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DIGITAL SYSTEMS AND NETWORKS

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The control of jitter and wander within the optical transport network (OTN)

Recommendation ITU-T G.8251



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Recommendation ITU-T G.8251

The control of jitter and wander within the optical transport network (OTN)

Summary

Recommendation ITU-T G.8251 specifies the maximum network limits of jitter and wander that shall not be exceeded and the minimum equipment tolerance to jitter and wander that shall be provided at any relevant interfaces which are based on the optical transport network (OTN).

The requirements for the jitter and wander characteristics that are specified in this Recommendation must be adhered to in order to ensure interoperability of equipment produced by different manufacturers and a satisfactory network performance.

History

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The World Telecommunication Standardization Assembly (WTSA), which meets every four years, establishes the topics for study by the ITU-T study groups which, in turn, produce Recommendations on these topics.

The approval of ITU-T Recommendations is covered by the procedure laid down in WTSA Resolution 1.

In some areas of information technology which fall within ITU-T's purview, the necessary standards are prepared on a collaborative basis with ISO and IEC.

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As of the date of approval of this Recommendation, ITU had not received notice of intellectual property, protected by patents, which may be required to implement this Recommendation. However, implementers are cautioned that this may not represent the latest information and are therefore strongly urged to consult the TSB patent database at <http://www.itu.int/ITU-T/ipr/>.

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Introduction

In an optical transport network (OTN), jitter and wander accumulate on transmission paths according to the jitter and wander generation and transfer characteristics of each respective equipment interconnected. This equipment may be, for example, 3R regenerators, client mappers, and client demappers/desynchronizers.

An excessive amount of jitter and wander can adversely affect both digital (e.g., by generation of bit errors, frame slips and other abnormalities) and analogue baseband signals (e.g., by unwanted phase modulation of the transmitted signal). The consequences of such impairment will, in general, depend on the particular service that is being carried and the terminating or adaptation equipment involved.

It is therefore necessary to set limits on the maximum magnitude of jitter and wander, and the corresponding minimum jitter and wander tolerance at network interfaces, in order to guarantee a proper quality of the transmitted signals and a proper design of the equipment.

These network limits are independent of the particular service that is being carried.

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Recommendation ITU-T G.8251

The control of jitter and wander within the optical transport network (OTN)

1 Scope

The scope of this Recommendation is to define the parameters and the relevant limits that satisfactorily control the amount of jitter and wander present at the OTN network-node interface (NNI).

OTN network interfaces, to which this Recommendation is applicable, are defined in terms of bit rates and frame structures in [ITU-T G.709]; the relevant equipment characteristics are described in [ITU-T G.798] and the optical characteristics in [ITU-T G.959.1] or [ITU-T G.693]. Additional information regarding the architecture of the OTN is found in [ITU-T G.872].

The network limits given in clause 5, OTN interface tolerance specifications given in clause 6.1, and OTN equipment interface specifications given in Annex A apply at or refer to the OTU_k interface. The relevant bit rates for these specifications are the OTU_k bit rates. Note that some of the other requirements in this Recommendation, e.g., the demapper clock (ODC_p), asynchronous mapper clock (ODC_a), and bit-synchronous mapper clock (ODC_b) requirements in Annex A, apply to other interfaces and other bit rates (i.e., the demapper resides in the sink adaptation function between the ODU_kP and CBR, ODU_j[/i] or ODU_kP/ODU_j_A client, while the asynchronous and bit-synchronous mapper clocks reside in the source adaptation function between the ODU_kP and client). In this Recommendation the term 'clock', when used in ODU clock (ODC), refers to a frequency source. Note that this Recommendation contains requirements for both non-OTN CBR_x clients mapped into ODU_k and ODU_j[/i] clients multiplexed into ODU_k ($k > j$).

The OTN physical layer is not required to transport network synchronization. More precisely, neither the ODU_k nor any layers below it are required to transport synchronization. Network synchronization distribution is a function of the client layer, e.g., SDH.

[ITU-T G.825] specifies the jitter and wander requirements for SDH clients, and any SDH signal (which must meet [ITU-T G.825]) is suitable for providing synchronization (see [ITU-T G.803]). SDH clients must meet [ITU-T G.825] requirements for both asynchronous and bit-synchronous mappings.

[ITU-T G.8261] specifies the jitter and wander requirements of synchronous Ethernet for providing synchronization (see Annex D of [ITU-T G.8261]). Synchronous Ethernet clients must meet [ITU-T G.8261] requirements for both GMP and bit-synchronous mappings.

Jitter and wander requirements for SDH networks are specified in [ITU-T G.825]. Jitter and wander requirements for PDH and synchronization networks are specified in [ITU-T G.823], for networks based on the first level bit rate of 2048 kbit/s, and in [ITU-T G.824] for networks based on the first-level bit rate of 1544 kbit/s.

The jitter and wander control philosophy is based on the need:

- to recommend a maximum network limit that should not be exceeded at any relevant OTN NNI;
- to recommend a consistent framework for the specification of individual digital equipment (i.e., jitter and wander transfer, tolerance and generation requirements);
- to provide sufficient information and guidelines for organizations to measure and study jitter and wander accumulation in any network configuration.

Note that there may exist hybrid network element (NE) types that contain SDH, Ethernet, and/or OTN atomic functions. For such hybrid NEs, it may not be possible to access the respective ports to make measurements to verify compliance with the requirements in this Recommendation. Measurements to verify compliance for hybrid NE types is outside the scope of this Recommendation.

2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

- [ITU-T G.693] Recommendation ITU-T G.693 (2006), *Optical interfaces for intra-office systems*.
- [ITU-T G.707] Recommendation ITU-T G.707/Y.1322 (2000), *Network node interface for the synchronous digital hierarchy (SDH)*.
- [ITU-T G.709] Recommendation ITU-T G.709/Y.1331 (2009), *Interfaces for the optical transport network (OTN), including its Amendment 1 (2010)*.
- [ITU-T G.783] Recommendation ITU-T G.783 (2006), *Characteristics of synchronous digital hierarchy (SDH) equipment functional blocks, including its amendments*.
- [ITU-T G.798] Recommendation ITU-T G.798 (2010), *Characteristics of optical transport network hierarchy equipment functional blocks*.
- [ITU-T G.803] Recommendation ITU-T G.803 (2000), *Architecture of transport networks based on the synchronous digital hierarchy (SDH)*.
- [ITU-T G.810] Recommendation ITU-T G.810 (1996), *Definitions and terminology for synchronization networks*.
- [ITU-T G.811] Recommendation ITU-T G.811 (1997), *Timing characteristics of primary reference clocks*.
- [ITU-T G.813] Recommendation ITU-T G.813 (2003), *Timing characteristics of SDH equipment slave clocks (SEC)*.
- [ITU-T G.823] Recommendation ITU-T G.823 (2000), *The control of jitter and wander within digital networks which are based on the 2048 kbit/s hierarchy*.
- [ITU-T G.824] Recommendation ITU-T G.824 (2000), *The control of jitter and wander within digital networks which are based on the 1544 kbit/s hierarchy*.
- [ITU-T G.825] Recommendation ITU-T G.825 (2000), *The control of jitter and wander within digital networks which are based on the synchronous digital hierarchy (SDH), including its Amendment 1 (2008)*.
- [ITU-T G.872] Recommendation ITU-T G.872 (2001), *Architecture of optical transport networks*.

- [ITU-T G.959.1] Recommendation ITU-T G.959.1 (2009), *Optical transport network physical layer interfaces*.
- [ITU-T G.8261] Recommendation ITU-T G.8261/Y.1361 (2008), *Timing and synchronization aspects in packet networks*.
- [IEEE 802.3] IEEE Std. 802.3-2008, *Information Technology – Local and Metropolitan Area Networks – Part 3: Carrier Sense Multiple Access with Collision Detection (CSMA/CD) Access Method and Physical Layer Specifications*.
- [IEEE 802.3ba] IEEE Std. 802.3ba-2010, *Information Technology – Local and Metropolitan Area Networks – Part 3: Carrier Sense Multiple Access with Collision Detection (CSMA/CD) Access Method and Physical Layer Specifications – Amendment 4: Media Access Control Parameters, Physical Layers and Management Parameters for 40 Gb/s and 100 Gb/s Operation*.

3 Definitions

The terms and definitions used in this Recommendation that pertain to timing and jitter are contained in [ITU-T G.810] and [ITU-T G.825]. The terms and definitions used in this Recommendation that pertain to the OTN are contained in [ITU-T G.709], [ITU-T G.798] and [ITU-T G.872]. The terms and definitions used in this Recommendation that pertain to SDH are contained in [ITU-T G.707], [ITU-T G.783] and [ITU-T G.803].

