64 kbit/s	One 64 kbit/s
E1	2.048 Mbit/s	32 E0
E2	8.448 Mbit/s	128 E0
E3	34.368 Mbit/s	16 E1
E4	139.264 Mbit/s	64 E1

Table J 2. SDH Hierarchy

Bit Rate	Abbr.	SDH	SDH Capacity
51.840 Mbit/s	51 Mbit/s	STM 0	21 E1
155.520 Mbit/s	155 Mbit/s	STM 1	63 E1 or 1 E4
622.080 Mbit/s	622 Mbit/s	STM 4	252 E1 or 4 E4
2488.320 Mbit/s	2.4 Gbit/s	STM 16	1008 E1 or 16 E4
9953.280 Mbit/s	10 Gbit/s	STM 64	4032 E1 or 64 E4

STM = Synchronous Transport Module

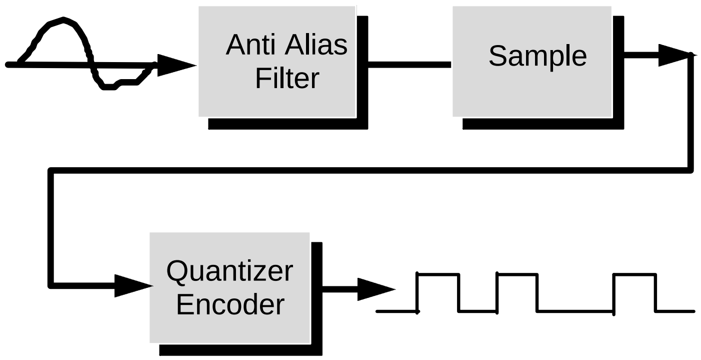
PDH Basics

Plesiochronous Data Hierarchy (PDH) is a telecommunications transmission technology, implemented thirty years ago, based on PCM (Pulse Code Modulation) and TDM (time division multiplexing).

PDH is tailored to voice communication; has dedicated bandwidth for each voice channel and a fixed channel assignment. PDH is worldwide compatible only at the 64 kbit/s digitized voice level.

Pulse Code Modulation (PCM)

In the early 1970’s, digital transmission began to appear in the world’s telephone network, utilizing a method known as Pulse Code Modulation. PCM allowed analogue waveforms, such as the human voice, to be represented in binary form. Using this PCM method, it was possible to represent a standard 4 kHz analogue telephone signal as a 64 kbit/s digital bit stream.



8,000 samples/second x 8 bits/sample =
64 kb/s digital bit stream (one timeslot)

Figure J 1: Pulse Code Modulation

Engineers saw the potential to produce more cost effective transmission systems by combining several PCM channels and transmitting them down the same copper twisted pair as had previously been occupied by a single analogue signal.

The method used to combine multiple 64 kbit/s channels into a single high speed bit stream is known as Time Division Multiplexing (TDM). In simple terms, a byte from each incoming channel is transmitted in turn down the outgoing high speed channel. This process is sometimes referred to as ”sequential byte interleaving.”

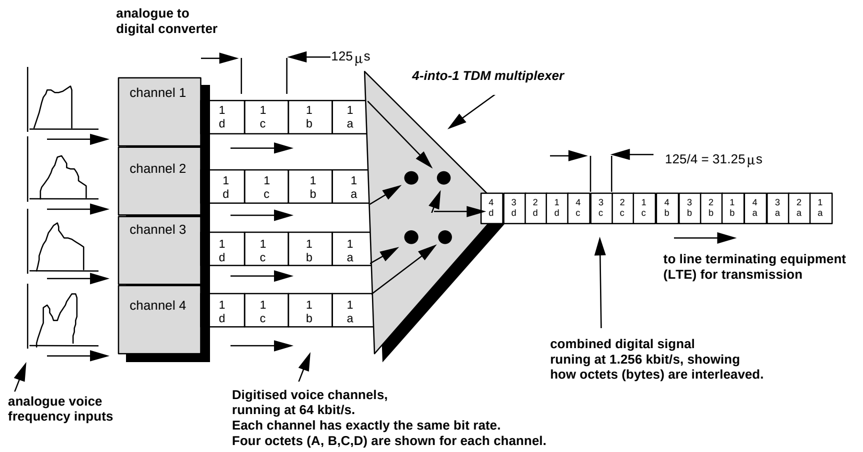


Figure J 2: Time Division Multiplexing

In Europe, and other parts of the world, a standard TDM scheme was adopted where thirty 64 kbit/s channels were combined, together with two additional channels carrying control information, to produce a channel with a bit rate of 2.048 Mb/s.

