I n t e r n a t i o n a l   T e l e c o m m u n i c a t i o n   U n i o n

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OF ITU

O.172

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SERIES O: SPECIFICATIONS OF MEASURING EQUIPMENT

Equipment for the measurement of digital and analogue/digital parameters

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Jitter and wander measuring equipment for digital systems which are based on the synchronous digital hierarchy (SDH)

ITU-T Recommendation O.172

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ITU-T O-SERIES RECOMMENDATIONS

SPECIFICATIONS OF MEASURING EQUIPMENT

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ITU-T Recommendation O.172

Jitter and wander measuring equipment for digital systems which are based on the synchronous digital hierarchy (SDH)

Summary

This Recommendation specifies instrumentation that is used to generate and measure jitter and wander in digital systems based on the SDH. Measurement requirements for both SDH line interfaces and SDH tributary interfaces operating at PDH bit rates are addressed in this Recommendation.

The requirements for the characteristics of the jitter and wander measuring equipment that are specified in this Recommendation must be adhered to in order to ensure consistency of results between equipment produced by different manufacturers.

Source

ITU-T Recommendation O.172 was approved on 13 April 2005 by ITU-T Study Group 4 (2005-2008) under the ITU-T Recommendation A.8 procedure.

Keywords

Input jitter tolerance, Input wander tolerance, Jitter generation, Jitter measurement, Jitter transfer function, Output jitter, Output wander, Phase transients, Pointer jitter, Pointer sequence generation, Wander generation, Wander measurement, Wander noise transfer.

FOREWORD

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Introduction

The timing and synchronization performance of SDH networks and SDH network equipment elements is specified in a number of ITU-T Recommendations, using jitter and wander parameters. This Recommendation specifies the various characteristics of jitter/wander measuring equipment, which are needed in order to support the requirements of these ITU-T Recommendations and to perform other test and measuring tasks.

This Recommendation has been developed to ensure maximum compatibility with the relevant SDH network and equipment measurement requirements, whilst maintaining backwards compatibility with the associated PDH test equipment requirements of ITU-T Rec. O.171 [18] where possible.

ITU-T Recommendation O.172

Jitter and wander measuring equipment for digital systems which are based on the synchronous digital hierarchy (SDH)

1 Scope

This Recommendation specifies test instrumentation that is used to generate and measure timing jitter and synchronization wander in digital systems based on the Synchronous Digital Hierarchy (SDH).

This Recommendation also specifies requirements for the measurement of SDH tributaries operating at PDH bit rates.

The test instrumentation consists principally of a jitter/wander measurement function and a jitter/wander generation function. Measurements can be performed at the physical layer of SDH systems. A bit-error rate test set may also be required for certain types of measurements; this may be part of the same instrumentation or it may be physically separate.

Test instrumentation for the generation and measurement of jitter and wander in digital systems based on the Plesiochronous Digital Hierarchy (PDH) is specified in ITU-T Rec. O.171 [18].

It is recommended that ITU-T Recs G.783 [6], G.812 [9], G.813 [10], G.825 [13] and G.798 [15] be read in conjunction with this Recommendation.

2 References

2.1 Normative 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.

[1] ITU-T Recommendation G.691 (2003), *Optical interfaces for single channel STM-64 and other SDH systems with optical amplifiers*.

[2] ITU-T Recommendation G.693 (2005), *Optical interfaces for intra-office systems*.

[3] ITU-T Recommendation G.703 (2001), *Physical/electrical characteristics of hierarchical digital interfaces*.

[4] ITU-T Recommendation G.707/Y.1322 (2003), *Network node interface for the synchronous digital hierarchy (SDH)*.

[5] ITU-T Recommendation G.772 (1993), *Protected monitoring points provided on digital transmission systems*.

[6] ITU-T Recommendation G.783 (2004), *Characteristics of synchronous digital hierarchy (SDH) equipment functional blocks*.

[7] ITU-T Recommendation G.810 (1996), *Definitions and terminology for synchronization networks*.

[8] ITU-T Recommendation G.811 (1997), *Timing characteristics of primary reference clocks*.

[9] ITU-T Recommendation G.812 (2004), *Timing requirements of slave clocks suitable for use as node clocks in synchronization networks*.

[10] ITU-T Recommendation G.813 (2003), *Timing characteristics of SDH equipment slave clocks (SEC)*.

[11] ITU-T Recommendation G.823 (2000), *The control of jitter and wander within digital networks which are based on the 2048 kbit/s hierarchy*.

[12] ITU-T Recommendation G.824 (2000), *The control of jitter and wander within digital networks which are based on the 1544 kbit/s hierarchy*.

[13] ITU-T Recommendation G.825 (2000), *The control of jitter and wander within digital networks which are based on the synchronous digital hierarchy (SDH)*.

[14] ITU-T Recommendation G.957 (1999), *Optical interfaces for equipments and systems relating to the synchronous digital hierarchy*.

[15] ITU-T Recommendation G.798 (2004), *Characteristics of optical transport network hierarchy equipment functional blocks*.

[16] ITU-T Recommendation O.3 (1992), *Climatic conditions and relevant tests for measuring equipment*.

[17] ITU-T Recommendation O.150 (1996), *General requirements for instrumentation for performance measurements on digital transmission equipment*.

[18] ITU-T Recommendation O.171 (1997), *Timing jitter and wander measuring equipment for digital systems which are based on the plesiochronous digital hierarchy (PDH)*.

[19] ITU-T Recommendation O.181 (2002), *Equipment to assess error performance on STM-N interfaces*.

[20] ITU-R Recommendation F.750-4 (2000), *Architectures and functional aspects of radio-relay systems for synchronous digital hierarchy (SDH)-based networks*.

2.2 Informative references

[21] ANSI T1.105.03-2003, *Synchronous Optical Network (SONET) – Jitter and Wander at Network and Equipment Interfaces**.

[22] ANSI T1.105.06-2002, *Synchronous Optical Network (SONET): Physical Layer Specifications.**

3 Definitions

For the purposes of this Recommendation, the following definitions apply (refer to ITU-T Rec. G.810 [7]):

3.1 (timing) jitter: The short-term variations of the significant instances of a digital signal from their ideal positions in time (where "short-term" implies that these variations are of frequency greater than or equal to 10 Hz).

3.2 wander: The long-term variations of the significant instances of a digital signal from their ideal position in time (where "long-term" implies that these variations are of frequency less than 10 Hz).

3.3 time interval error (function): The difference between the measure of a time interval as provided by a clock and the measure of that same time interval as provided by a reference clock.

* T1 standards are maintained since November 2003 by ATIS.

It may be useful to note that ITU-T Rec. G.810 [7] provides additional definitions and abbreviations used in timing and synchronization Recommendations. It also provides background information on the need to limit phase variation and the impairments on digital systems.

4 Abbreviations

This Recommendation uses the following abbreviations:

AU-n Administrative Unit, level n

CMI Coded Mark Inversion

MTIE Maximum Time Interval Error

NRZ Non Return to Zero

PDH Plesiochronous Digital Hierarchy

PJE Pointer Justification Event

PLL Phase-Locked Loop

ppm parts per million

PRBS Pseudo Random Binary Sequence

RMS Root-Mean-Square

SDH Synchronous Digital Hierarchy

STM-N Synchronous Transport Module, level N

TDEV Time Deviation

TIE Time Interval Error

TSS Test Signal Structure

TU-m Tributary Unit, level m

UI Unit Interval

UIpp Unit Interval, peak-to-peak

5 Conventions

For the purposes of this Recommendation, the following conventions are adopted:

a) Particular interface signals used are denoted either by their standardized signal formats, e.g., STM-1 or by their bit rate, e.g., 139 264 kbit/s. The default physical format of SDH interfaces is considered to be optical and the default physical format of PDH interfaces is considered to be electrical.

b) Where the electrical form of an SDH interface is specifically used in this Recommendation, the interface is denoted by "e", e.g., STM-1e (refer also to clause 7).

c) Particular interface signals used may be categorized either as SDH line interfaces, or as SDH tributary interfaces. In this Recommendation, SDH line interfaces refer to those which support STM-N signals, whilst SDH tributary interfaces refer to those which support signals operating at PDH bit rates.

6 Functional block diagram

Figure 1 shows the block diagram of the instrumentation in general form, identifying the main functions that are addressed in this Recommendation. The figure does not describe a specific implementation.