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations:

3R	Reamplification, Reshaping, and Retiming
A	Adaptation
AI	Adapted Information
AIS	Alarm Indication Signal
AMP	Asynchronous Mapping Procedure
AP	Access Point
CBR	Constant Bit Rate
CI	Characteristic Information
CK	Clock
CP	Connection Point
D	Data
EEC	synchronous Ethernet Equipment Clock
FC-x	Fibre Channel of rate x
FEC	Forward Error Correction
GMP	Generic Mapping Procedure
HRM	Hypothetical Reference Model
MC	Master Clock
MTIE	Maximum Time Interval Error

NE	Network Element
NNI	Network-Node Interface
OA	Optical Amplifier
OCh	Optical Channel with full functionality
OChr	Optical Channel with reduced functionality
OCI	Open Connection Indication
ODC	ODUk Clock
ODCx	ODUk Clock of type "x", where x is "a", "b", "r", or "p"
ODU	Optical channel Data Unit
ODUk	Optical channel Data Unit-k
ODUkP	ODUk Path
ODUkT	ODUk Tandem connection
OTL	Optical channel Transport Lane
OMS	Optical Multiplex Section
OPSM	Optical Physical Section Multilane
OPU	Optical channel Payload Unit
OPUk	Optical channel Payload Unit-k
OTM	Optical Transport Module
OTN	Optical Transport Network
OTS	Optical Transmission Section
OTU	Optical channel Transport Unit
OTUk	completely standardized Optical channel Transport Unit-k
PDH	Plesiochronous Digital Hierarchy
PI	Proportional plus Integral
PLL	Phase-Locked Loop
PMD	Polarization Mode Dispersion
ppm	parts per million
PRBS	Pseudo-Random Binary Sequence
PRC	Primary Reference Clock
PSD	Power Spectral Density
rms	root mean square
RS	Reed-Solomon
SDH	Synchronous Digital Hierarchy
SEC	SDH Equipment Clock
Sk	Sink

So	Source
SSU	Synchronization Supply Unit
STM	Synchronous Transport Module
STM-N	Synchronous Transport Module – level N
TCP	Termination Connection Point
TDEV	Time Deviation
TVAR	Time Variance
UI	Unit Interval
UIpp	Unit Interval peak-to-peak
UTC	Coordinated Universal Time
VCO	Voltage-Controlled Oscillator
WFM	White Frequency Modulation
WPM	White Phase Modulation

5 Network limits for the maximum output jitter and wander at an OTUk interface

The jitter and wander limits given in this clause are the maximum permissible levels at OTUk interfaces within an OTN. The OTUk interface is just below the OCh/OTUk adaptation function in Figure 1-3 of [ITU-T G.798]. One example of this interface is the input to a 3R regenerator (sink) or output from a 3R regenerator (source).

NOTE – The OTUk is precisely defined in [ITU-T G.709]; essentially, it is the digital signal that is mapped into the Optical Channel (OCh). The OTUk bit rate is essentially the line rate associated with the OCh and respective wavelength that the OCh is assigned to. The OTUk bit rates are given in Table 7-1 of [ITU-T G.709], and are equal to the inverses of the bit periods given in Table 5.1-1.

5.1 Network limits for jitter

Table 5.1-1 gives the maximum permissible levels of jitter at OTUk interfaces. Jitter as measured over a 60-second interval shall not exceed the limits given in Table 5.1-1, when using the specified measurement filters. The limits shall be met for all operating conditions and regardless of the amount of equipment preceding the interface. In general, these network limits are compatible with the minimum tolerance to jitter that all equipment input ports are required to provide. Guidelines for the derivation of the parameters values of Table 5.1-1 are given in Appendix I.

There is a close relationship between network limits and input tolerance such that the jitter measurement filter cut-off frequencies used in Table 5.1-1 have the same values as the jitter tolerance mask corner frequencies used in clause 6.1. Appendix I provides further information about this relationship.

The high-pass measurement filters of Table 5.1-1 have a first-order characteristic and a roll-off of 20 dB/decade. The low-pass measurement filters for OTU1, OTU2, and OTU3 have a maximally-flat, Butterworth characteristic and a roll-off of –60 dB/decade.

Table 5.1-1 – Maximum permissible jitter at OTUk interfaces

Interface	Measurement bandwidth, –3 dB frequencies (Hz)	Peak-to-peak amplitude (UI _{pp})
OTU1	5 k to 20 M	1.5
	1 M to 20 M	0.15
OTU2	20 k to 80 M	1.5
	4 M to 80 M	0.15
OTU3	20 k to 320 M	6.0
	16 M to 320 M	0.18
OTL3.4 (OTU3 Multilane) per lane	FFS	FFS
	4 M measured up to fourth-order Bessel-Thomson filter defined in clause 87.8.9 of [IEEE 802.3ba]	Each lane according to clause 87.7.2, Table 87-8, and clause 87.8.11 of [IEEE 802.3ba]
OTL4.4 (OTU4 Multilane) per lane	FFS	FFS
	10 M measured up to fourth-order Bessel-Thomson filter defined in clause 88.8.8 of [IEEE 802.3ba]	Each lane according to clause 88.8.10, Table 88-13 of [IEEE 802.3ba]
NOTE – OTU1 $1 \text{ UI} = \frac{238}{(255)(2.48832)} \text{ ns} = 375.1 \text{ ps}$ OTU2 $1 \text{ UI} = \frac{237}{(255)(9.95328)} \text{ ns} = 93.38 \text{ ps}$ OTU3 $1 \text{ UI} = \frac{236}{(255)(39.81312)} \text{ ns} = 23.25 \text{ ps}$ OTL3.4 $1 \text{ UI} = \frac{4 \times 236}{(255)(39.81312)} \text{ ns} = 92.98 \text{ ps per lane}$ OTL4.4 $1 \text{ UI} = \frac{4 \times 227}{(255)(99.5328)} \text{ ns} = 35.77 \text{ ps per lane}$		

5.2 Network limits for wander

OTUk interfaces are not synchronization interfaces. None of the ODUk clocks are significant sources of wander. There is no need for specification of network wander limits.

6 Jitter and wander tolerance of network interfaces

6.1 Jitter and wander tolerance of OTN interfaces

This clause specifies the jitter and wander tolerance for OTUk input ports. This is the minimum jitter and wander that must be tolerated at the input to the OCh/OTUk_A_Sk and OPSM/OTUk_A_Sk atomic function. This represents, for example, the jitter and wander tolerance for a 3R regenerator. The input ports of all equipment must be capable of accommodating levels of jitter and wander up to at least the minimum limits defined in clauses 6.1.1, 6.1.2, 6.1.3, and 6.1.4 in order to ensure that, in general, any equipment can be connected to any appropriate interface within a network.

NOTE 1 – As stated above, both the jitter and wander tolerance requirements apply at the OTUk input port, which is the input to the OCh/OTUk_A_Sk or the OPSM/OTUk_A_Sk atomic function. However, while the requirements apply at this interface, they are not all driven by this atomic function. For example, the high-band jitter tolerance requirement (i.e., the tolerance above the highest frequency breakpoint, which is 1 MHz for OTU1, 4 MHz for OTU2 and OTL3.4 lane of the OTU3 Multilane, 16 MHz for OTU3, and 10 MHz for an OTL4.4 lane of the OTU4 Multilane) is driven by the wideband clock recovery circuit in the OCh/OTUk_A_Sk atomic function; however, the wideband jitter tolerance requirement (i.e., the tolerance between 5 kHz and 100 kHz for OTU1 and between 20 kHz and 400 kHz for OTU2 and OTU3) is driven by the ODCr in the OTUk/ODUk_A_So and OTUk/ODUk_A_Sk atomic functions.

The jitter and wander tolerance of an OTUk interface indicates the minimum level of phase noise that the input port shall accommodate whilst:

- not causing any alarms;
- not causing any slips or loss of lock in the clock recovery phase-locked loop; and
- not causing any bit errors in excess of those allowed by an equivalent 1 dB optical power penalty.

The limit of tolerable input jitter is measured by the 1 dB optical power penalty method as follows:

The optical input power is reduced until a BER of 10^{-10} is reached. Then, the power is increased by 1 dB and jitter is applied to the input signal. The amount of jitter that results in BER of 10^{-10} is the limit of tolerable input jitter. If the system uses FEC, this shall be disabled for the measurement when using an external bit error detector. Alternatively, BER may be measured by leaving the FEC enabled and counting the number of corrected bit errors per unit time.

NOTE 2 – This definition is subject to further study, taking into account the effects of, e.g., optical amplifiers (OA), polarization mode dispersion (PMD), and forward error correction (FEC).

All OTUk input ports of equipment shall be able to tolerate an OCh_AI_D signal that has:

- a) optical characteristics of [ITU-T G.959.1] or [ITU-T G.693],
- b) a frequency offset (relative to the nominal value) within the range defined in clause A.3, and
- c) a sinusoidal phase deviation having an amplitude-frequency relationship, defined in the following clauses, which indicates the appropriate limits for the different interfaces.

In principle, these requirements shall be met regardless of the information content of the digital signal. However, for test purposes, the content of the signal with jitter and wander modulation should be a structured test sequence as defined in [ITU-T G.709].

For convenience of testing, the required tolerance is defined in terms of the peak-to-peak amplitude and frequency of sinusoidal jitter which modulates a digital test pattern. It is important to recognize that this test condition is not, in itself, intended to be representative of the type of jitter found in practice in a network.

Guidance on the measurement set-up for input jitter and wander tolerance is provided in Appendix III of [ITU-T G.823].

Requirements for jitter and wander tolerance for each OTUk rate are given in the following subclauses. These requirements specify the minimum levels of jitter that must be accommodated at an OTUk interface.

6.1.1 OTU1 jitter and wander tolerance

The level of sinusoidal jitter that must be accommodated by OTU1 interfaces is specified in Table 6.1-1 and illustrated in Figure 6.1-1. A phase-locked loop with corner frequency greater than or equal to 5 kHz that can tolerate jitter and wander indicated by the 20 dB/decade sloped portion of

the mask between 500 Hz and 5 kHz will also tolerate jitter and wander indicated by an extension of this sloped region to lower frequencies, because such jitter and wander is within the bandwidth of the phase-locked loop. OTU1 interfaces must tolerate this jitter and wander but, for practical reasons, it is not required to measure them below 500 Hz.