As demand for voice telephony increased, and levels of traffic in the network grew, it became clear that the standard 2 Mb/s signal was not sufficient to cope with the traffic loads occurring in the trunk network. In order to avoid having to use excessively large numbers of 2 Mb/s links, it was decided to create a further level of multiplexing. The standard adopted in Europe involved the combination of four 2 Mb/s channels to produce a single 8 Mb/s channel. This level of multiplexing differed slightly for the previous in that the incoming signals were combined one bit at a time, instead of one byte at a time, that is, bit interleaving was used instead of byte interleaving.

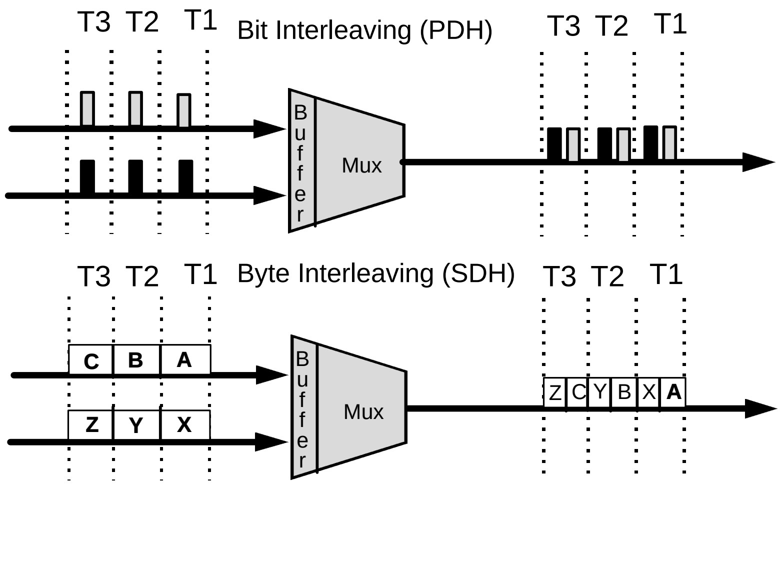


Figure J 3: Bit & Byte Interleaving

As the need arose, further levels of multiplexing were added to the PDH standard at 34 Mb/s, 140 Mb/s and 565 Mb/s to produce a full hierarchy of bit rates.

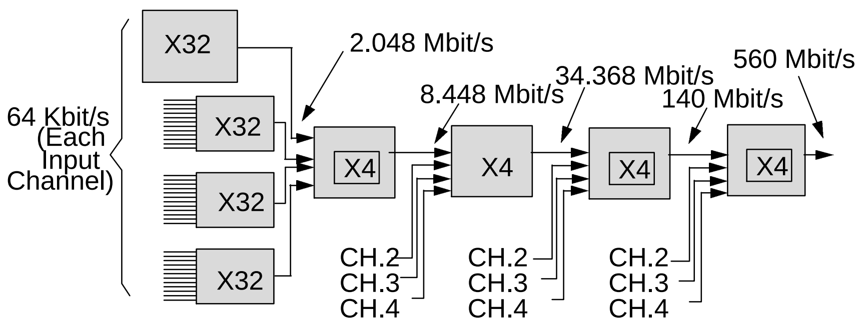


Figure J 4: Higher Order Multiplexing Hierarchy

Asynchronous Multiplexing

Traditionally, transmission systems have been asynchronous, with each terminal in the network running on its own recovered clock timing. In digital transmission, ”timing” is one of the most fundamental operations.

Since these clocks are not synchronised, large variations can occur in the clock rate and thus the signal bit rate. For example, a E3 signal specified at 34 Mbit/s ± 20 ppm (parts per million) can produce a timing difference of up to 1789 bit/s between one incoming E3 signal and another.

Asynchronous multiplexing uses multiple stages. Signals such as asynchronous E1s (2 Mbit/s) are multiplexed (bit interleaving), extra bits are added (bit stuffing) to account for the variations of each individual stream and are combined with other bits (framing bits) to form an E2 (8 Mbit/s) stream. Bit interleaving and bit stuffing is used again to multiplex up to E3 (34 Mbit/s). The E1s are neither visible nor accessible within an E3 frame. E3s are multiplexed up to higher rates in the same manner. At the higher asynchronous rate, they cannot be accessed without demultiplexing.