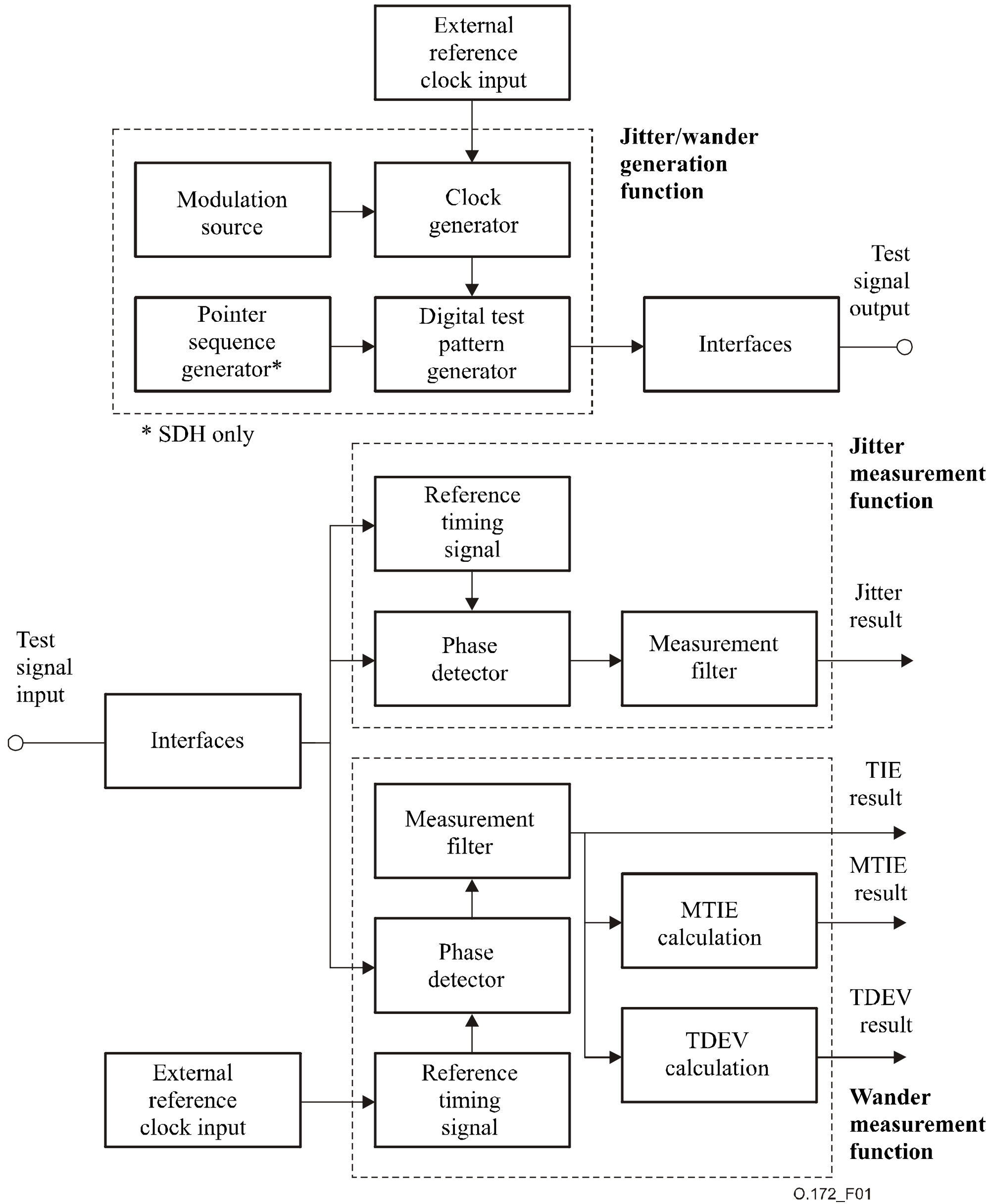

Figure 1/O.172 – Functional block diagram for jitter and wander test set

7 Interfaces

7.1 Optical interfaces

The instrumentation shall be capable of operating at one or more of the following bit rates and corresponding optical interface characteristics as defined in the appropriate clauses of ITU-T Recs G.957 [14] and G.691 [1] and also ANSI T1.105.06 [22] (for 51 840 kbit/s interfaces).

– STM-0 51 840 kbit/s

– STM-1 155 520 kbit/s

– STM-4 622 080 kbit/s

– STM-16 2 488 320 kbit/s
– STM-64 9 953 280 kbit/s
– STM-256 39 813 120 kbit/s

7.2 Electrical interfaces

The instrumentation shall be capable of operating at one or more of the following bit rates and corresponding electrical interface characteristics as defined in the appropriate clauses of ITU-T Rec. G.703 [3] and also ITU-R Rec. F.750-4 [20] (for 51 840 kbit/s electrical interfaces). However, for all bit rates the signal applied to the input of the jitter/wander measuring circuit shall be a nominal rectangular pulse. Other signal shapes may produce inter-symbol interference – which cannot be corrected by simple line equalization – thus affecting measurement accuracy.

– 1544 kbit/s
– 2048 kbit/s
– 6312 kbit/s
– 34 368 kbit/s
– 44 736 kbit/s
– 51 840 kbit/s, STM-0e
– 139 264 kbit/s
– 155 520 kbit/s, STM-1e

The jitter/wander measurement function input and jitter/wander generation function output ports shall have a return loss as specified in the appropriate clauses of ITU-T Rec. G.703 [3].

As an option, the jitter/wander measurement function shall be capable of measuring jitter/wander at a clock output port when such an access is provided on digital equipment.

7.3 External reference clock input

The measuring equipment shall accept data signals at bit rates of 1544 kbit/s or 2048 kbit/s as a reference. If 2048 kbit/s can be accepted, the equipment shall also accept a clock signal at 2048 kHz as a reference. The characteristics of the clock signals shall be in accordance with ITU-T Rec. G.703 [3].

7.4 Input interface sensitivity

The jitter/wander measurement function is required to operate satisfactorily under the following input conditions:

a) the specification for equipment optical interfaces defined in ITU-T Recs G.957 [14] and G.691 [1];
b) the specification for equipment electrical interfaces defined in ITU-T Rec. G.703 [3];
c) protected monitoring points as defined in ITU-T Rec. G.772 [5].

8 Jitter/wander generation function

Tests of digital equipment may be made with either a jittered, wandered or a non-jittered/wandered digital signal. This will require the digital test pattern generator, clock generator and modulation source shown in Figure 1.

8.1 Modulation source

The modulation source, required to perform tests in conformance with relevant Recommendations, may be provided within the clock generator and/or digital test pattern generator or it may be provided separately. In this Recommendation, the modulation source is defined to be sinusoidal. However, other stimuli may be required for certain tests.

8.2 Clock generator

It shall be possible to phase-modulate the clock generator from the modulation source and to indicate the peak-to-peak phase deviation of the modulated signal.

The generated peak-to-peak jitter/wander and the modulating frequencies shall meet the minimum requirements of Table 3 and Figure 3.

If the output interfaces for the modulated clock signal and/or the external timing reference signal are provided, the minimum amplitude shall be 1 Volt peak-to-peak into 75 Ω or 0.25 Volt peak-to-peak into 50 Ω.

8.2.1 Accuracy of the clock generator

The frequency deviation of the internal clock signal from its nominal value shall be less than ±4.6 ppm.

As an option, the clock generator may provide adjustable frequency offset of sufficient magnitude to facilitate testing across the clock tolerance range of the equipment-under-test, e.g., ±10 ppm to ±100 ppm, as defined for the various bit rates in ITU-T Recs G.703 [3] and G.813 [10].

It shall be possible to phase-lock the generation function to an external reference clock source of arbitrary accuracy; refer also to 7.3.

8.3 Digital test pattern generator

The jitter/wander measurement function will normally be used in conjunction with any suitable digital test pattern generator providing the following facilities.

8.3.1 Digital test patterns

The digital test pattern generator shall be capable of providing one or more of the following signals, for use at STM-N bit rates:

a) framed SDH signals in accordance with ITU-T Rec. G.707/Y.1322 [4];

b) structured test signals in accordance with ITU-T Rec. O.181 [19], dependent on the type of network element to be tested;

c) structured test signals defined in Annex A.

8.3.2 Digital test patterns for SDH tributary signals

The test sequence generator shall be capable of providing the following signals:

For use at bit rates of 2048 kbit/s, 6312 kbit/s and 44 736 kbit/s, a pseudo random test sequence of $2^{15} – 1$ length corresponding to 5.3/O.150 [17].

For use at bit rates of 1 544 kbit/s, 6 312 kbit/s and 44 736 kbit/s, a pseudo random test sequence of $2^{20} – 1$ bit length corresponding to 5.5/O.150 [17].

For use at bit rates of 34 368 kbit/s and 139 264 kbit/s, a pseudo random test sequence of $2^{23} – 1$ bit length corresponding to 5.6/O.150 [17].

For use at all bit rates, a 10001000 repetitive test sequence.