Table 6.1-1 – OTU1 input sinusoidal jitter tolerance limit

Frequency f (Hz)	Peak-to-peak amplitude (UIpp)
$500 < f \leq 5 \text{ k}$	$7500 f^{-1}$
$5 \text{ k} < f \leq 100 \text{ k}$	1.5
$100 \text{ k} < f \leq 1 \text{ M}$	$1.5 \times 10^5 f^{-1}$
$1 \text{ M} < f \leq 20 \text{ M}$	0.15

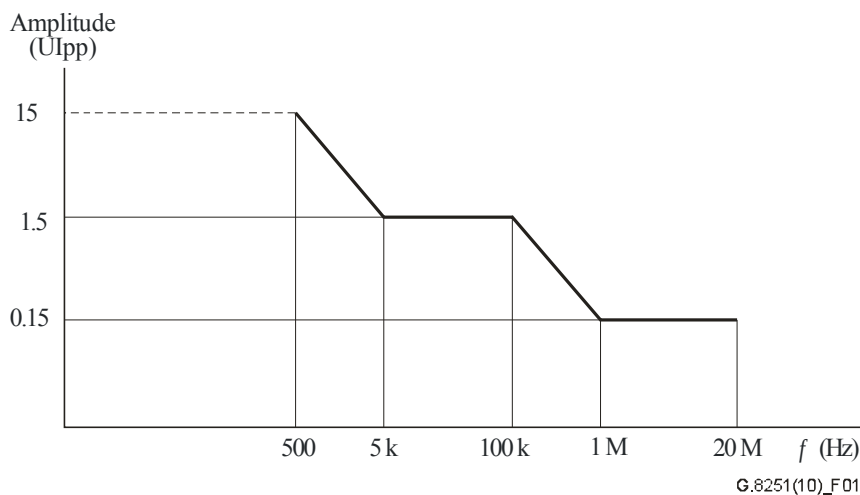


Figure 6.1-1 – OTU1 input sinusoidal jitter tolerance limit

6.1.2 OTU2 jitter and wander tolerance

The level of sinusoidal jitter that must be accommodated by OTU2 interfaces is specified in Table 6.1-2 and illustrated in Figure 6.1-2. A phase-locked loop with corner frequency greater than or equal to 20 kHz that can tolerate jitter and wander indicated by the 20 dB/decade sloped portion of the mask between 2 kHz and 20 kHz will also tolerate jitter and wander indicated by an extension of this sloped region to lower frequencies, because such jitter and wander is within the bandwidth of the phase-locked loop. OTU2 interfaces must tolerate this jitter and wander but, for practical reasons, it is not required to measure them below 2 kHz.

Table 6.1-2 – OTU2 input sinusoidal jitter tolerance limit

Frequency f (Hz)	Peak-to-peak amplitude (UIpp)
$2 \text{ k} < f \leq 20 \text{ k}$	$3.0 \times 10^4 f^{-1}$
$20 \text{ k} < f \leq 400 \text{ k}$	1.5
$400 \text{ k} < f \leq 4 \text{ M}$	$6.0 \times 10^5 f^{-1}$
$4 \text{ M} < f \leq 80 \text{ M}$	0.15

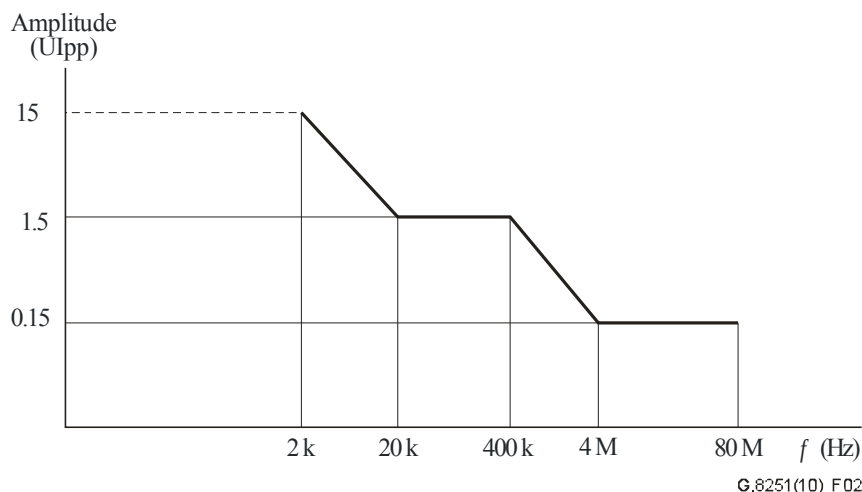


Figure 6.1-2 – OTU2 input sinusoidal jitter tolerance limit

6.1.3 OTU3 jitter and wander tolerance

The level of sinusoidal jitter that must be accommodated by OTU3 interfaces is specified in Table 6.1-3 and illustrated in Figure 6.1-3. A phase-locked loop with corner frequency greater than or equal to 20 kHz that can tolerate jitter and wander indicated by the 20 dB/decade sloped portion of the mask between 8 kHz and 20 kHz will also tolerate jitter and wander indicated by an extension of this sloped region to lower frequencies, because such jitter and wander is within the bandwidth of the phase-locked loop. OTU3 interfaces must tolerate this jitter and wander but, for practical reasons, it is not required to measure it below 8 kHz.

Table 6.1-3 – OTU3 input sinusoidal jitter tolerance limit

Frequency f (Hz)	Peak-to-peak amplitude (UIpp)
$8\text{ k} < f \leq 20\text{ k}$	$1.2 \times 10^5 f^{-1}$
$20\text{ k} < f \leq 480\text{ k}$	6.0
$480\text{ k} < f \leq 16\text{ M}$	$2.88 \times 10^6 f^{-1}\text{ UI}$
$16\text{ M} < f \leq 320\text{ M}$	0.18

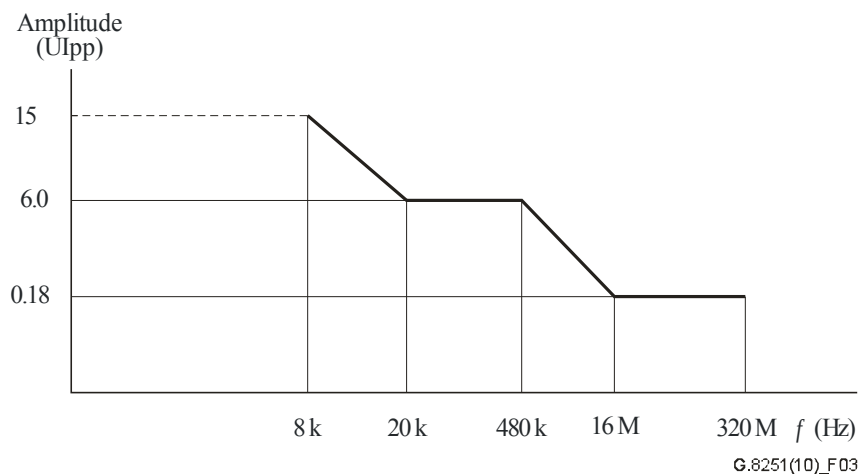


Figure 6.1-3 – OTU3 input sinusoidal jitter tolerance limit

The jitter tolerance of the OTU3 multilane interface is given in Table 6.1-4 and illustrated in Figure 6.1-4.

Table 6.1-4 – OTL3.4 per lane input sinusoidal jitter tolerance limit

Frequency f (Hz)	Peak-to-peak amplitude (UIpp)
FFS	FFS
FFS	FFS
FFS	FFS
$4\text{ M} < f \leq$ measured up to fourth-order Bessel-Thomson filter defined in [IEEE 802.3ba], clause 87.8.9.	Each lane according to clause 87.7.2, Table 87-8, and clause 87.8.11 of [IEEE 802.3ba]

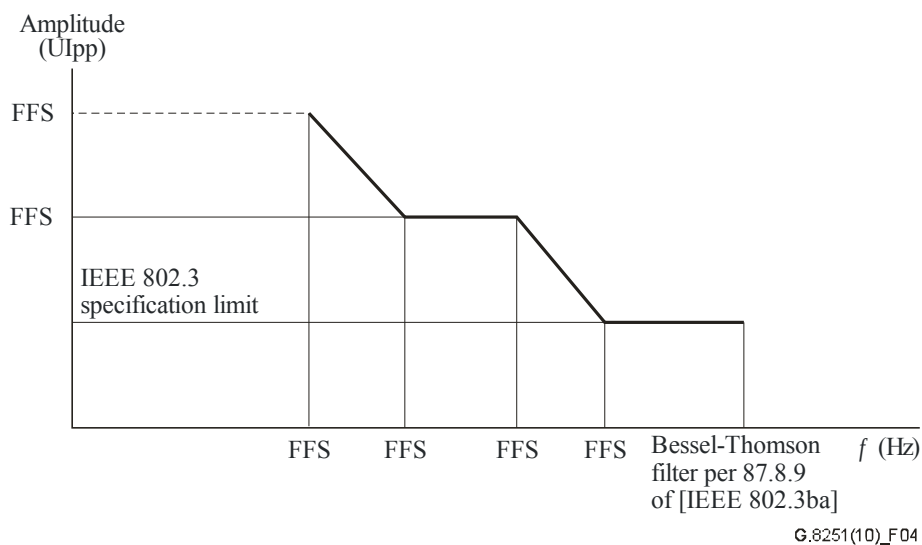


Figure 6.1-4 – OTL3.4 per lane input sinusoidal jitter tolerance limit

6.1.4 OTU4 jitter and wander tolerance

The level of jitter that must be accommodated by the OTU4 multilane interface is given in Table 6.1-5 and illustrated in Figure 6.1-5.