In a synchronous system, such as SDH, the average frequency of all clocks in the system will be the same. Every slave clock can be traced back to a highly stable reference clock. Thus, the STM 1 rate remains at a nominal 155.52 Mbit/s, allowing many synchronous STM 1 signals to be multiplexed without any bit stuffing. Thus, the STM 1s are easily accessed at a higher STM–N rate.

Low speed synchronous virtual container (VC) signals are also simple to interleave and transport at higher rates. At low speeds, 2.048 Mbit/s E1 signals are transported within synchronous VC 12 signals which run at a constant rate of 2.304 Mbit/s. Single step multiplexing up to STM 1 requires no bit stuffing and VCs are easily accessed.

A mechanism known as ”pointers” accommodates differences in the reference source frequencies and phase wander, and so prevents data loss during synchronisation failures.

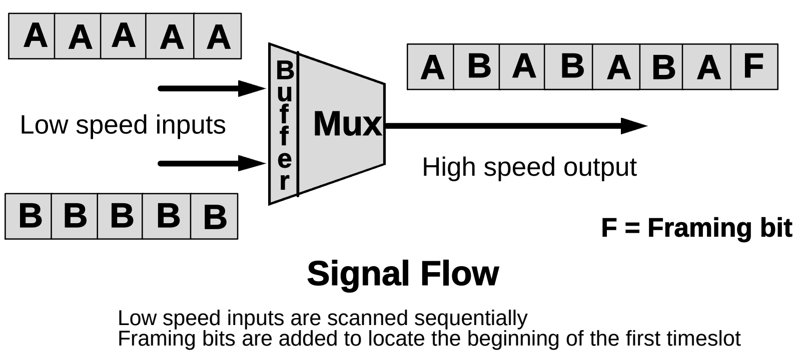
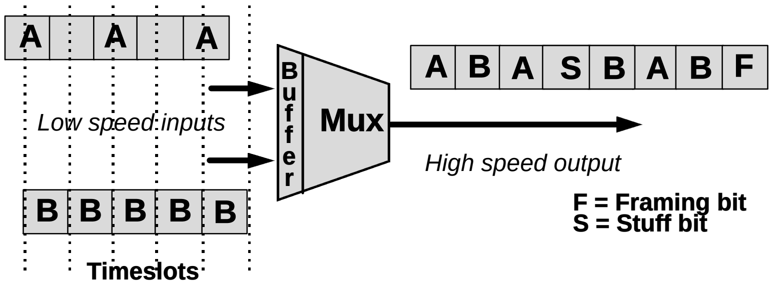


Figure J 5: Multiplexing and Digital Transmission



Asynchronous Multiplexing is designed to accommodate timing differences in low speed speed signals. Sometimes input timeslots are not available for multiplexing; the input timeslot is filled with a “stuff” bit. Control bits are used to indicate this condition (not shown).

Figure J 6: Asynchronous Multiplexing

PDH Multiplexing

Traditionally, digital transmission systems and hierarchies have been based on multiplexing signals which are plesiochronous (running at almost the same speed). Also, various parts of the world use different hierarchies which lead to problems of international interworking, for example, between those countries using 1.544 Mbit/s systems (U.S.A. and Japan) and those using the 2.048 Mbit/s system.

In the PDH, tributaries and higher order bit streams are allowed to deviate from a pre defined bit rate by a specified amount. The justification (bit stuffing) process is required which brings all the tributaries up to the same bit rate before multiplexing takes place. However, the justification method makes it impossible to identify the location of specific tributary channels within a higher order bit stream, without demultiplexing back down to the 2 Mb/s tributaries.

To recover a 64 kbit/s channel from a 140 Mbit/s PDH signal, it is necessary to demultiplex the signal all the way down to the 2 Mbit/s level before the location of the 64 kbit/s channel can be identified. PDH requires "steps" (140 34, 34 8, 8 2 demultiplex; 2 8, 8 34, 34 140 multiplex) to drop out or add an individual speech or data channel. This is due to the bit stuffing used at each level. Extra bits are added (stuffed) in to the digital tributaries which increases the speed of the tributaries until they are all identical.