As an option and for use at all bit rates:

a) two freely programmable 8-bit test sequences capable of being alternated at a low rate (e.g., from 10 Hz to 100 Hz);

b) a freely programmable 16-bit test sequence.

8.4 Pointer sequence generator

In order to test the effect of pointer justification events (PJEs) on SDH desynchronizer equipment, the digital test pattern generator shall be capable of generating complete test sequences of pointer justifications in accordance with the appropriate clauses of ITU-T Rec. G.783 [6].

As an option, the equipment may provide additional PJE control functions to facilitate further pointer jitter testing.

Appendix III provides further information regarding the test set configuration and capability for testing using pointer sequences.

8.4.1 Pointer test sequence generation capability

The equipment shall provide a minimum set of pointer test sequences applicable at particular SDH tributary bit rates, denoted by "X" in Table 1, in accordance with clause 10/G.783 [6].

For particular SDH tributary bit rates, the pointer adjustments shall be applied either to the AU-n or the TU-m pointers, as shown in Table 1. The direction or polarity of the pointer test sequence shall be selectable between incrementing or decrementing pointer values.

The test procedure specified in clause 15/G.783 [6] shall be followed.

Table 1/O.172 – G.783 pointer test sequence description

G.783 pointer test sequence		SDH tributary bit rate (kbit/s) and SDH container					
		1544	2048	6312	34 368	44 736	139 264
ID	Description	TU-11	TU-12	TU-2	TU-3	AU-3	AU-4
a	Single Alternating		X	(Note)	X		X
b	Regular + Double		X		X		X
c	Regular + Missing		X		X		X
d	Double Alternating				X		X
e	Single	X				X	
f	Burst					X	
g1	Periodic 87-3					X	X
g2	Periodic 87-3 with Add					X	X
g3	Periodic 87-3 with Cancel					X	X
h1	Periodic	X				X	
h2	Periodic with Add	X				X	
h3	Periodic with Cancel	X				X	
i	Phase Transient					X	
j1	Periodic 26-1	X					
j2	Periodic 26-1 with Add	X					
j3	Periodic 26-1 with Cancel	X					
NOTE – Pointer test sequences for 6312 kbit/s, TU-2 are for further study.							

The time intervals between PJEs within a test sequence depend on the particular sequence and the bit rate of the SDH tributary under test. ITU-T Rec. G.783 [6] shall be consulted for precise detail of the pointer sequences applicable to a particular tributary bit rate. Table 2 specifies the time intervals that shall be provided between PJEs for particular SDH tributary bit rates, and which are illustrated in a generic fashion in Figure 2. Time intervals T1 and T2 may be adjustable to values greater than the minimum shown in Table 2.

Table 2/O.172 – Time intervals between G.783 pointer justification events

	SDH tributary bit rate (kbit/s)					
Time interval	**1544**	**2048**	**6312**	**34 368**	**44 736**	**139 264**
T1 (minimum)	30 s	10 s	(Note)	10 s	30 s	10 s
T2 (minimum)	1 s	750 ms	(Note)	(Note)	34 ms	(Note)
T3	2 ms	2 ms	(Note)	(Note)	0.5 ms	(Note)
NOTE – Value is for further study in ITU-T Rec. G.783 [6].						

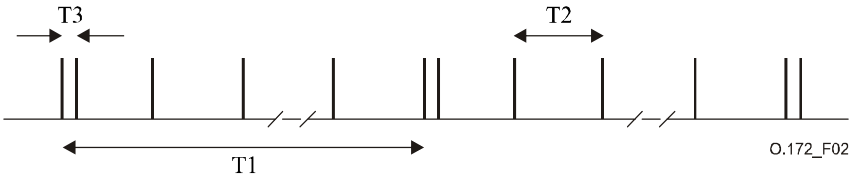

Figure 2/O.172 – Generic G.783 pointer sequence, illustrating the time intervals of Table 1

8.5 Minimum jitter/wander generation capability

The jitter/wander amplitude/frequency characteristic of the generation function shall meet the minimum requirements of Figure 3 and Table 3 for SDH line signals or Table 3a for SDH tributary signals.

Table 3/O.172 – Minimum amplitude of adjustable generated jitter/wander amplitude versus jitter/wander frequency for SDH line signals

Signal	Minimum peak-to-peak jitter/wander amplitude [UIpp]					Jitter/wander frequency breakpoints [Hz]									
	A_0	A_1	A_2	A_3	A_4	f_0	f_{12}	f_{11}	f_{10}	f_9	f_8	f_1	f_2	f_3	f_4
STM-0e, STM-0	*	*	20	2	0.2	*	*	*	*	10	30	300	2 k	20 k	400 k
STM-1e, STM-1	3600	400	50	2	0.2	12 µ	178 µ	1.6 m	15.6 m	125 m	19.3	500	6.5 k	65 k	1.3 M
STM-4	14400	1600	200	2	0.2	12 µ	178 µ	1.6 m	15.6 m	125 m	9.65	1 k	25 k	250 k	5 M
STM-16	57600	6400	800	2	0.2	12 µ	178 µ	1.6 m	15.6 m	125 m	12.1	5 k	100 k	1 M	20 M
STM-64	230400	25600	3200	2	0.2	12 µ	178 µ	1.6 m	15.6 m	125 m	12.1	20 k	400 k	4 M	80 M
STM-256	FFS	FFS	FFS	FFS	FFS	FFS	FFS	FFS	FFS	FFS	FFS	FFS	FFS	FFS	FFS
NOTE 1 – Values denoted by "*" are not defined.															
NOTE 2 – Values are based on the requirements of ITU-T Rec. G.825 [13].															
NOTE 3 – Values for STM-0 are based on the requirements of ANSI T1.105.03 [21].															
NOTE 4 – FFS denotes that the value is for further study.															

Table 3a/O.172 – Minimum amplitude of adjustable generated jitter/wander amplitude versus jitter/wander frequency for SDH tributaries

Signal [kbit/s]	Minimum peak-to-peak jitter/wander amplitude [UIpp]					Jitter/wander frequency breakpoints [Hz]									
	A_0	A_1	A_2	A_3	A_4	f_0	f_{12}	f_{11}	f_{10}	f_9	f_8	f_1	f_2	f_3	f_4
1544	40	*	20	10	0.5	12 µ	50 m	*	*	100 m	5	10	400	8 k	40 k
2048	50	*	30	10	0.5	12 µ	12 m	*	*	20 m	3.3	10	900	18 k	100 k
6312	150	*	50	10	0.5	12 µ	3 m	*	*	10 m	0.4	2	1600	32 k	60 k
34 368	200	*	50	10	0.5	10 m	50 m	*	*	200 m	20	100	1 000	20 k	800 k
44 736	1000	*	100	10	0.5	12 µ	11 m	*	*	110 m	2.19	21.9	5000	100 k	400 k
139 264	800	*	200	10	0.5	10 m	33 m	*	*	130 m	5	100	500	10 k	3500 k

NOTE 1 – Values denoted by "*" are not defined.
NOTE 2 – These requirements are based on consideration of ITU-T Recs G.823 [11] and G.824 [12].

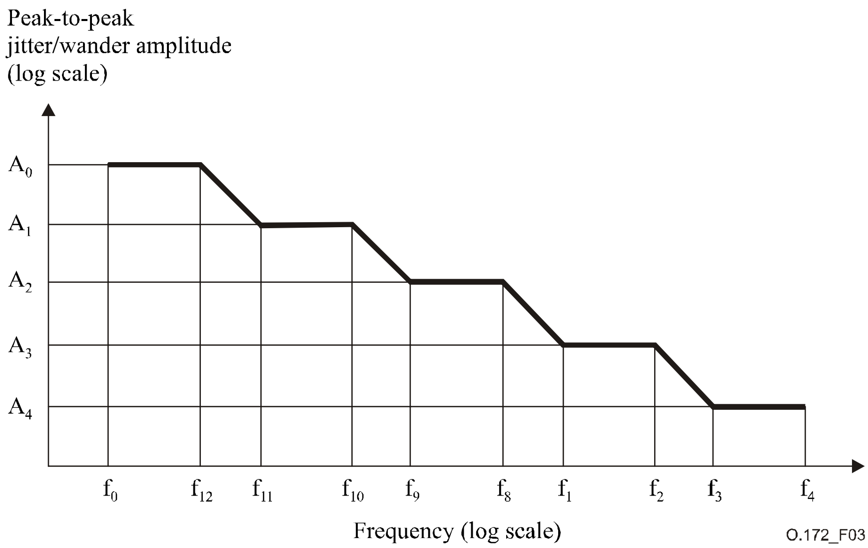

Figure 3/O.172 – Generated jitter/wander amplitude versus jitter/wander frequency

8.6 Generation accuracy

The test signal source shall be compatible with the jitter/wander measurement function in such a way that the overall measuring accuracy is not substantially deteriorated. The generation accuracy may be increased by measuring the jitter/wander applied to the unit under test using a corresponding jitter/wander measuring device.