Table 6.1-5 – OTL4.4 per lane input sinusoidal jitter tolerance limit

Frequency f (Hz)	Peak-to-peak amplitude (U _{lpp})
FFS	FFS
FFS	FFS
FFS	FFS
$10\text{ M} < f \leq$ measured up to fourth-order Bessel-Thomson filter defined in clause 88.8.8 of [IEEE 802.3ba]	Each lane according to clause 88.7.2, Table 88-8 and clause 88.8.10 of [IEEE 802.3ba]

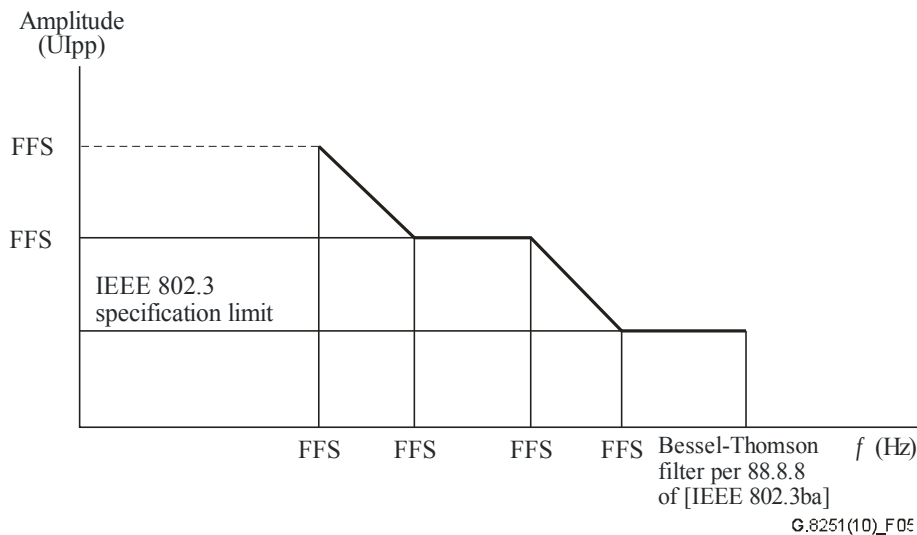


Figure 6.1-5 – OTL4.4 per lane input sinusoidal jitter tolerance limit

6.2 Jitter and wander tolerance of client interfaces

Jitter and wander tolerance requirements and network limits for CBR0G155, CBR0G622, CBR2G5, CBR10G, and CBR40G are derived from the corresponding requirements for STM-1, STM-4, STM-16, STM-64 and STM-256 signals, respectively, given in [ITU-T G.825].

STM input ports, i.e., the input to the ODUkP/CBRx-a_A_So and ODUkP/CBRx-b_A_So atomic functions, must tolerate jitter and wander levels specified in [ITU-T G.825]. Guidelines for measuring the input jitter and wander tolerance of equipment input interfaces are given in Appendix III of [ITU-T G.823].

For input ports to the ODU0P-to-Client adaptation function (ODU0P/CBRx_A, $0 < x \leq 1G25$), the specification of the particular clients applies. Jitter and wander tolerance requirements and network limits for 1GE are derived from the corresponding requirements for (transcoded) 1GE signals, given in [IEEE 802.3]. For SDH rates, the [ITU-T G.825] specifications apply; for native Ethernet, the [IEEE 802.3] specifications apply (clock tolerance of 100 ppm).

The 10GE signals shall support the 10G Ethernet specifications in [IEEE 802.3].

For 40G and 100G Ethernet to be transported over ODU3 and ODU4, respectively, the jitter as defined in [IEEE 802.3ba] is applicable on the multilane client port.

The FC-x (x = 100, 200, 400, 800, and 1200) signals shall support the fibre channel specifications of [b-ANSI 352] and [b-ANSI 364].

Annex A

Specification of the ODUk clock (ODC)

(This annex forms an integral part of this Recommendation)

A.1 Scope

This annex contains the requirements for the ODUk clock (ODC). Here, the term 'clock' refers to a clock filtering and/or generating circuit. Four ODC types are defined, for different applications (see clause A.2):

- 1) ODCa for asynchronous mapping (AMP or GMP) of constant bit rate (CBR) clients (e.g., generic CBRx client, RS client, etc.) and variable bit rate (VBR) clients (e.g., VP client, GFP client, etc.) into ODUk, asynchronous multiplexing of ODUj[i] (AMP mapping into 2.5G timeslots) or ODUj (mapping into 1.25G timeslots) clients into ODUk ($k > j$), generation of Test/NULL signals, and AIS and OCI generation;
- 2) ODCb for bit-synchronous mapping of CBRx clients into ODUk;
- 3) ODCr for 3R regeneration of the ODUk signal; and
- 4) ODCp for demapping of constant bit rate (CBR) clients and demultiplexing of ODUj[i] or ODUj clients from ODUk ($k > j$).

The ODCa and ODCb generate the timing signal for the ODUk and OTUk signals produced by an OTN network element. The ODCr generates the timing signal for the OTUk produced by a 3R regenerator. The ODCp generates the timing signal for a demapped CBRx client signal or demultiplexed ODUj[i] or ODUj signal.

The four ODC types, the atomic functions they reside in, and their applicable requirements, are summarized in Table A.1-1. The requirements are described in more detail in the clauses that follow.

Table A.1-1 – Summary of ODUk clock (ODC) types

	ODCa (Note 4)	ODCb (Note 4)	ODCr	ODCp (Note 4)
Atomic function	ODUkP/CBRx-a_A_So ODUkP/GFP_A_So ODUkP/NULL_A_So ODUkP/PRBS_A_So ODUkP/RSn-a_A_So ODUkP/VP_A_So ODUkP/ODU[i]j_A_So ODUkP/ODUj_A_So ODUkP/ODUi[j]_A_Sk (AIS clock) OTUk/ODUk_A_Sk (AIS clock) OTUkV/ODUk_A_Sk (AIS clock) ODUk_C (OCI clock)	ODUkP/CBRx-b_A_So ODUkP/RSn-b_A_So	OTUk/ODUk_A_So and OTUk/ODUk_A_Sk (i.e., the clocks of these atomic functions are concentrated in a single ODCr; see [ITU-T G.798])	ODUkP/CBRx_A_Sk ODUkP/ODU[i]j_A_Sk ODUkP/ODUj_A_Sk
Frequency accuracy	±20 ppm	±20 ppm for ODUk (k = 0, 1, 2, 3, 4) ±20 ppm for CBRx (x = 2G5, 10G, 40G) ±100 ppm for ODU2e, ODUflex, 10GE, and FC-x (x = 100, 200, 400, 800, 1200)	±20 ppm	±20 ppm for ODUk (k= 0, 1, 2, 3, 4) ±20 ppm for CBRx (x = 0G155, 0G622, 2G5, 10G, 40G) ±100 ppm for 1GE, 10GE, 40GE, 100GE, FC-x, ODUflex, and ODU2e
Free-run mode supported	Yes	Yes	Yes	Yes
Locked mode supported	No	Yes	Yes	Yes
Holdover mode supported	No	No	No	No
Pull-in range	NA	±20 ppm (SDH clients) ±100 ppm (Ethernet and FC-x (x = 100, 200, 400, 800, 1200) clients)	±20 ppm	±20 ppm (SDH clients) ±100 ppm (Ethernet and FC-x (x = 100, 200, 400, 800, 1200) clients)

Table A.1-1 – Summary of ODUk clock (ODC) types

	ODCa (Note 4)	ODCb (Note 4)	ODCr	ODCp (Note 4)
Pull-out range	NA	±20 ppm (SDH clients) ±100 ppm (Ethernet and FC-x (x = 400, 800, 1200) clients)	±20 ppm	±20 ppm (SDH clients) ±100 ppm (Ethernet and FC-x (x = 100, 200, 400, 800, 1200) clients)
Jitter generation	Table A.5-1	Table A.5-1	Table A.5-1	Table A.5-2
Wander generation	NA	NA (Note 1)	NA	NA (Note 2)
Jitter tolerance	NA	[ITU-T G.825] for SDH clients [IEEE 802.3] for Ethernet clients	Table 6.1-1, Figure 6.1-1 (OTU1) Table 6.1-2, Figure 6.1-2 (OTU2) Table 6.1-3, Figure 6.1-3 (OTU3) Table 6.1-4, Figure 6.1-4 (OTU3/OTL3.4) Table 6.1-5, Figure 6.1-5 (OTU4/OTL4.4)	Table 6.1-1, Figure 6.1-1 (OTU1) Table 6.1-2, Figure 6.1-2 (OTU2) Table 6.1-3, Figure 6.1-3 (OTU3) Table 6.1-4, Figure 6.1-4 (OTU3/OTL3.4) [IEEE 802.3] for Ethernet clients
Wander tolerance	NA	[ITU-T G.825]	Clause 6.1	Clause 6.1

Table A.1-1 – Summary of ODUk clock (ODC) types

	ODCa (Note 4)	ODCb (Note 4)	ODCr	ODCp (Note 4)
Jitter transfer	NA	Maximum bandwidth: ODU0: 0.5 kHz ODU1: 1 kHz ODU2: 4 kHz ODU2e: 4 kHz ODU3: 16 kHz ODUflex: FFS Maximum gain peaking: 0.1 dB for ODU0, 1, 2, 2e, and 3 FFS for ODUflex (see Table A.7-1 and Figure A.7-1)	Maximum bandwidth: OTU1: 250 kHz OTU2: 1000 kHz OTU3: 4000 kHz OTU4: 10000 kHz Maximum gain peaking: 0.1 dB for OTU1, 2, 3 and 4 (see Table A.7-2 and Figure A.7-1)	Maximum bandwidth: 300 Hz for ODUk (k=0, 1, 2, 2e, 3, flex) 300 Hz for CBRx (x = 0G155, 0G622, 2G5, 10G, 40G), 10GE, 40GE, 100GE, FC-x (x = 100, 200, 400, 800, 1200) 100 Hz for 1GE Maximum gain peaking: 0.1 dB (see clause A.7.3)
Output when input signal is lost	AIS (CBRx client) OTUk: no frame hit OTUk frequency unchanged	AIS (CBRx client) Local Fault (Ethernet and FC-x (x = 100, 200, 400, 800, 1200) clients) OTUk: no frame hit OTUk initial frequency change ≤ 9 ppm (See clause A.8)	AIS (OTUk) OTUk: frame hit allowed Temporary OTUk frequency offset > 20 ppm allowed	AIS (CBRx client), AIS (ODUj[i] client) Frequency offset ≤ 20 ppm Local Fault (Ethernet and FC-x (x = 100, 200, 400, 800, 1200) clients) Frequency offset ≤ 100 ppm

NA No requirement because not applicable

NOTE 1 – The wander generation of ODCb is expected to be negligible compared to the wander on the input CBR (e.g., SDH) client signal, because the ODCb bandwidth is relatively wideband.