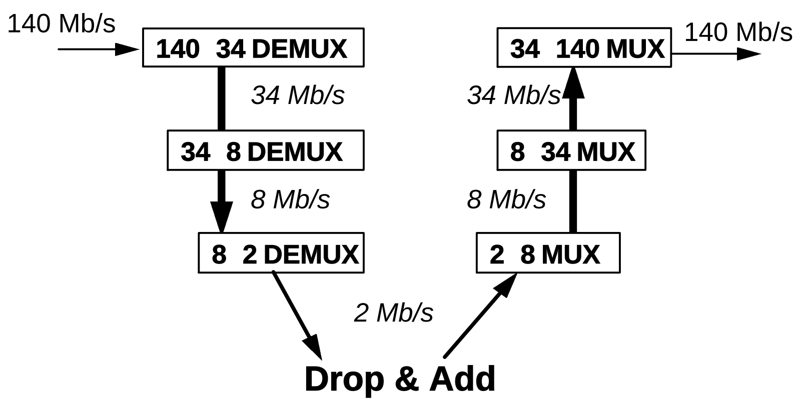


Figure J 7: PDH Multiplexing by steps showing add/drop function

G.826, M.2101.1, M.2100, and G.821 Analysis

G.826 Error Performance By monitoring Severly Errored Seconds (SES) events for both directions at a single path end point, a network provider is able to determine the unavailable state of the path. This service measure is intended for in service quality measurements of 2 Mb/s and above (including SDH rates). G.826 uses block based measurements, that is, multiple errors in a block are counted as one block error.

PDH G.826 is based on frame and CRC errors and is an in service measurement. G.826 makes use of block based measurements to get media independent results and thus is more convenient for in service measurement.

M.2101.1 This ITU T provides limits for bringing into service (BIS), and limits for maintenance of international SDH paths and international SDH multiplex sections in order to achieve the performance objectives given for a multiservice environment. These objectives include error performance (Recommendation G.826) and unavailability (Recommendation G.827).

M.2100 This measure of service quality is similar to G.821 in that is uses bit based error measurement. M.2100 combines all error sources during a one (1) errored second count without regard to source (for example, FAS, CRC 4, Code violation, etc.). Out of service measurements use a PRBS pattern, and count bit errors as well as frame related in service error types (for example, FAS, CRC 4). In service measurements count frame related in service error types only (FAS, CRC 4).

G.821 analysis is based on pattern bit errors occurring within the payload of an SDH or PDH rate signal. Bit based measurements are made on the payload with a PRBS pattern. G.821 is an out of service measurement since the normal traffic payload is replaced by a test pattern.

G.821 Service Quality (PDH/SDH)

The G.821 standard was originally intended to measure 64 kbit/s circuits. Extrapolation is necessary for higher PDH rates (8 Mb/s, 34 Mb/s, and 140 Mb/s). Bit based measurements are made on the payload with a PRBS pattern.

Service quality, per the G.821 ITU T standard involves the following error categories:

- Errored Seconds (ES) a count of seconds which had at least one error during a period of availability;
- Severely Errored Seconds (SES) Number of seconds with a Bit Error Rate (BER) worse than 1 x 10^{3};
- Unavailable Seconds (UAS) Unavailable seconds start counting after ten contiguous SES;
- Degraded Minutes (DM) A count of the number of minutes where the BER is worse than 1 x 10^{6} and better than 1 x 10^{3}; and,
- Error Free Seconds (EFS) Number of seconds that contained no errors.

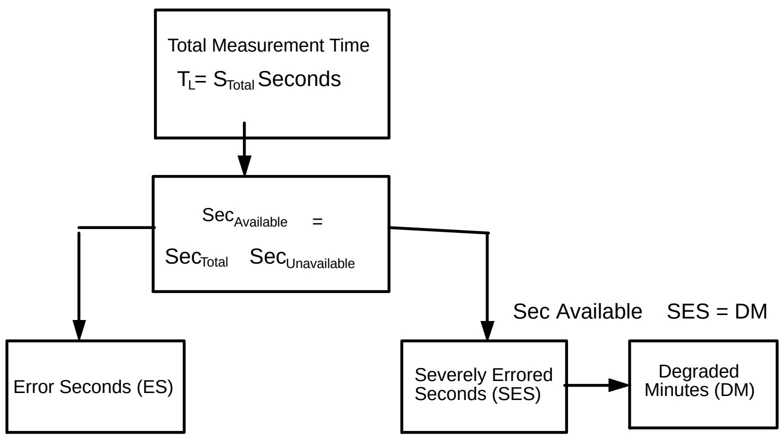


Figure J 8: Guaranteeing G.821 Service Quality

M.2100 Service Quality (PDH)

This measure of service quality is similar to G.821 in that is used bit based error measurement, however it also specifies availability limits. M.2100 combines all error sources during a one (1) errored second count without regard to source (for example, FAS, CRC 4, Code violation, etc.). Out of service measurements use a PRBS pattern, and count bit errors as well as frame related in service error types (for example, FAS, CRC 4). In service measurements count frame related in service error types only (FAS, CRC 4).