The generating accuracy of the jitter/wander generation function is dependent upon several factors such as fixed intrinsic error, setting resolution, distortion and frequency response error. In addition, there is an error that is a function of the actual setting.

8.6.1 Phase amplitude error

The amplitude error of sinusoidal jitter/wander generation shall be less than:

$$Q\% \text{ of setting } \pm 0.02 \text{ UIpp}$$

where Q is a variable error specified in Table 4 for SDH line signals and in Table 4a for SDH tributary signals. The frequencies f_0, f_1, f_4 and f_9 used in Tables 4 and 4a are defined in Tables 3 and 3a.

NOTE – This Recommendation excludes any wideband intrinsic jitter/wander components.

8.6.2 Phase slope error

The band-limited peak-to-peak phase slope error in UI/s shall be less than:

$$\frac{(\pm 2.5 \cdot \text{Q\% of setting} \pm 0.05\ \text{UIpp}) \cdot 2\pi f_m}{\sqrt{1 + (f_m / f_{3\text{dB}})^2}}$$

over the range:

$$10\ \text{Hz} \leq f_m \leq 2 \cdot f_3$$

where f_m is the modulation frequency, $f_{3\text{dB}} = 2 \cdot f_3$ ±10% is the bandwidth of the low-pass filter, f_3 is defined in Table 3 for SDH line signals and in Table 3a for SDH tributary signals, and Q is a variable error specified in Table 4 for SDH line signals and in Table 4a for SDH tributary signals. The frequencies f_0, f_1, f_4 and f_9 used in Tables 4 and 4a are defined in Tables 3 and 3a.

See Annex B for the definition of band-limited peak-to-peak phase slope error.

NOTE – This Recommendation includes modulation harmonics (within the low-pass filter bandwidth) due to distortion, but it excludes any wideband intrinsic jitter/wander components.

Table 4/O.172 – Variable error (*Q*) of SDH line jitter/wander generation

Signal	Error, *Q*	Frequency range
STM-0e, STM-0	FFS	f_9 to f_1
	±8%	f_1 to f_4
STM-1e, STM-1	FFS	f_0 to f_1
	±8%	f_1 to 500 kHz
	±12%	500 kHz to f_4
STM-4, STM-16, STM-64	FFS	f_0 to f_1
	±8%	f_1 to 500 kHz
	±12%	500 kHz to 2 MHz
	±15%	2 MHz to f_4
STM-256	FFS	FFS
NOTE – FFS denotes that the value is for further study.		

Table 4a/O.172 – Variable error (*Q*) of SDH tributary jitter/wander generation

Signal	Error, *Q*	Frequency range
1544, 2048, 6312, 44 736	±8%	f_1 to f_4
34 368	±8%	f_1 to 500 kHz
	±12%	500 kHz to f_4
139 264	±8%	f_1 to 500 kHz
	±12%	500 kHz to 2 MHz
	±15%	2 MHz to f_4

8.6.3 Intrinsic jitter/wander of generation function

The intrinsic jitter of the jitter/wander generation function measured in a bandwidth f_1-f_4 as defined in Table 7 with the amplitude set to zero shall be less than:

0.04 UIpp for an output signal with structure defined in Annex A; or

0.02 UIpp for a clock signal.

The specification for maximum allowable intrinsic wander is for further study.

9 Jitter measurement function

9.1 Reference timing signal

A reference timing signal for the phase detector is required. For end-to-end measurements of jitter, it may be derived in the jitter measurement function from the input digital test pattern. For looped measurements, it may be derived from a suitable clock source.

9.2 Measurement capabilities

9.2.1 Measurement range

The jitter measurement function shall be capable of measuring peak-to-peak jitter. The measurement ranges to be provided are optional but for reasons of compatibility the jitter amplitude/jitter frequency characteristic of the jitter measurement function shall meet the minimum requirements of Figure 4 and Table 5 for SDH line signals or Table 5a for SDH tributary signals. The frequencies f_6 to f_4 define the range of jitter frequencies to be measured; capability to measure the range of frequencies lower than f_1 is optional.

NOTE – Operation of the jitter measurement function over one continuous frequency range f_6 to f_4 is optional.

Table 5/O.172 – Minimum amplitude of measured jitter versus jitter frequency

Signal	Minimum peak-to-peak jitter amplitude [UIpp]			Jitter frequency breakpoints [Hz]					
	A_2	A_3	A_4	f_6	f_7	f_1	f_2	f_3	f_4
STM-0e, STM-0	20	2	0.2	10	30	300	2 k	20 k	400 k
STM-1e	50	2	0.1	10	19.3	500	3.25 k	65 k	1.3 M
STM-1	50	2	0.2	10	19.3	500	6.5 k	65 k	1.3 M
STM-4	200	2	0.2	*	10	1 k	25 k	250 k	5 M
STM-16	800	2	0.2	10	12.1	5 k	100 k	1 M	20 M
STM-64	3200	2	0.2	10	12.1	20 k	400 k	4 M	80 M
STM-256	FFS	FFS	FFS	FFS	FFS	FFS	FFS	FFS	FFS

NOTE 1 – Values denoted by "*" are not defined.

NOTE 2 – The accuracy of the instrument is specified between frequencies f_1 and f_4.

NOTE 3 – Values for STM-0 are based on the requirements of ANSI T1.105.03 [21].

Table 5a/O.171 – Minimum measured jitter amplitude versus jitter frequency

Signal [kbit/s]	Minimum peak-to-peak jitter amplitude [UIpp]			Jitter frequency breakpoints [Hz]					
	A_2	A_3	A_4	f_6	f_7	f_1	f_2	f_3	f_4
1544	*	10	0.5	*	*	10	400	8 k	40 k
2048	*	10	0.5	*	*	20	900	18 k	100 k
6312	*	10	0.5	*	*	10	1600	32 k	60 k
34 368	*	10	0.5	*	*	100	1000	20 k	800 k
44 736	*	10	0.5	*	*	10	5000	100 k	400 k
139 264	*	10	0.5	*	*	200	500	10 k	3500 k
NOTE 1 – Values denoted by "*" are not defined.									
NOTE 2 – The accuracy of the instrument is specified between frequencies f_1 and f_4.									

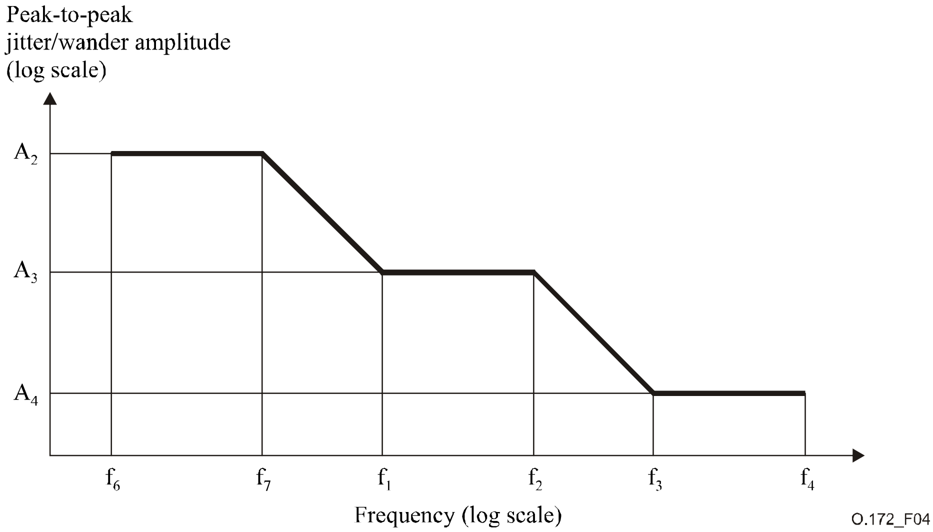

Figure 4/O.172 – Measured jitter amplitude versus jitter frequency

9.2.2 Selectable threshold

When measuring peak-to-peak jitter it shall be possible to count the number of occasions and the period of time for which a given selectable threshold of jitter is exceeded. It shall be possible to record these events by means of an external counter, or an internal counter as an option.

It shall be possible to set the threshold at any selected value within the measuring range of the jitter measurement function.

9.2.3 Measurement of RMS jitter

Measurement of RMS jitter may be performed internally within the instrumentation, or externally using the analogue output mentioned in 9.5.1.