NOTE 2 – The intrinsic wander generation of the ODCp is negligible compared to the wander generated by the demapping process.

NOTE 3 – To achieve the compliance of STM-1 and STM-4 signals mapped with GMP into ODU0 with SDH jitter wander specification in addition to the ODCp clock filtering, the use of one bit additional phase information as specified in [ITU-T G.709] and [ITU-T G.798] is required.

NOTE 4 – An ODCa, ODCb, or ODCp for one client is not required to support another client simultaneously.

The output timing signals at the lower layers are derived from the ODUkP_AI_CK (i.e., from the ODCa, ODCb, or ODCr output) by frequency multiplication. For example, the OTUk timing signal is the OTUk_AI_CK, which is output from the OTUk/ODUk_A_So atomic function (see clause 13.3.1.1 of [ITU-T G.798]). This signal is derived from the ODUk_CI_CK (characteristic information of the ODUk; this signal has the same frequency as the ODUkP_AI_CK) via frequency multiplication by 255/239. The OTUk_AI_CK provides the timing input to the OCh/OTUk_A_So and OPSM/OTUk_A atomic functions, whose output is the OCh data signal (OCh_AI_D).

NOTE – In the case of asynchronous mapping or multiplexing, there is no requirement for a single master clock, i.e., single ODCa, in OTN equipment. Within OTN equipment there may be multiple, independent ODCa clocks for each outgoing wavelength (i.e., for the source of each OCh, OTUk, and ODUk). In the case of bit-synchronous mapping, 3R regeneration, and demapping there cannot be a single master clock for multiple OCh's, i.e., an ODCb, ODCr, or ODCp supplies timing for a single ODUk, OTUk, or CBR client, respectively.

A.2 Applications

The ODCa and ODCb are used for the mapping of payload to the ODUk signal; the ODCr is used for the 3R regeneration; the ODCp is used in the CBR demapper and ODU[i]j demultiplexer.

The ODCa, used for asynchronous mapping (AMP and GMP) and ODU[i]j multiplexing, is free running and the bit rate offset is accommodated by appropriately controlled stuffing. The ODCa is also the AIS and OCI clock.

The ODCb, used for bit-synchronous mapping, is locked to the bit rate of the incoming payload signal and the bit rate offset is accommodated by a fixed stuff pattern. The synchronous operation is continued even if the received payload contents is AIS. If the incoming signal fails, the ODC enters the free-run condition.

The ODCr, used for 3R regeneration, is locked to the bit rate of the incoming OCh_AP signal (including AIS). If the incoming signal fails, the ODC enters the free-run condition.

The ODCp, used for the CBR demapper and the ODU[i]j demultiplexer, is locked to the bit rate of the gapped OPUk clock (i.e., the timing of the signal that results from taking the OPUk payload and applying the justification control). If the incoming signal fails, the ODCp enters a free-run condition.

A.3 Frequency accuracy

Under free-running conditions, the output frequency accuracy of ODCa and ODCp shall not be worse than 20 ppm with respect to a reference traceable to an [ITU-T G.811] clock. Under free-running conditions, the output frequency accuracy of ODCb shall not be worse than 100 ppm for 1GE, 10GE, 40GE, 100GE, and FC-x clients and ODU2e, and shall not be worse than 20 ppm for all other respective clients and ODUs (see Table A.1-1). Under free-running conditions, the output frequency accuracy of ODCp shall not be worse than 100 ppm for 1GE, 10GE, 40GE, 100GE, and FC-x clients and ODU2e, and shall not be worse than 20 ppm for all other respective clients and ODUs (see Table A.1-1).

A.4 Pull-in and pull-out ranges

A.4.1 Pull-in range

The minimum pull-in range of ODCb, ODCr, and ODCp shall be ± 100 ppm for 1GE, 10GE, 40GE, 100GE, and FC-x clients and ODU2e, and ± 20 ppm for all other clients and ODUs (see Table A.1-1), whatever the internal oscillator frequency offset may be. There is no requirement for the pull-in range of ODCa because it is free-running.

A.4.2 Pull-out range

The minimum pull-out range of ODCb, ODCr, and ODCp shall be ± 100 ppm for 1GE, 10GE, 40GE, 100GE, and FC-x clients and ODU2e, and ± 20 ppm for all other clients and ODUs (see Table A.1-1), whatever the internal oscillator frequency offset may be. There is no requirement for the pull-out range of ODCa because it is free-running.

A.5 Noise generation

This clause limits the output jitter and wander for each applicable clock type, in the absence of any input jitter or wander. Note that the respective input and output signals depend on the clock type, because the different clock types are located in different atomic functions.

A.5.1 Jitter generation

A.5.1.1 ODCa, ODCb, and ODCr jitter generation

In the absence of input jitter, jitter of the ODCa and ODCb output, i.e., the ODUkP_AI_CK signal, shall not exceed the values specified in Table A.5-1 when measured over a 60-second interval with the measurement filters specified in that table. Since ODCa is free-running, there is no input jitter by definition. For ODCb, it is the input client signal that is jitter-free.

NOTE 1 – The ODU2e has a ± 100 ppm clock tolerance aligned to the 10G Ethernet client, but the ODU2e jitter generation requirements are identical to ODU2 and enable transport of synchronous Ethernet.

Table A.5-1 – ODCa, ODCb, and ODCr jitter generation requirements

Interface	Measurement bandwidth, –3 dB frequencies (Hz)	Peak-to-peak amplitude (UIpp) (Note 2)
ODU0	2.5 k to 10 M	0.3
	0.5 M to 10 M	0.1
ODU1, OTU1	5 k to 20 M	0.3
	1 M to 20 M	0.1
ODU2, OTU2	20 k to 80 M	0.3
	4 M to 80 M	0.1
ODU2e	20 k to 80 M	0.3
	4 M to 80 M	0.1
ODU3, OTU3	20 k to 320 M	1.2 (Note 1)
	16 M to 320 M	0.14
OTL3.4	FFS	FFS
	4 M measured up to fourth-order Bessel-Thomson filter defined in clause 87.8.9 of [IEEE 802.3ba]	Each lane as defined in clause 87.7.1, Table 87-7, and clause 87.8.9 of [IEEE 802.3ba]
OTL4.4	FFS	FFS
	10 M to fourth-order Bessel-Thomson filter defined in clause 88.8.8 of [IEEE 802.3ba]	Each lane as defined in clause 88.7.1, Table 88-7, and clause 88.8.8 of [IEEE 802.3ba]

Table A.5-1 – ODCa, ODCb, and ODCr jitter generation requirements

Interface	Measurement bandwidth, –3 dB frequencies (Hz)	Peak-to-peak amplitude (UIpp) (Note 2)
ODUflex	FFS	FFS
NOTE 1 – See clause IV.4 for additional information.		
NOTE 2 – ODU0	$1UI = \frac{1}{1.24416} [\text{ns}] = 803.8 \text{ ps}$	
ODU1	$1UI = \frac{238}{(239)(2.48832)} [\text{ns}] = 400.2 \text{ ps}$	
ODU2	$1UI = \frac{237}{(239)(9.95328)} [\text{ns}] = 99.63 \text{ ps}$	
ODU3	$1UI = \frac{236}{(239)(39.81312)} [\text{ns}] = 24.80 \text{ ps}$	
OTU1	$1UI = \frac{238}{(255)(2.48832)} \text{ ns} = 375.1 \text{ ps}$	
OTU2	$1UI = \frac{237}{(255)(9.95328)} \text{ ns} = 93.38 \text{ ps}$	
OTU3	$1UI = \frac{236}{(255)(39.81312)} \text{ ns} = 23.25 \text{ ps}$	
OTL3.4	$1UI = \frac{4 \times 236}{(255)(39.81312)} \text{ ns} = 92.98 \text{ ps per lane}$	
OTL4.4	$1UI = \frac{4 \times 227}{(255)(99.5328)} \text{ ns} = 35.77 \text{ ps per lane}$	

In the absence of input jitter to a 3R regenerator (i.e., to the OCh/OTUk_A_Sk atomic function), the output jitter on the clock information in the OCh_AI_D signal output from the OCh/OTUk_A_So atomic function shall not exceed the values specified in Table A.5-1 when measured over a 60-second interval with the measurement filters specified in that table. The signal that must be free of input jitter when this measurement is made is the OCh_AI_D signal input to the corresponding OCh/OTUk_A_Sk atomic function. Specifically, it is the clock information in this signal that must have no input jitter.

NOTE 2 – This is actually a requirement for the jitter generation of a 3R regenerator; it constrains the total jitter generation in all the atomic functions from OCh/OTUk_A_Sk to OCh/OTUk_A_So (inclusive) or OPSM/OTUk_A_Sk to OPSM/OTUk_A_So (inclusive). The ODCr is included in this, as it resides in the OTUk/ODUk_A_So and OTUk/ODUk_A_Sk atomic functions (i.e., the clocks of these atomic functions are concentrated in a single ODCr; see [ITU-T G.798]).

A.5.1.2 ODCp jitter generation

In the absence of input jitter, jitter of the ODCp output, i.e., the CBR/RS_CI_CK signal or the ODUj[i]_CI_Ck or ODUj_CI_Ck signal, shall not exceed the values specified in Table A.5-2 when measured over a 60-second interval with the measurement filters specified in that table. Note that the output is at the CBRx/RSn_CP interface, the ODUj[i]_CP interface, or the ODUj_CP interface. The requirements shall be met when the input frequency of the CBRx/ODUj[i] or the CBRx/ODUj client is constant within the limits –20 ppm to +20 ppm from the nominal frequency and when the

input frequency of the 10GE/ODU2e, 40GE or 100GE client is constant within the limits –100 ppm to +100 ppm from the nominal frequency.