G.826 Service Quality (PDH/SDH)

This service measure is intended for in service quality measurements of 2 Mb/s and above (including SDH rates). G.826 uses block based measurements, that is, multiple errors in a block are counted as one block error. CRC error checks (for PDH) and BIP n (for SDH) are utilized by G.826.

G.826 Error Events are:

- Errored Block A block in which one or more bits are errored.
- Errored Seconds (ES) A one second interval containing one or more errored block(s).
- Severely Errored Seconds (SES) A one second interval containing at least 30% errored blocks or a defect.
- Background Block Error (BBE) An errored block which does not belong to a SES.

G.826 Relative Error parameters (only measured during availability) are:

- Errored Second Ratio The ratio of errored seconds to the total number of seconds in the measurement interval.
- Severely Errored Seconds Ratio (SESR) The ratio of severely errored seconds to the total number of seconds in the measurement interval.
- Background Block Error Ratio (BBER) The ratio of errored blocks not belonging to a SES to the total number of blocks in the measurement interval.

Error Counts (PDH/SDH)

Error counts are used to determine if the circuit is basically working. Every error is counted. Every second with an error is counted. This measure is used to derive the Bit Error Rate (BER).

Error analysis is used for formal performance testing. It is also used to determine who or what in the network is at fault. Error counts/ error seconds are not counted during ”unavailable” time. A circuit is declared ”unavailable” when there are ten consecutive ES. A circuit is declared as ”available” when there are ten consecutive error free seconds.

Jitter & Wander Tutorial

Timing & sync working together in the Network?

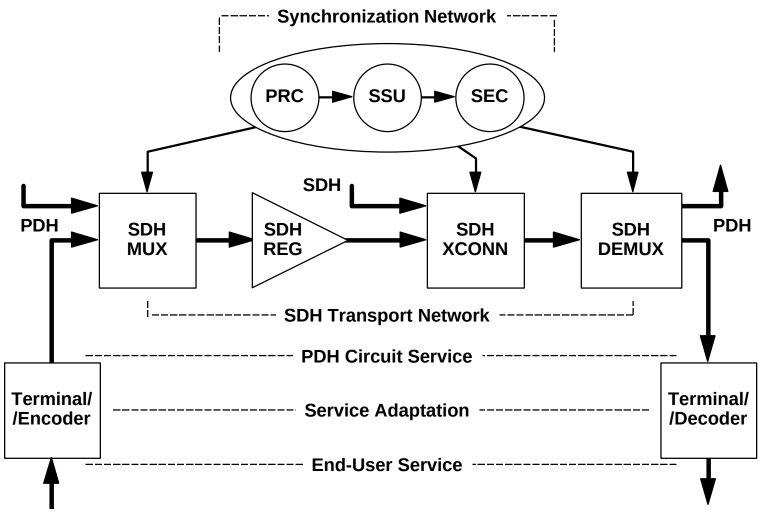
Summary As little as one or two years ago, network synchronisation was something invisible. It worked and the PDH technology was mature and stable. Now the technology has become unstable and timing/sync has become the first point of contention between inter connected operators.

Telecommunication networks transport two entities data and timing as part of a service. As a result, timing has always been very carefully specified, controlled and distributed within networks, across network interfaces and between customers.

To deliver the timing part of the service, the network must be properly synchronised. Good synchronisation is the foundation of Convergence (integrated voice, video and data services). Without management of timing and synchronisation, Convergence just cannot happen. Tektronix is pioneering new measurement methods, particularly in the area of jitter and wander, that can help to establish timing quality parameters.

The new SDH equipment being installed in public networks around the world represents a quantum leap in performance, management and flexibility for network operators. However, the behavior of a working SDH (and/or SONET) network is very different from today's existing PDH networks, something that is being more widely recognised as new networks continue their expansion.

As a consequence, timing and synchronisation are of strategic importance to network operators as they work in the new deregulated environment of the 1990's.