9.2.4 Input phase tolerance for SDH tributary signals

The test set shall tolerate input sinusoidal phase variation at particular tributary bit rates, according to the following frequency/amplitude specifications of Table 6. These frequency/amplitude values represent the relevant worst-case pointer test sequences defined in ITU-T Rec. G.783 [6].

Table 6/O.172 – Input phase tolerance of test set when measuring SDH tributary jitter

Bit rate [kbit/s]	Input phase variation	
	Amplitude [UIpp]	Frequency [Hz]
1544	17	3.0
2048	30	0.5
6312	FFS	FFS
34 368	22	5.0
44 736	60	1.5
139 264	75	1.5
NOTE – FFS denotes that the value is for further study.		

In this context, "tolerate" means that the test set shall measure within the accuracy specified in this Recommendation, considering that the input phase variation may have been attenuated by the applied measurement filters.

9.3 Measurement bandwidths

The measurement bandwidth shall be limited in order to measure the specified jitter spectra as defined in relevant Recommendations and for other uses. The bandwidth f_1-f_4 or f_3-f_4 of the jitter measurement function shall be in accordance with Table 7 for SDH line signals and with Table 7a for SDH tributary signals.

Table 7/O.172 – Jitter measurement function bandwidth for SDH line signals

Signal	Jitter measurement bandwidth (–3 dB cut-off frequencies)			
	f_1 [Hz] high-pass	f_{12} [Hz] high-pass	f_3 [Hz] high-pass	f_4 [Hz] low-pass
STM-0e, STM-0	100	–	20 k	400 k
STM-1e,	500	–	65 k	1.3 M
STM-1	500	12 k	65 k	1.3 M
STM-4	1 k	12 k	250 k	5 M
STM-16	5 k	12 k	1 M	20 M
STM-64	20 k	–	4 M	80 M
STM-256	80 k	–	16 M	320 M
NOTE 1 – Values for STM-0 are based on the requirements of ANSI T1.105.03 [21]. NOTE 2 – Values for STM-256 are to be considered provisional, since network requirements are not yet defined in ITU-T Rec. G.825 [13]. NOTE 3 – The f_{12} high-pass filter is optional.				

Table 7a/O.172 – Jitter measurement function bandwidth for SDH tributary signals

Bit rate [kbit/s]	Jitter measurement bandwidth (–3 dB cut-off frequencies)		
	f_1 [Hz] high-pass	f_3 [Hz] high-pass	f_4 [Hz] low-pass
1544	10	8 k	40 k
2048	20	18 k (0.7 k)	100 k
6312	10	3 k	60 k
34 368	100	10 k	800 k
44 736	10	30 k	400 k
139 264	200	10 k	3.5 M
NOTE – Two values are specified for f_3 at 2048 kbit/s. The value shown in parenthesis only apply to measurements at certain national interfaces.			

9.3.1 Frequency response of jitter measurement function for SDH line signals

The response of all filters within the pass band shall be such that the accuracy requirements of the jitter measurement function are met (refer to 9.4).

For all SDH line bit rates, the following requirements apply to the jitter measurement function when the measurement filters at frequencies f_1, f_3 and f_4 are used:

a) The high-pass measurement filters with cut-off frequencies f_1 and f_3 have a first-order characteristic and a roll-off of 20 dB/decade.

b) The nominal f_1 and f_3 cut-off frequencies for each bit rate are specified in Table 7 and the nominal –3 dB point of the measurement filters shall be at frequencies f_1 ± 10% and f_3 ± 10%, respectively.

c) The low-pass measurement filter with cut-off frequency f_4 has a maximally-flat, Butterworth characteristic and a roll-off of –60 dB/decade.

d) The nominal f_4 cut-off frequency for each bit rate is specified in Table 7 and the –3 dB point of the measurement filter shall be at a frequency f_4 ± 10%.

e) The maximum attenuation of the measurement filters shall be at least 60 dB.

These jitter measurement functional requirements are compatible with ITU-T Rec. G.825 [13].

9.3.2 Frequency response of jitter measurement function for SDH tributary signals

The response of all filters within the pass band shall be such that the accuracy requirements of the jitter measurement function are met (refer to 9.4).

For all SDH tributary bit rates, the following requirements apply to the jitter measurement function when the measurement filters at frequencies f_1, f_3 and f_4 are used:

a) The high-pass measurement filters with cut-off frequency f_1 or f_3 have a first-order characteristic and a roll-off of 20 dB/decade.

b) The nominal f_1 and f_3 cut-off frequency for each bit rate is specified in Table 7a and the nominal –3 dB point of the measurement filters shall be at a frequency f_1 ± 10% and f_3 ± 10% respectively.

c) The low-pass measurement filter with cut-off frequency f_4 has a maximally-flat, Butterworth characteristic and a roll-off of at least –60 dB/decade for bit rates 2048, 34 368 and 139 264 kbit/s and –20 dB/decade for bit rates 1544, 6312 and 44 736 kbit/s.

d) The nominal f_4 cut-off frequency for each bit rate is specified in Table 7a and the nominal −3 dB point of the measurement filter shall be at a frequency f_4 ±10%.

e) The maximum attenuation of the measurement filters shall be at least 60 dB.

f) In addition, the following requirements apply when the high-pass filter function is at f_1. The variable error of the measurement filters below f_1 shall be as defined in Table 10A for frequency f_1. A second filter pole is allowed at a frequency of less than 0.1 Hz, where the roll-off characteristic can increase to 40 dB/decade.

These jitter measurement functional requirements are compatible with ITU-T Recs G.783 [6], G.823 [11] and G.824 [12].

Appendix IV illustrates how these filter requirements and the specifications of the following subclauses may be combined into a total jitter measurement function response.

9.4 Measurement accuracy

9.4.1 Measurement result accuracy

The measuring accuracy of the jitter measurement function is dependent upon several factors such as fixed intrinsic error, frequency response and digital test pattern-dependent error of the internal reference timing circuits. In addition there is an error that is a function of the actual reading.

The accuracy of the jitter measurement shall not be affected by frequency offset on the input signal that is within the limits defined for the various bit rates in ITU-T Recs G.703 [3], G.783 [6], G.813 [10] and G.798 [15].

The measurement accuracy is specified using an input signal with structure defined in Annex A for SDH line signals or in 8.3.2 for pseudorandom sequences for SDH tributary signals and physical characteristics of either:

a) an electrical signal in conformance with ITU-T Rec. G.703 [3] having the nominal terminated signal level and with no additional frequency-dependent loss; or

b) an optical signal in conformance with ITU-T Recs G.957 [14] or G.691 [1] and with a nominal power in the range −10 dBm to −12 dBm. Operation at higher input power levels may be permitted at STM-64 and STM-256 in accordance with the mean launch powers specified in ITU-T Rec. G.693 [2].

The total measurement error shall be less than:

$$\pm R\% \text{ of reading } \pm W$$

where R is the variable error specified in Table 10 or Table 10a and W is the fixed error of Table 8 or Table 9, which includes any contribution from the internal timing extraction function.

9.4.2 Fixed error of SDH line jitter measurements

For the STM-N bit rates and for the indicated digital signals, the fixed error of the jitter measurement function shall be as specified in Table 8 within the frequency ranges f_1-f_4 and f_3-f_4 indicated. Frequencies f_1, f_3 and f_4 used in Table 8 are defined in Table 7.

Table 8/O.172 – Fixed error (W) of SDH line jitter measurements

Signal	Maximum peak-to-peak jitter error [UIpp] for given digital signals					
	Structured signal			Clock signal		
	f_1-f_4	f_{12}-f_4	f_3-f_4	f_1-f_4	f_{12}-f_4	f_3-f_4
STM-0e	FFS	–	FFS	FFS	–	FFS
STM-0	0.07	–	0.035	0.05	–	0.03
STM-1e	0.07	–	0.025	0.05	–	0.02
STM-1	0.07	0.035	0.035	0.05	0.03	0.03
STM-4	0.1	0.035	0.035	0.05	0.03	0.03
STM-16	0.1	0.035	0.035	0.05	0.03	0.03
STM-64	0.1	–	0.035	0.05	–	0.03
STM-256	0.15	–	0.05	0.05	–	0.03

NOTE 1 – FFS denotes that the value is for further study.

NOTE 2 – Structured digital signals are defined in Annex A.

NOTE 3 – Clock interfaces are optional.

NOTE 4 – At STM-256 the objective is to reduce the fixed error W within the frequency ranges f_1-f_4 and f_3-f_4 to 0.1 UIpp and 0.035 UIpp.

NOTE 5 – The f_{12} high-pass filter is optional.

NOTE 6 – Reduced STM-16 and STM-64 fixed error terms applicable for new measuring equipment.