NOTE – The CBR_CP and ODUk[i]_CP are internal to a network element, and are therefore generally not accessible to testing. Compliance with the requirement may be verified by varying the frequency of the CBRx/ODUj[i], CBRx/ODUj or 10GE/ODU2e client input at the OS_CP or OCh_CP within the limits –20 ppm to +20 ppm or –100 ppm to +100 ppm, respectively, from nominal frequency and verifying that, for jitter-free input, the jitter on the demapped client output of the ODCp is within the limits specified in Table A.5-2.

One purpose of the ODCp wideband jitter generation requirements is to ensure that the gaps due to fixed overhead in the OTUk frame will not cause excessive output jitter. Additional information on this is provided in clause V.3.

Table A.5-2 – ODCp jitter generation requirements

Interface	Measurement bandwidth, –3 dB frequencies (Hz)	Peak-to-peak amplitude (UIpp) (Note 3)
CBR0G155	0.5 k to 1.3 M	1.0
	65 k to 1.3 M	0.1
CBR0G622	1 k to 5 M	1.0
	250 k to 5 M	0.1
1GE	2.52 k to 10 M	1.0
	0.673 M to f_4 (Note 1)	TP2, according to clause 38.5, Table 38-10 of [IEEE 802.3]
ODU0	2.5 k to 10 M	1.0
	0.673 M to 10 M	0.1
CBR2G5, ODU1	5 k to 20 M	1.0
	1 M to 20 M	0.1
CBR10G, ODU2	20 k to 80 M	1.0
	4 M to 80 M	0.1
10GE, ODU2e	20 k to 80 M	1.0
	4 M to f_4 (Note 2)	Transmit eye mask, defined in clause 52.7.1, Table 52-16 of [IEEE 802.3]
CBR40G, ODU3	80 k to 320 M	1.0
	16 M to 320 M	0.14
40GE, ODU3 Multilane	FFS	FFS
	4 M measured up to fourth-order Bessel-Thomson filter defined in clause 87.8.9 of [IEEE 802.3ba]	Each lane as defined in clause 87.7.1, Table 87-7, and clause 87.8.9 of [IEEE 802.3ba]

Table A.5-2 – ODCp jitter generation requirements

Interface	Measurement bandwidth, –3 dB frequencies (Hz)	Peak-to-peak amplitude (UIpp) (Note 3)
100GE	FFS	FFS
	10 M to fourth-order Bessel-Thomson filter defined in clause 88.8.8 of [IEEE 802.3ba]	Each lane as defined in clause 88.7.1, Table 88-7, and clause 88.8.8 of [IEEE 802.3ba]
ODUflex and its CBRx clients	FFS	FFS

NOTE 1 – f_4 = bandwidth of fourth-order Bessel-Thomson filter defined in clause 38.6.5 of [IEEE 802.3].
NOTE 2 – f_4 = bandwidth of fourth-order Bessel-Thomson filter defined in clause 52.9.7 of [IEEE 802.3].
NOTE 3 – 1GE $1 \text{ UI} = \frac{1}{1.25} \text{ [ns]} = 800 \text{ ps}$

CBR2G5 $1 \text{ UI} = \frac{1}{2.48832} \text{ [ns]} = 401.9 \text{ ps}$

CBR10G $1 \text{ UI} = \frac{1}{9.95328} \text{ [ns]} = 100.5 \text{ ps}$

CBR40G $1 \text{ UI} = \frac{1}{39.81312} \text{ [ns]} = 25.12 \text{ ps}$

ODU0 $1 \text{ UI} = \frac{1}{1.24416} \text{ [ns]} = 803.8 \text{ ps}$

ODU1 $1 \text{ UI} = \frac{238}{(239)(2.48832)} \text{ [ns]} = 400.2 \text{ ps}$

ODU2 $1 \text{ UI} = \frac{237}{(239)(9.95328)} \text{ [ns]} = 99.63 \text{ ps}$

ODU2e $1 \text{ UI} = \frac{237}{(239)(10.31250)} \text{ [ns]} = 97.78 \text{ ps}$

ODU3 $1 \text{ UI} = \frac{236}{(239)(39.81312)} \text{ [ns]} = 25.43 \text{ ps}$

ODU3 (Multilane) $1 \text{ UI} = \frac{236 \times 4}{(239)(39.81312)} \text{ [ns]} = 99.21 \text{ ps}$

ODU4 (Multilane) $1 \text{ UI} = \frac{227 \times 4}{(239)(99.53280)} \text{ [ns]} = 38.17 \text{ ps}$

A.5.2 Wander generation

There are no wander generation requirements for ODCa, ODCb, ODCr, and ODCp. For ODCb, any intrinsic wander generation is expected to be negligible compared to the wander on the input CBR (e.g., SDH) client signal, because the ODCb bandwidth is relatively wideband. The intrinsic wander generation of the ODCp is negligible compared to the wander generated by the demapping process.

A.6 Noise tolerance

This clause specifies the jitter and wander tolerance of ODCb, ODCr, and ODCp. There are no jitter and wander tolerance requirements for ODCa because ODCa is free-running.

ODCb must satisfy the same jitter and wander tolerance requirements as CBR2G5, CBR10G, CBR40G, 1GE, 10GE, 40GE, 100GE, or FC-x client interfaces (the input to the ODUkP/CBRx-b_A_So atomic function). These requirements are given in clause 6.2, which references [ITU-T G.825] and the Ethernet specifications in [IEEE 802.3].

Note that the ODCb is contained in the ODUkP/CBRx-b_A_So atomic function.

ODCr and ODCp must satisfy the same jitter and wander tolerance requirements as OTUk input ports (the input to the OCh/OTUk_A_Sk atomic function). These requirements are given in clause 6.1 and its subclauses. Note that the ODCr is contained in the OTUk/ODUk_A_So and OTUk/ODUk_A_Sk atomic functions, and the ODCp is contained in the ODUkP/CBRx_A_Sk atomic function.

A.7 Jitter transfer

This clause specifies the jitter transfer of ODCb, ODCr, and ODCp. There are no jitter transfer requirements for ODCa because ODCa is free-running.

A.7.1 Jitter transfer for ODCb

The jitter transfer function for ODCb is defined as the ratio of the output sinusoidal jitter amplitude to input sinusoidal jitter amplitude, as a function of frequency. The ODCb input is the CBRx_CI_CK signal at the ODUkP/CBRx-b_A_So atomic function. The ODCb output is the CBRx_AI_CK signal at the ODUkP/CBRx-b_A_Sk atomic function.

The jitter transfer function of ODCb shall be under the curve given in Figure A.7-1 when input sinusoidal jitter up to the respective masks referenced in clause A.6 is applied. The parameters of Figure A.7-1 are given in Table A.7-1. Note that the parameter f_C may be considered the maximum bandwidth of the ODCb, and the parameter P the maximum gain peaking of the ODCb. The jitter transfer limit is specified between frequencies of f_L and f_H . The jitter transfer limit is not specified for frequencies higher than f_H nor lower than f_L .

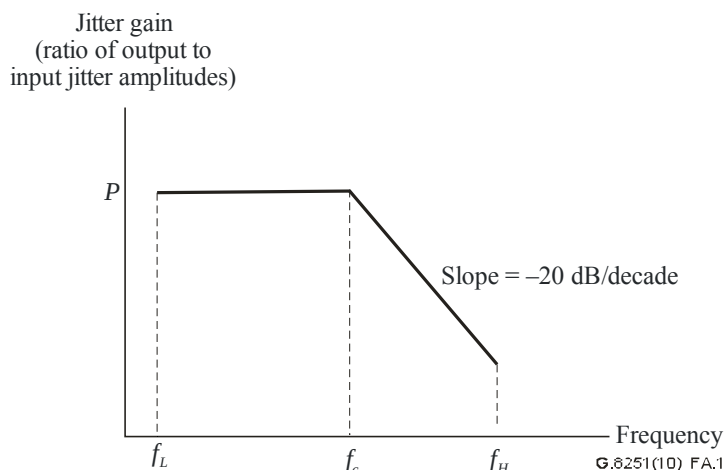


Figure A.7-1 – ODCb jitter transfer

Table A.7-1 – ODCb jitter transfer requirement

ODUk level	f_L (Hz)	f_C (kHz)	f_H (kHz)	P (dB)	Input mask
ODU1	10	1	100	0.1	Clause A.6
ODU2	40	4	400	0.1	Clause A.6
ODU2e	40	4	400	0.1	Clause A.6
ODU3	160	16	1600	0.1	Clause A.6
ODUflex	FFS	FFS	FFS	FFS	FFS

A.7.2 Jitter transfer for ODCr

The jitter transfer requirements for ODCr are, essentially, the transfer requirements for a 3R regenerator. While the 3R regenerator encompasses all the atomic functions between the OCh/OTUk_A_Sk adaptation function and OCh/OTUk_A_So adaptation function, and includes the wideband clock recovery circuit in the OCh/OTUk_A_Sk, the ODCr (contained in the OTUk/ODUk_A_So and OTUk/ODUk_A_Sk atomic functions) bandwidth is, in practice, significantly narrower than any of the other bandwidths present in the regenerator and therefore determines the transfer characteristics. Because the ODCr bandwidth is much larger than 10 Hz (i.e., the upper limit of the wander region), the regenerators transfer wander without attenuation; there are no explicit wander transfer requirements.