PRC = Primary Reference Clock
SEC Synchronous Equipment Clock
SSU = Synchronization Supply Unit

Figure J 9: Simple SDH/PDH network model

In the figure above, a PDH circuit is transported over an SDH path, while being multiplexed with other PDH circuits, cross connected with other SDH payloads and regenerated. The model network is synchronized from a logically separate sync network, although it is likely that sync signals will be physically carried on parts of the SDH network.

In the figure above, the middle cross connect (SDH XCONN) takes several AU 4 payloads from its inputs and generates a new aggregate output signal. The timing of its outgoing STM N signal is determined by a separate synchronization reference signal from the sync network.

Jitter & Wander in the Network

Jitter is defined as the *short term*, and wander is defined as the *long term,* variations of the significant instants of a digital signal from their ideal positions in time

Jitter and wander have both an amplitude (how much the signal is shifting in phase), and a frequency (how quickly the signal is shifting in phase). Jitter is defined in the ITU T G.810 standard as phase variation with frequency components greater than or equal to 10 Hz. Wander is defined as phase variations at a rate less than 10 Hz.

PDH Network Systems

In an asynchronous system, timing is derived by phase locked loops that track the slow phase variations (the wander), so wander is not seen by the system. The jitter component of the phase, which is not tracked, reduces the operating margins of the system. Therefore in an asynchronous system, jitter is the main parameter of interest.

SDH Network Systems

In a synchronous system, such as the Synchronous Digital Hierarchy (SDH), both jitter and wander are of interest. There are still phase locked loops for clock recovery which are sensitive to jitter. But there are also First In, First Out (FIFO) data buffers that are sensitive to wander. These FIFOs operate open loop, depending on inherent synchronisation between the write clock and the read clock. Therefore a key parameter of interest is the variation of phase from 10 Hz all the way down to dc, i.e., wander.

Consequences in the Network

There are four major consequences of excessive jitter on a received signal:

Bit errors can be produced because decision logic circuits do not operate at the optimum time. At high jitter frequencies, the clock recovery circuitry can no longer keep up with the rapid phase changes of the incoming signal. And when the recovered clock gets out of step with the incoming signal by more than 0.5 UI, the signal bit is incorrectly sampled and may cause an error.

Data can be lost because input buffers can either become empty (too little data being received) or overflow (too much data), causing frame slips, data loss or data repetition resulting in Severely Errored Seconds (SES) and other defects. Particularly at low jitter frequencies, jitter amplitude can become extremely large (and is theoretically unbounded). The consequences of interconnecting and meshing new synchronous networks together is still largely uncharacterised.

If the SDH (SONET) transport is carrying a coded analogue signal, degradation will occur when the analogue signal is reconstructed after it has been demapped from the SDH payload. Jitter on the output digital signal directly causes unwanted phase modulation of the analogue signal. This is not normally a problem with voice and data services, but can be a significant degradation for digitized TV signals which depend on maintaining good low frequency phase information within tight specifications.

In new hybrid SDH/PDH networks, a major cause of payload jitter is upstream wander. This wander forces pointer adjustments, which jitter the payload, which leads to FIFO slips. These slips prompt Severely Errored Seconds (SES), which force a retransmission of the data, tying up the circuit, and preventing the circuit from earning additional revenue.

Principles & Metrics of Jitter and Wander

Jitter and wander are defined respectively as “the *short term* and the *long term* variations of the significant instants of a digital signal from their ideal positions in time”. One way to think of this is a digital signal continually varying its position in time by moving backwards and forwards with respect to an ideal clock source. Most engineers’ first introduction to jitter is viewed on an oscilloscope (Figure J 10). When triggered from a stable reference clock, jittered data is clearly seen to be moving in relation to a reference clock.

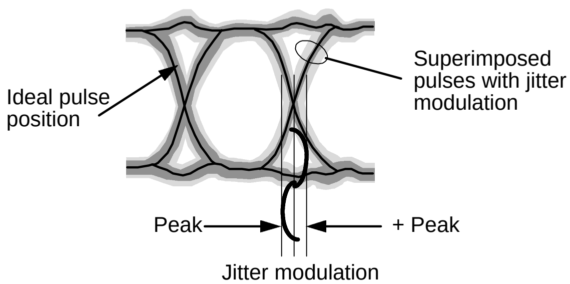


Figure J 10: Jitter as viewed on an oscilloscope

In fact, jitter and wander on a data signal are equivalent to a phase modulation of the clock signal used to generate the data (Figure J 11). Naturally, in a practical situation, jitter will be composed of a broad range of frequencies at different amplitudes.