9.4.3 Fixed error of SDH tributary jitter measurements

For the tributary bit rates and for the indicated digital signals, the fixed error of the jitter measurement function shall be as specified in Table 9 within the frequency ranges f_1-f_4 and f_3-f_4 indicated. Frequencies f_1, f_3 and f_4 used in Table 9 are defined in Table 7a.

Table 9/O.172 – Fixed error (W) of SDH tributary jitter measurements

Bit rate [kbit/s]	Maximum peak-to-peak jitter error [UIpp] for given digital signals			
	Pseudo-random signal		Clock signal	
	f_1-f_4	f_3-f_4	f_1-f_4	f_3-f_4
1544	0.04	0.025	0.015	0.01
2048	0.04	0.025	0.015	0.01
6312	0.04	0.025	0.015	0.01
34 368	0.04	0.025	0.03	0.02
44 736	0.04	0.025	0.03	0.02
139 264	0.04	0.025	0.03	0.02

NOTE 1 – Pseudo-random digital signals are defined in 8.3.2.

NOTE 2 – Clock interfaces are optional.

9.4.4 Variable error of SDH line jitter measurements

The variable error *R* shall be as specified in Table 10 for SDH line signals. Frequencies f_1, f_3 and f_4 used in Table 10 are defined in Table 7.

Table 10/O.172 – Variable error (R) of SDH line jitter measurements

Signal	Error, *R*	Frequency range
STM-0e, STM-0	FFS	f_1 to f_4
STM-1e, STM-1	±7%	f_1 to 300 kHz
	±8%	300 kHz to 1 MHz
	±10%	1 MHz to f_4
STM-4	±7%	f_1 to 300 kHz
	±8%	300 kHz to 1 MHz
	±10%	1 MHz to 3 MHz
	±15%	3 MHz to f_4
STM-16, STM-64, STM-256	±7%	f_1 to 300 kHz
	±8%	300 kHz to 1 MHz
	±10%	1 MHz to 3 MHz
	±15%	3 MHz to 10 MHz
	±20%	10 MHz to f_4

9.4.5 Variable error of SDH tributary jitter measurements

At jitter frequencies between f_1 and f_4, the variable error R shall be as specified in Table 10a for SDH tributary signals. Frequencies f_1 and f_4 used in Table 10a are defined in Table 7a.

Table 10a/O.172 – Variable error (R) of SDH tributary jitter measurements

Bit rate [kbit/s]	Error, *R*	Frequency range
544	±9%	f_1 to 1 kHz
	±7%	1 kHz to f_4
2048	±7%	f_1 to f_4
6312	±9%	f_1 to 1 kHz
	±7%	1 kHz to f_4
34 368	±7%	f_1 to 300 kHz
	±8%	300 kHz to f_4
44 763	±9%	f_1 to 200 Hz
	±7%	200 Hz to 300 kHz
	±8%	300 kHz to f_4
139 264	±7%	f_1 to 300 kHz
	±8%	300 kHz to 1 MHz
	±10%	1 MHz to 3 MHz
	±15%	3 MHz to f_4

9.4.6 Digital test signal-dependent error

The accuracy requirements stated in previous subclauses shall be met when digital test signals defined in Annex A are used to perform the jitter measurement. When using other structured signals, pseudo-random or random signals, larger measurement errors could be expected. Considering the measurement bandwidths specified above, signals with a higher "zero" or "one" content (i.e., fewer signal transitions) may even infringe the sampling theorem which – for theoretical reasons – makes it impossible to meet the specified accuracy requirements.

9.5 Jitter transfer measurement accuracy

The specification of SDH equipment jitter transfer characteristics in ITU-T Rec. G.783 [6] uses a gain-versus-frequency mask to limit the maximum transfer gain (P) and the maximum transfer bandwidth (f_C). This mask is specified in-between the frequency range f_L to f_H. The accuracy of the jitter transfer measurement depends on several factors: the repeatability of the jitter generator's performance, the linearity and repeatability of the jitter measurement equipment's performance, and the noise floor of the measurement. Where the jitter frequency f_m is less than f_C, the measurement accuracy affects the determination of whether the gain limit P has been met. Where the jitter frequency f_m is greater than f_C, the measurement accuracy affects the determination of whether the bandwidth limitation mask above f_C is not exceeded.

The total measurement error in the jitter frequency range $f_L = 0.01 \cdot f_C$ and $f_H = 100 \cdot f_C$ or f_4, if f_4 is lower than $100 \cdot f_C$, when using input jitter amplitude equal to the applicable jitter tolerance masks, shall be less than:

$$\pm 0.05 \text{ dB} \pm 0.12 \cdot g$$

where g is the measured jitter transfer gain at the jitter frequency f_m in dB. This measurement error applies for g greater or equal to –45 dB. No accuracy is specified for g less than –45 dB.

9.6 Additional facilities

9.6.1 Analogue output

The jitter measurement function may provide an analogue output signal to enable measurements to be made externally to the jitter measurement function, e.g., by using an oscilloscope or an RMS meter.

10 Wander measurement function

Appendix II provides further information regarding the test configurations for measurement of wander.

10.1 Reference timing signal

For the testing of wander, it shall be possible to phase-lock the measurement function to an external reference clock source of arbitrary accuracy; refer also to 7.3.

10.2 Measurement of TIE (Time Interval Error)

The instrumentation shall be capable of measuring Time Interval Error (TIE) as defined in ITU-T Rec. G.810 [7]. TIE is the basic function whereby many different stability parameters (such as MTIE and TDEV) may be calculated.

TIE can be interpreted as the time difference between the signal being measured and the reference clock. It is typically measured in nanoseconds and set to zero at the start of the measurement period. Therefore, TIE gives the timing change since the measurement began.

10.2.1 Sampling interval

In order to calculate and estimate the various wander parameters specified in following subclauses, TIE is treated as a sampled parameter since continuous knowledge of the time interval error is not practically attainable (refer to ITU-T Rec. G.810 [7]).

The maximum sampling time τ_0, of TIE shall be:

$$1/30 \text{ s}$$

in accordance with ITU-T Recs G.813 [10] and G.812 [9].

10.2.2 Measurement bandwidth

Wander shall be measured through an equivalent 10 Hz, first-order, low-pass measurement filter, in accordance with ITU-T Recs G.813 [10] and G.812 [9], and with the following characteristics:

a) The low-pass measurement filter has a single-order characteristic and a roll-off of –20 dB/decade. The −3 dB point of the measurement filter shall be at a frequency 10 Hz ± 10%.

b) The amplitude of pass-band ripple in the range 1 to 10 Hz shall be less than ±0.2 dB (relative to the gain at 0.1 Hz) and the maximum attenuation of the measurement filter shall be at least 30 dB.

10.2.3 Measurement range

The dynamic range of the TIE measurement shall be a minimum of:

$$\pm 1 \times 10^9 \text{ ns}$$

(corresponding, for example, to a frequency offset of ±4.6 ppm for 200 000 seconds or over 55 hours).

10.2.4 Measurement result accuracy

The measuring accuracy of the wander measurement function is dependent upon several factors such as the magnitude of the reading, fixed intrinsic error, frequency response and TIE sampling interval.

For each measurement of TIE over an Observation Interval τ, the total TIE measurement error shall be less than:

$$\pm 5\% \text{ of the measured TIE value } \pm Z_0(\tau)$$

where $Z_0(\tau)$ is based on the measurement requirements of ITU-T Rec. G.811 [8] and is specified in Table 11.

Table 11/O.172 – Fixed error (Z_0) of TIE measurement

$Z_0(\tau)$ [ns]	Observation Interval, τ [s]
$2.5 + 0.0275\ \tau$	$0.05 \le \tau \le 1000$
$29 + 0.001\ \tau$	$\tau > 1000$
NOTE – There is an additional frequency-dependent error term above 1 Hz due to the measurement filter response (refer to 10.2.2).	

10.3 Measurement of transient TIE (Time Interval Error)

The instrument may be capable of measuring transient Time Interval Error (TIE). Transient TIE is defined as TIE measured through an equivalent 100 Hz, first-order, low-pass measurement filter as described in ITU-T Recs G.783 [6] and G.813 [10].

Transient TIE may be used for measurement of pointer adjustments specified in ITU-T Rec. G.783 [6] or for clock phase transients specified in ITU-T Recs G.812 [9] and G.813 [10].

10.3.1 Sampling interval

The maximum sampling time τ_0, of transient TIE shall be:

$$1/1000 \text{ s}$$

in accordance with ITU-T Recs G.783 [6] and G.812 [9].