The jitter transfer function of a 3R regenerator is defined as the ratio of the output sinusoidal jitter amplitude to input sinusoidal jitter amplitude, as a function of frequency. The 3R regenerator input is the OCh_AI_D signal at the OCh/OTUk_A_Sk atomic function. The 3R regenerator output is the OCh_AI_D signal at the OCh/OTUk_A_So atomic function. Note that the jitter transfer is not associated with a single atomic function; rather, it is associated with all the atomic functions between and including the OCh/OTUk adaptation sink and source functions. Normally, at least part of the 3R regeneration function must occur in the OCh/OTUk_A_Sk function because a clock must be recovered. However, the jitter transfer and jitter tolerance requirements imply the presence of a second, narrower bandwidth phase-locked loop; this phase-locked loop is in the ODCr, contained in the OTUk/ODUk_A_So and OTUk/ODUk_A_Sk atomic functions.

The jitter transfer function of a 3R regenerator shall be under the curve given in Figure A.7-1 when input sinusoidal jitter up to the masks of Figures 6.1-1, 6.1-2, 6.1-3, and 6.1-5 and for OTU1, OTU2, OTU3, and, OTU4 respectively, is applied. The parameters of Figure A.7-1 are given in Table A.7-2. Note that the parameter f_C may be considered the maximum bandwidth of the 3R regenerator, and the parameter P the maximum gain peaking of the 3R regenerator. The jitter transfer limit is specified between frequencies of f_L and f_H . The jitter transfer limit is not specified for frequencies higher than f_H nor lower than f_L .

Table A.7-2 – ODCr jitter transfer requirement

OTUk level	f_L (kHz)	f_C (kHz)	f_H (MHz)	P (dB)	Input mask
OTU1	2.5	250	20	0.1	Figure 6.1-1, Table 6.1-1
OTU2	10	1000	80	0.1	Figure 6.1-2, Table 6.1-2
OTU3	40	4000	320	0.1	Figure 6.1-3, Table 6.1-3
OTU4	100	10000	800	0.1	Figure 6.1-5, Table 6.1-5, (values per lane)

A.7.3 Jitter transfer for ODCp

The jitter transfer requirements for ODCp are, essentially, the transfer requirements for a CBR (e.g., SDH) demapper (i.e., a desynchronizer) or ODU[i] demultiplexer. The demapper function, including the ODCp, is contained in the ODUkP/CBRx_A_Sk and ODUkP/RSn_A_Sk atomic functions. The demultiplexer functions, including the ODCp, are contained in the ODUkP/ODU[i]_A_Sk atomic function. The ODCp performs filtering, which is necessary to control the mapping/demapping jitter and wander accumulation over multiple OTN islands.

The 3 dB bandwidth of the desynchronizer shall not exceed 300 Hz for:

- ODUk (k=0, 1, 2, 2e, 3, flex);
- CBRx (x = 0G155, 0G622, 2G5, 10G, 40G);
- 10GE, 40GE, 100GE;
- FC-x (x = 100, 200, 400, 800, 1200).

The 3 dB bandwidth of the desynchronizer shall not exceed 100 Hz for 1GE.

The maximum gain peaking of the desynchronizer shall be 0.1 dB. These requirements apply to all ODUk rates. Additional information, on demapper phase error, is given in Appendix V.

A.8 Transient response

When a CBR client signal is lost and AIS is inserted, or when the CBR client is restored and AIS is removed, the ODUk and OTUk timing must be maintained. This requirement is met automatically for asynchronous mappings because the ODCa is free-running and therefore independent of the client signal clock. However for bit-synchronous mapping, the ODCb takes its timing from the client. Specifically, the client signal timing is recovered by the clock recovery circuit that resides in the OS/CBR_A_Sk atomic function; the output of this clock recovery circuit is input to the ODCb (see Appendix VI for a summary of the atomic functions). Loss of the client signal results in the ODCb either entering free-run or switching to a free-running AIS clock or Ethernet local fault clock; restoration of the client signal results in the ODCb switching from free-run condition or from a free-running AIS clock to an independent client-signal clock. In addition, there may be a short period between the instant the client input to the clock recovery circuit is lost and the detection of this loss; during this period, the clock recovery circuit output may be off frequency and still be input to the ODCb. In all these cases, [ITU-T G.798] requires that the ODUk clock shall stay within its limits and no frame phase discontinuity shall be introduced. The maximum possible frequency difference between a ± 20 ppm CBRx (e.g., SDH) client and free-running ODCb or free-running AIS clock is 40 ppm (because the largest possible offset for each signal is ± 20 ppm). The maximum possible frequency difference between a ± 100 ppm 1GE, 10GE, 40GE, 100GE or FC-x client and free-running replacement signal (local fault) clock is 200 ppm.

The above requirements mean that the ODCb must adequately filter a frequency step whose size is the maximum possible frequency difference, as indicated above, between the client and either AIS clock or replacement signal (local fault) clock, such that downstream equipment in the OTN, i.e., 3R regenerators, can tolerate the resulting filtered phase transient. Specifically, this means that the phase transient shall not cause buffer overflow in an ODCr that meets the jitter and wander tolerance requirements of clause 6.2. In addition, the ODCb must adequately filter the clock recovery circuit output during the short period between the loss of the client input to the clock recovery circuit and the removal of the clock recovery circuit output from the ODCb input.

If:

- 1) the clock recovery circuit in the OS/CBR_A_So atomic function loses its input and/or the ODCb loses its input and either enters free-run or switches to an AIS clock; or

- 2) the ODCb recovers from AIS to the output of the clock recovery circuit, the ODCb output shall meet the following requirements:
- a) Any initial frequency step shall not exceed 9 ppm.
 - b) Any frequency drift rate following the initial frequency step shall not exceed 200 ppm/s.
 - c) The total change in frequency shall not exceed the maximum possible frequency difference between the client signal and either the AIS clock or the replacement signal (local fault) clock.

Then, the ODCb is allowed to lose synchronization for a period up to 600 ms.

NOTE – An ODCb, for one client is not required to support another client simultaneously.

Appendix I

Relationship between network interface jitter requirements and input jitter tolerance

(This appendix does not form an integral part of this Recommendation)

I.1 Network interface jitter requirements

For all OTUk bit rates, two network limits are specified in Table 5.1-1: one for a wideband measurement filter and one for a high-band measurement filter. The general form of this specification is shown in Table I.1-1 and is applicable to all OTUk rates.

Table I.1-1 – General form for OTUk interface jitter requirements

Measurement filter	Measurement bandwidth	Peak-to-peak amplitude (UIpp)
Wideband	f_1 to f_4	A_2
High-band	f_3 to f_4	A_1

At any OTUk interface, the following output jitter specifications must be met:

- 1) Timing jitter as measured over a 60-second interval with a band pass filter with a lower cut-off frequency f_1 and a minimum upper cut-off frequency f_4 shall not exceed A_2 unit intervals (UI) peak-to-peak.
- 2) Timing jitter as measured over a 60-second interval with a band pass filter with a lower cut-off frequency f_3 and a minimum upper cut-off frequency f_4 shall not exceed A_1 unit intervals (UI) peak-to-peak.

The roll off at lower cut-off frequency, f_1 and f_3 , shall be 20 dB/decade. The roll off at the upper cut-off frequency, f_4 , shall be –60 dB/decade.

The value of f_1 reflects the narrowest timing circuit cut-off frequency expected in a line system. The timing circuit may time a regenerator's output signal and could be implemented as a phase-locked loop (PLL). Jitter at frequencies higher than the bandwidth of this PLL will be partially absorbed by the PLL's buffer. The portion not absorbed could cause transmission errors due to buffer spill. Jitter at frequencies lower than this bandwidth will simply pass through without affecting transmission performance. The value of f_1 therefore represents the narrowest bandwidth that might be used in this output timing circuit. The value of f_3 is related to the bandwidth of input timing acquisition circuitry. Jitter at frequencies higher than this bandwidth will constitute alignment jitter and will cause an optical power penalty due to its effect on the eye pattern. This high frequency jitter must therefore be limited to the same degree that equipment specifications limit optical power penalty through jitter tolerance.

The value of f_4 reflects reasonable measurement limitations and is specified to establish minimum measurement bandwidth requirements. f_4 is chosen to include all expected, significant alignment jitter. A value between one and two decades beyond the widest expected 3R regenerator 3 dB bandwidth (cut-off frequency) was chosen (see clause A.7.2).

The values of A_1 and A_2 are directly related to input sinusoidal jitter tolerance. These parameters have built-in margin and are reasonably conservative because:

- 1) sinusoidal jitter represents worst-case jitter with respect to input jitter tolerance; and
- 2) accumulated OTN line (OTUk) jitter will not be sinusoidal (instead, it will be noisy).

I.2 Input jitter tolerance of network equipment

The general form of the weighting filters used for measuring output jitter at a network interface given in Table I.1-1 are reproduced here in Figure I.2-1. The filter responses are given in Equations (I.2-1) and (I.2-2).