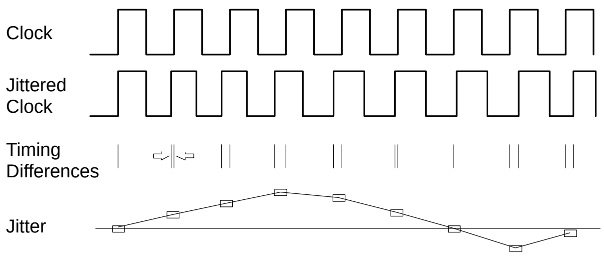


Figure J 11: Phase variation between two signals

Jitter and wander have both an amplitude: how much the signal is shifting in phase and a frequency: how quickly the signal is shifting in phase. Jitter is defined in the ITU T G.810 standard as phase variation with frequency components greater than or equal to 10 Hz whilst wander is defined as phase variations at a rate less than 10 Hz (Figure J 12).

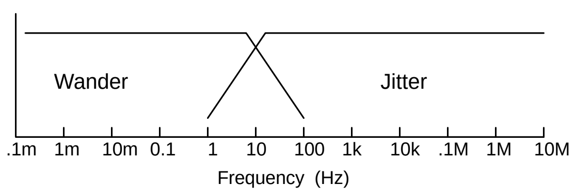


Figure J 12: Frequency ranges of jitter & wander (ref. G.810)

When measuring jitter or wander, always be sure what the reference clock is. By definition, a signal has no phase variation when referenced to itself jitter or wander always refers to a difference between one timed signal and another.

Metrics for Jitter

Jitter is normally specified and measured as a maximum phase amplitude within one or more measurement bandwidths. A single interface may be specified using several different bandwidths since the effect of jitter varies depending on its frequency, as well as its amplitude.

UI (Unit Intervals)

Jitter amplitude is specified in Unit Intervals (UI), such that one UI of jitter is equal to one data bit width, irrespective of the data rate. For example, at a data rate of 2048 kbit/s, one UI is equivalent to 488 ns, whereas at a data rate of 155.52 Mbit/s, one UI is equivalent to 6.4 ns.

Jitter amplitude is normally quantified as a Peak to Peak value rather than an RMS value, since it is the peak jitter that would cause a bit error to be made in network equipment.

However, RMS values are useful for characterising or modelling jitter accumulation in long line systems using SDH regenerators, for example, and the appropriate specifications use this metric instead of Peak to Peak.

Metrics for Wander

A wander measurement requires a “wander free” reference, relative to which the wander of another signal is measured. Any Primary Reference Clock (PRC) can serve as a reference because of its long term accuracy (10^{-11} or better) and good short term stability. A PRC is usually realised with a caesium based clock, although it may also be realised using GPS technology.

Because it involves low frequencies with long periods, wander data can consist of hours of phase information. However, because phase transients are of importance, high temporal resolution is also needed. So to provide a concise measure of synchronisation quality, three wander parameters have been defined and are used to specify performance limits:

- TIE: Time Interval Error (wander in ns)
- MTIE: Maximum Time Interval Error (related to Peak to Peakwander)
- TDEV: Time Deviation (related to rms wander)

Formal mathematical definitions of these and other parameters can be found in ITU T G.810 standard.

TIE (Time Interval Error)

TIE is defined as the phase difference between the signal being measured and the reference clock, typically measured in ns. TIE is conventionally set to zero at the start of the total measurement period *T*. Therefore TIE gives the phase change since the measurement began. An example is given in Figure J 13. The increasing trend shown is due to a frequency offset of about 1 ns per 10 s, or 10^{-10} in this case.

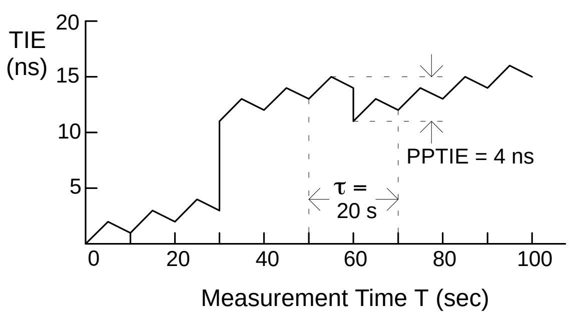


Figure J 13: Example of TIE wander measurement

MTIE (Maximum Time Interval Error)

MTIE is a measure of wander that characterises frequency offsets and phase transients. It is a function of a parameter τ called the *Observation Interval*. The definition (Figure J 14) is:

MTIE(τ) is the largest Peak to PeakTIE (i.e.,. wander) in any observation interval of length τ.