10.3.2 Measurement bandwidth

Transient TIE shall be measured through an equivalent 100 Hz, first-order, low-pass measurement filter.

a) The low-pass measurement filter has a single-order characteristic and a roll-off of −20 dB/decade. The −3-dB point of the measurement filter shall be at a frequency 100 Hz ±10%.

b) The amplitude of pass-band ripple in the range 10 to 100 Hz shall be less than ±0.2 dB (relative to the gain at 1 Hz) and the maximum attenuation of the measurement filter shall be at least 30 dB.

10.3.3 Measurement range

The dynamic range of the transient TIE measurement shall be a minimum of:

$$\pm 1 \times 10^6 \text{ ns}$$

10.3.4 Measurement result accuracy

The measuring accuracy of the transient TIE measurement function is dependent upon several factors such as the magnitude of the reading, fixed intrinsic error, frequency response and sampling interval.

For each measurement of transient TIE over an Observation Interval τ, the total measurement error shall be less than:

$$\pm 5\% \text{ of the measured transient TIE value } \pm Z_9(\tau)$$

where $Z_9(\tau)$ is based on the measurement requirements of ITU-T Rec. G.811 [8] and is specified in Table 12.

Table 12/O.172 – Fixed error (Z_9) of transient TIE measurement

$Z_9(\tau)$ [ns]	Observation Interval, τ [s]
$2.5 + 0.0275\ \tau$	$0.001 \leq \tau \leq 100$
NOTE – There is an additional frequency-dependent error term above 10 Hz due to the measurement filter response (refer to 10.3.2).	

10.4 Measurement of MTIE (Maximum Time Interval Error)

The capability of measuring Maximum Time Interval Error (MTIE) as defined in ITU-T Rec. G.810 [7] may be provided.

MTIE is a measure of wander that characterizes frequency offsets and phase transients. It is a function of a parameter τ called the Observation Interval. MTIE(τ) can be said to be the largest peak-to-peak TIE in any observation interval of length τ.

10.4.1 Measurement and observation interval ranges

In order to support the MTIE specifications of various ITU-T Recommendations, it shall be possible to measure MTIE over a range of observation intervals at least from:

– 0.05 s to 100 000 s for TIE as described in 10.2;

– 0.001 s to 100 s for transient TIE as described in 10.3.

The maximum range of calculated MTIE results shall be at least:

50 000 ns

(corresponding to 10 times the maximum specification defined in ITU-T Rec. G.813 [10], for example).

NOTE – The minimum measurement period T for MTIE(τ) is the observation interval (i.e., $T = \tau$).

10.4.2 Calculation algorithm accuracy

In certain cases, the MTIE calculation algorithm can be functionally separated from the TIE measurement, in which case the following accuracy requirements apply to the stand-alone algorithm.

When provided with a given set of TIE measurement data, an algorithm used to calculate MTIE shall yield results within a certain error of the values calculated in accordance with the standard estimator formula given in II.5/G.810 [7].

The total MTIE calculation error shall be less than:

$$\pm 2\% \text{ of the MTIE value } \pm Z_1(\tau)$$

where $Z_1(\tau)$ is specified in Table 13 and τ is the observation interval.

Table 13/O.172 – Fixed error (Z_1) of MTIE calculation algorithm

$Z_1(\tau)$ [ns]	Observation Interval, τ [s]
$0.5 + 0.0055\ \tau$	$0.001 \leq \tau \leq 1000$
$5.8 + 0.0002\ \tau$	$\tau > 1000$
NOTE – These requirements are based on a consideration of ITU-T Rec. G.811 [8].	

In order to verify the accuracy of a stand-alone MTIE calculation algorithm, a defined TIE noise source can be used, which is described in Appendix V.

10.4.3 Measurement result accuracy

The total measurement error (i.e., including error from a TIE measurement and error from the MTIE calculation algorithm) shall be less than:

$$\pm 7\% \text{ of the MTIE value } \pm Z_3(\tau)$$

where $Z_3(\tau)$ is specified in Table 14 and τ is the observation interval.

Table 14/O.172 – Fixed error (Z_3) of MTIE measurement result

$Z_3(\tau)$ [ns]	Observation Interval, τ [s]
$3 + 0.033\ \tau$	$0.001 \leq \tau \leq 1000$
$35 + 0.0012\ \tau$	$\tau > 1000$
NOTE – These requirements are based on a consideration of ITU-T Rec. G.811 [8].	

10.5 Measurement of TDEV (Time Deviation)

The capability of measuring Time Deviation (TDEV) as defined in ITU-T Rec. G.810 [7] may be provided.

TDEV is a measure of wander that characterizes its spectral content. It is a function of a parameter τ called the Observation Interval. TDEV(τ) can be said to be the RMS of filtered TIE, where a band-pass filter is centred on a frequency of $0.42/\tau$.

10.5.1 Measurement and observation interval ranges

In order to support the TDEV specifications of various ITU-T Recommendations, it shall be possible to measure TDEV over a range of observation intervals at least

from 0.05 s to 10 000 s

The maximum range of calculated TDEV results shall be at least:

10 000 ns

(corresponding to 10 times the maximum specification defined in ITU-T Rec. G.813 [10], for example).

NOTE – The minimum measurement period T for TDEV(τ) is twelve times the observation interval (i.e., $T = 12\tau$), in accordance with ITU-T Recs G.813 [10], G.812 [9] and G.811 [8].

10.5.2 Calculation algorithm accuracy

In certain cases, the TDEV calculation algorithm can be functionally separated from the TIE measurement, in which case the following accuracy requirements apply to the stand-alone algorithm.

When provided with a given set of TIE measurement data, an algorithm used to calculate TDEV shall yield results within a certain error of the values calculated in accordance with the standard estimator formula given in II.3/G.810 [7].

The total TDEV calculation error shall be less than:

$$\pm 2\% \text{ of the TDEV value } \pm Z_2(\tau)$$

where $Z_2(\tau)$ is specified in Table 15 and τ is the observation interval.

Table 15/O.172 – Fixed error (Z_2) of TDEV calculation algorithm

$Z_2(\tau)$ [ns]	Observation Interval, τ [s]
0.06	$0.05 \leq \tau \leq 100$
$0.0006\ \tau$	$100 < \tau \leq 1000$
0.6	$1000 < \tau \leq 10\,000$
NOTE – These requirements are based on a consideration of ITU-T Rec. G.811 [8].	

In order to verify the accuracy of a stand-alone TDEV calculation algorithm, a defined TIE noise source can be used, which is described in Appendix V.

10.5.3 Measurement result accuracy

The total measurement error (i.e., including error from a TIE measurement and error from the TDEV calculation algorithm) shall be less than:

$$\pm 7\% \text{ of the TDEV value } \pm Z_4(\tau)$$

where $Z_4(\tau)$ is specified in Table 16 and τ is the observation interval.

Table 16/O.172 – Fixed error (Z_4) of TDEV measurement result

$Z_4(\tau)$ [ns]	Observation Interval, τ [s]
0.36	$0.05 \le \tau \le 100$
0.0036 τ	$100 < \tau \le 1000$
3.6	$1000 < \tau \le 10\,000$
NOTE – These requirements are based on a consideration of ITU-T Rec. G.811 [8].	

10.6 Measurement of frequency offset

The capability of measuring frequency offset, as defined below, may be provided.

Frequency offset is the first time derivative of phase. The transfer function of the derivative process grows in proportion to the frequency with which the frequency offset varies. Therefore the bandwidth of the measurement must be limited. The measurement bandwidth is controlled by the time period over which the frequency offset is calculated from a set of TIE values x_i.

Fractional frequency offset (in ns/s) measured over a period T is defined as:

$$y(n\tau_0) = \frac{6}{N\tau_0}\sum_{i=1}^{N} x_{n+i}\left[\frac{2i}{N^2-1} - \frac{1}{N-1}\right]$$

where:

τ_0 is the sampling interval in seconds,

N is the number of phase samples in the measurement period,

$T = N\tau_0$ is the measurement period in seconds,

$t = n\tau_0$ is the time at the beginning of the measurement period,

x_i are the phase samples in ns.

NOTE – This measurement attenuates frequency offset components that vary at frequencies greater than $0.55/T$. The user must choose the value of $T = N\tau_0$ to attenuate noise and pass the frequencies of interest.

10.6.1 Measurement range

In order to support the frequency offset measurement specifications of various ITU-T Recommendations, it shall be possible to measure frequency offset over a measurement period range of at least:

$$0.05 \text{ s} \le T \le 10\,000 \text{ s}$$

The maximum range of calculated frequency offset results shall be at least:

75 000 ns/s

(corresponding to 10 times the maximum specification in ITU-T Rec. G.813 [10]).

10.6.2 Calculation algorithm accuracy

In certain cases, the frequency offset calculation algorithm can be functionally separated from the TIE measurement, in which case the following accuracy requirements apply to the stand-alone algorithm.