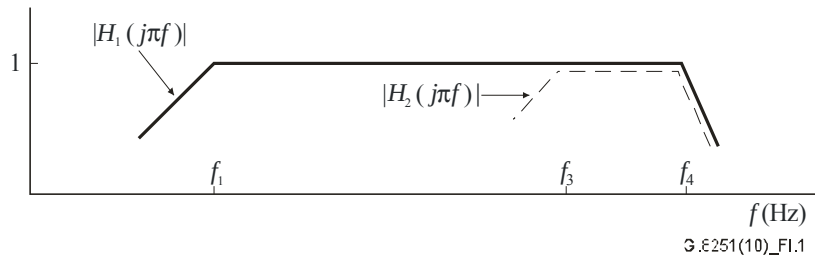


Figure I.2-1 – Weighting filters for measuring network interface output jitter

$$H_1(s) = \frac{s}{s + \omega_1} \cdot \frac{\omega_4^3}{s^3 + 2\omega_4 s^2 + 2\omega_4^2 s + \omega_4^3} \quad (I.2-1)$$

$$|H_1(2\pi jf)|^2 = \frac{f^2}{f^2 + f_1^2} \cdot \frac{f_4^6}{f^6 + f_4^6}$$

$$H_2(s) = \frac{s}{s + \omega_3} \cdot \frac{\omega_4^3}{s^3 + 2\omega_4 s^2 + 2\omega_4^2 s + \omega_4^3} \quad (I.2-2)$$

$$|H_2(2\pi jf)|^2 = \frac{f^2}{f^2 + f_3^2} \cdot \frac{f_4^6}{f^6 + f_4^6}$$

where:

$$\omega_1 = 2\pi f_1 \quad \omega_3 = 2\pi f_3 \quad \omega_4 = 2\pi f_4$$

The first term of the function $H_1(s)$ represents the phase error transfer function $H_e(s)$ of some PLL, and its amplitude of $A_2 = 1.5$ UIpp represents its phase error tolerance.

Then the corresponding input phase tolerance of the PLL is given by:

$$A_{tol1} = \frac{A_2}{|H_1(j2\pi f)|} \quad (I.2-3)$$

Similarly, the input phase tolerance corresponding to $H_2(s)$ and its amplitude of $A_1 = 0.15$ UIpp is given by:

$$A_{tol2} = \frac{A_1}{|H_2(j2\pi f)|} \quad (I.2-4)$$

These sinusoidal jitter tolerance masks are illustrated in Figure I.2-2. If unweighted sinusoidal jitter at a network interface satisfies both of these masks, it also satisfies (i.e., lies below) a single mask that is the lower of the two masks for each frequency. Such a combined mask is shown as a dashed curve in Figure I.2-3.

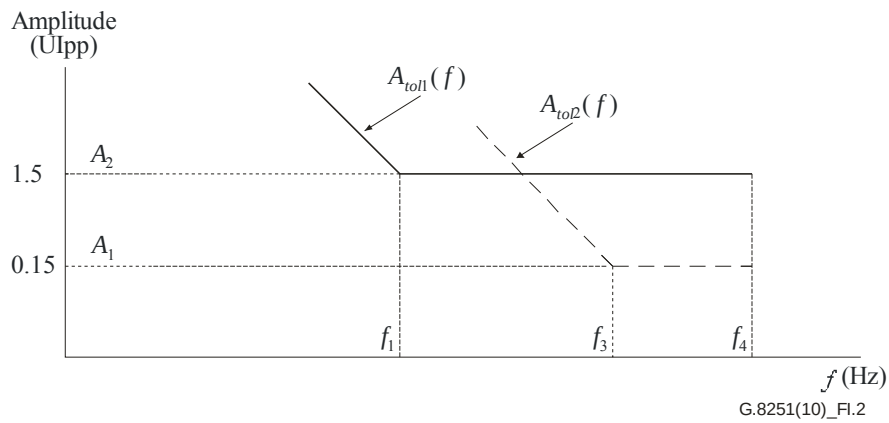


Figure I.2-2 – Upper bounds on sinusoidal jitter amplitude

Figure I.2-3 compares this combined mask with the OTU1 input jitter sinusoidal tolerance mask. They are the same in the range $500 \text{ Hz} < f < 20 \text{ MHz}$.

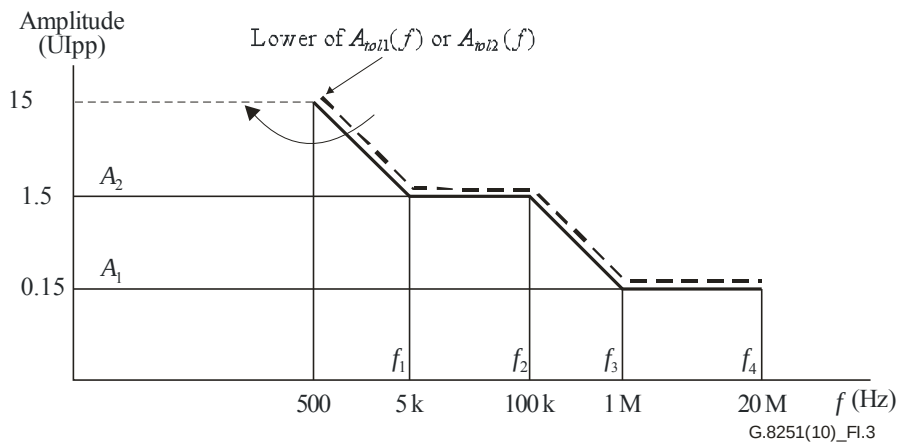


Figure I.2-3 – Upper bound on sinusoidal output jitter at an OTU1 interface [lower of $A_{tol1}(f)$ or $A_{tol2}(f)$] compared with input jitter/wander tolerance mask

Appendix II

Effect of OTN on the distribution of synchronization via STM-N and synchronous Ethernet clients

(This appendix does not form an integral part of this Recommendation)

II.1 Introduction

As stated in clause 1 (Scope) and in clause 5.2, the OTN physical layer will not be used to transport synchronization. The current standard for the transportation of synchronization over SDH or synchronous Ethernet is adequate. However, the introduction of the optical transport network (OTN) changes the position of an STM-N or synchronous Ethernet signal in the sense that it can now be a client signal within the OTN layer network. This might affect the synchronization network architecture, since the STM-N or synchronous Ethernet signal is currently used as a carrier for synchronization information (next to its payload-carrying capacity). This appendix analyses possible effects on the synchronization network of long-term wander (i.e., over time scales on the order of one day) associated with the introduction of the OTN layer. Appendix VII describes hypothetical reference models (HRMs) used to analyse the jitter and short-term wander associated with the introduction of the OTN layer. Appendix VII also provides a summary description of simulations based on the HRMs and an adapted ITU-T G.803 synchronization reference chain. Appendix VIII provides more detailed description of the simulation model used for OTN client payload jitter and wander accumulation, and describes some of the simulation results.

II.2 Provisional synchronization reference chain

To analyse the effect of the introduction of the OTN on the synchronization distribution network, the synchronization reference chain from [ITU-T G.803] has been provisionally adapted. The original reference chain contains 1 PRC, 10 SSUs and 60 SECs/EECs, under the condition that not more than 20 SECs/EECs are concatenated between any pair of SSUs. The provisionally adapted reference model has still 1 PRC and 10 SSUs, but the inter-SSU connections are now presumed to be over the OTN network. At the end of the chain there are 20 SECs/EECs (see Figure II.2-1).

NOTE – A more detailed analysis is done in Appendix VII and the correct reference chain is shown in Figure VII.3-2.

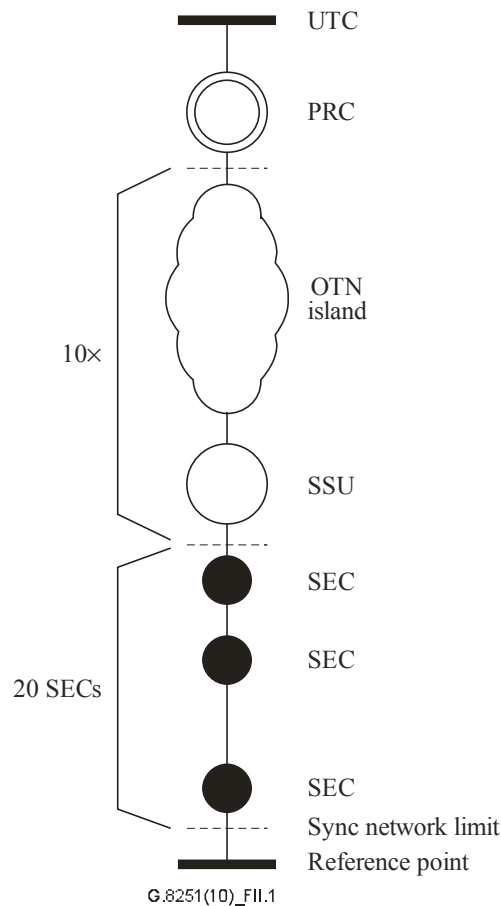


**Figure II.2-1 – Adapted synchronization reference chain (provisional).
For a synchronous Ethernet client, the SECs are replaced by EECs**

The OTN island in this model has to be understood as a conglomerate of OTN equipment that performs mapping of an STM-N into its corresponding ODUk, multiple NEs that perform (de)multiplexing and cross-connecting of ODUks and transport over optical channels (including optical multiplexing and cross-connecting), and finally demapping of the STM-N.

The composition of each OTN island in the provisional model is assumed to consist of 1 OTN network element that performs the mapping operation and nine other OTN network elements that perform multiplexing operations of ODUks.

In fact, the distribution of the OTN islands over the adapted synchronization reference model is not important for the long-term wander accumulation. In the model there is one OTN island between each SSU pair, but another distribution is also allowed. For example, five inter-SSU connections may have two OTN islands each while the other interconnections make use of the STM-N physical layer. Also, the number of multiplexing/mapping network elements may be freely re-divided over the OTN islands, to create some "large" and some "small" OTN islands.

II.3 Synchronization network limit

The network limit that is valid at the end of the synchronization reference chain, as defined in [ITU-T G.803], allows for 5 μ s of wander over 24 hours for Option 1 (see [ITU-T G.823]) and 1.86 μ s over 24 hours for Option 2 (see [ITU-T G.824]). It was agreed that in the adapted synchronization reference chain, 10% of the Option 1 budget should be adequate for the combined effect of the OTN islands, i.e., 500 ns (or $\sim$ 78 bytes at 1.25 Gbit/s).

Since there are 10 OTN islands in the synchronization reference chain, each with 10 mapper/multiplexer NEs (all assumed to work at the 1.25 Gbit/s rate which represents the worst