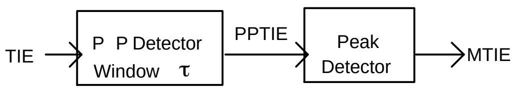


Figure J 14: Functional definition of MTIE

In order to calculate MTIE at a certain observation interval τ from the measurement of TIE, a time window of length τ is moved across the entire duration of TIE data, storing the peak value. The peak value is the MTIE(τ) at that particular τ. This process is repeated for each value of τ desired.

For example, Figure J 13 shows a window of length τ=20 sec at a particular position. The Peak to PeakTIE for that window is 4 ns. However, as the 20 sec window is slid through the entire measurement period, the largest value of ppTIE is actually 11 ns (at about 30 sec into the measurement). Therefore MTIE(20 s) = 11 ns.

The next figure J 15 shows the complete plot of MTIE(τ) corresponding to the plot of TIE in Figure J 13. The rapid 8 ns transient at *t* = 30 s is reflected in the value MTIE(τ) = 8 ns for very small τ.

It should be noted that the MTIE plot is monotonically increasing with observation interval and that the largest transient masks events of lesser amplitude.

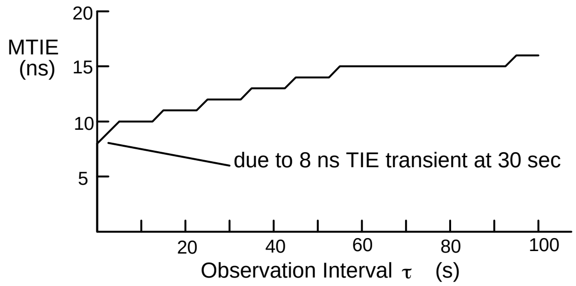


Figure J 15: Example of MTIE wander measurement (corresponding to Figure J 13)

TDEV (Time Deviation)

TDEV is a measure of wander that characterises its spectral content. It is also a function of the parameter τ called *Observation Interval.* The definition (Figure J 16) is:

TDEV(τ) is the rms of filtered TIE, where the bandpass filter (BPF) is centred on a frequency of 0.42/τ.

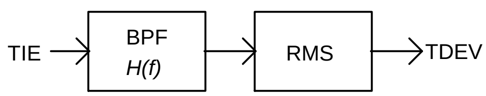


Figure J 16: Functional definition of TDEV

Figure J 17 shows two plots of TDEV(τ). The first plot (for *T*=100s), corresponding to the TIE data of Figure J 13 shows TDEV rising with τ. This is because, for the short measurement period *T*=100s, the two transients in 5 dominate.

If we were to make a longer TIE measurement out to *T* = 250s, the effect of the two transients on TDEV would become less, assuming there are no more transients. The TDEV characteristic labelled *T*=250 s would be the result.

It should also be noted that TDEV is insensitive to constant phase slope (frequency offset).

To calculate TDEV for a particular τ, the overall measurement period *T* must be at least 3τ. For an *accurate* measure of TDEV, a measurement period of at least 12τ is required. This is because the rms part of the TDEV calculation requires sufficient time to get a good statistical average.

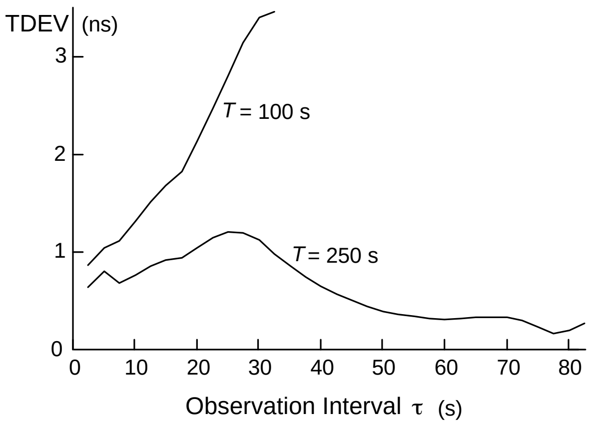


Figure J 17: Example of TDEV wander measurement (corresponding to Figure J 13)

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