When provided with a given set of TIE measurement data, an algorithm used to calculate frequency offset shall yield results within a certain error of the values calculated in accordance with the standard formula given in 10.6.

The total frequency offset calculation error shall be less than:

±2% of the frequency offset value ± Z_5(T)

where $Z_5(\tau)$ is specified in Table 17 and *T* is the measurement period.

Table 17/O.172 – Fixed error (Z_5) of frequency offset calculation algorithm

$Z_5(T)$ [ns/s]	Measurement period, *T* [s]
0.0055	$0.05 \le T \le 1000$
0.0002	$T > 1000$
NOTE – These requirements are based on a consideration of ITU-T Rec. G.811 [8].	

10.6.3 Measurement result accuracy

The total measurement error (i.e., including error from a TIE measurement and error from the frequency offset calculation algorithm) shall be less than:

±7% of the frequency offset value ±Z_6(T)

where $Z_6(\tau)$ is specified in Table 18 and *T* is the measurement period.

Table 18/O.172 – Fixed error (Z_6) of frequency offset measurement result

$Z_6(T)$ [ns/s]	Measurement period, *T* [s]
0.033	$0.05 \le T \le 1000$
0.0012	$T > 1000$
NOTE – These requirements are based on a consideration of ITU-T Rec. G.811 [8].	

10.7 Measurement of frequency drift rate

The capability of measuring frequency drift rate, as defined below, may be provided.

Frequency drift rate is the second time derivative of phase. The transfer function of the second-derivative process grows in proportion to the square of the frequency with which the frequency drift rate varies. Therefore the bandwidth of the measurement must be limited. The measurement bandwidth is controlled by the time period over which the frequency drift rate is calculated from a set of TIE values x_i.

Frequency drift rate (in ns/s^2) measured over a period *T* is defined as:

$$D(n\tau_0) = \frac{60}{N\tau_0^2}\sum_{i=1}^{N} x_{n+i}\left[\frac{6i^2}{N^4 - 5N^2 + 4} - \frac{6i}{N^3 - N^2 - 4N + 4} + \frac{1}{N^2 - 3N + 2}\right]$$

where:

τ_0 is the sampling interval in seconds,

N is the number of phase samples in the measurement period,

$T = N\tau_0$ is the measurement period in seconds,

$t = n\tau_0$ is the time at the beginning of the measurement period,

x_i are the phase samples in ns.

NOTE – This measurement attenuates frequency drift rate components that vary at frequencies greater than 0.8/*T*. The user must choose the value of $T = N\tau_0$ to attenuate noise and pass the frequencies of interest.

10.7.1 Measurement range

In order to support the frequency drift rate measurement specifications of various ITU-T Recommendations, it shall be possible to measure frequency drift rate over a measurement period range of at least:

$$0.05 \text{ s} \leq T \leq 10\,000 \text{ s}$$

The maximum range of calculated frequency drift rate results shall be at least:

$$0.06 \text{ ns/s}^2$$

(corresponding to 10 times the maximum specification in ITU-T Rec. G.813 [10]).

10.7.2 Calculation algorithm accuracy

In certain cases, the frequency drift rate calculation algorithm can be functionally separated from the TIE measurement, in which case the following accuracy requirements apply to the stand-alone algorithm.

When provided with a given set of TIE measurement data, an algorithm used to calculate frequency drift rate shall yield results within a certain error of the values calculated in accordance with the standard formula given in 10.7.

The total frequency drift rate calculation error shall be less than:

$$\pm 2\% \text{ of the frequency drift rate value } \pm Z_7(T)$$

where $Z_7(\tau)$ is specified in Table 19 and T is the measurement period.

Table 19/O.172 – Fixed error (Z_7) of frequency drift rate calculation algorithm

$Z_7(T)$ [ns/s²]	Measurement period, T [s]
$0.5 \cdot T^{-2}$	$0.05 < T < 2500$
$8 \cdot 10^{-8}$	$T > 2500$
NOTE – These requirements are based on a consideration of ITU-T Rec. G.812 [9].	

10.7.3 Measurement result accuracy

The total measurement error (i.e., including error from a TIE measurement and error from the frequency drift rate calculation algorithm) shall be less than:

$$\pm 7\% \text{ of the frequency drift rate value } \pm Z_8(T)$$

where $Z_8(\tau)$ is specified in Table 20 and T is the measurement period.

Table 20/O.172 – Fixed error (Z_8) of frequency drift rate measurement result

$Z_7(T)$ (ns/s²)	Measurement period, T [s]
T^{-2}	$0.05 < T < 2500$
$1.6 \cdot 10^{-7}$	$T > 2500$
NOTE – These requirements are based on a consideration of ITU-T Rec. G.812 [9].	

11 TDEV wander noise generation function

The capability of generating TDEV wander noise for wander tolerance and wander transfer measurements as described in ITU-T Recs G.812 [9] and G.813 [10] may be provided. To ensure sufficiently accurate, robust and consistent measurements, the following requirements shall be met:

a) The TDEV noise generator shall produce a test signal within ±20% of the applicable TDEV input noise tolerance mask. This accuracy shall be met when the measurement period $T \geq 12\tau_{max}$, where τ_{max} is the largest value of τ for the mask.

b) The MTIE of the test signal shall be not greater than the upper limit defined in Annex C.

c) The test signal shall be deterministic and repeatable, which implies that the signal is able to start at the same point of the signal time function.

Clause II.2/G.812 [9] shows an example for an adequate implementation algorithm for generating a TDEV wander noise signal.

Clause II.1/G.812 [9] has additional information on the application of the TDEV wander noise signal.

NOTE – The signal may exceed the corresponding MTIE tolerance mask limits. Since both requirements TDEV and MTIE have to be met for an input interface, the TDEV limits may be more stringent and therefore exceeding the MTIE values may be tolerable.

12 MTIE wander noise generation function

The capability of generating MTIE wander noise for wander tolerance measurements as described in ITU-T Recs G.812 [9] and G.813 [10] may be provided. To ensure sufficiently accurate, robust and consistent measurements, the following requirements shall be met:

a) The MTIE noise generator shall produce a test signal or set of test signals whose stress is within ±5% of the applicable MTIE input noise tolerance mask. For a set of test signals, the stress is considered to be the upper envelope of the set of corresponding MTIE curves.

b) The jitter generated by the MTIE noise generator shall not exceed the limits for the applicable network interface output jitter.

NOTE – When a test set is evaluated for compliance to these requirements, the generated wander must be measured with a low-pass filter whose bandwidth is adequate so that its effect on the measured MTIE is less than 1%. See Appendix VI for guidance on evaluating MTIE wander noise generation.

13 Operating environment

The performance requirements shall be met when operating within the climatic conditions as specified in 2.1/O.3 [16].

Annex A

Structured test signals for the measurement of jitter

A.1 Introduction

It is important to define the test signals to be used when performing jitter tests. This is of particular importance when testing SDH optical systems, since the scrambling system does not limit the length of runs of zeros/ones that can exist on a line signal, i.e., the maximum time period without any data transitions in the scrambled signal. ITU-T Rec. G.707/Y.1322 [4] provides further information regarding SDH signal structure and payload scrambling.

For example, if the traffic in an STM-N signal emulates the scrambling pattern, then many bytes of all zeros/ones will appear in the coded line signal. As the extreme cases of this will be rare occurrences, and also as it will be very difficult for a jitter test set to continue to perform accurate measurements under these conditions, it is important that a representative worst-case signal is defined for the purposes of test set specification.

A.1.1 Payload test conditions

Concatenated payloads provide the worst-case scenario for STM-N test signals. For bulk-filled concatenated signals with a $2^{23} - 1$ PRBS filling the container, the result of scrambling this data is a worst-case run of 30 consecutive identical zeros/ones (i.e., there will be 30 clock periods with no transitions on the line signal). For non-concatenated payloads generated by SDH test sets, the byte interleaving of the VC-4 containers reduces the maximum length of runs produced.

A.1.2 SDH overhead byte conditions

Care shall be taken in selecting the binary content of the J0 and Z0 bytes and of the bytes reserved for national use which are excluded from the scrambling process of the STM-N signal, to ensure that long sequences of "1"s or "0"s do not occur.

The content of these overhead bytes shall be set to a "10101010" (AA_H) or “11001100” (CC_H) pattern.

A.2 Test signal structure for STM-N signals

A.2.1 STM-1 signal

The STM-1 test signal structure illustrated in Figure A.1 consists of a PRBS test sequence of length $2^{23} - 1$ bits according to ITU-T Rec. O.150 [17], which is applied to all bytes of the C-4 container.

NOTE – This is equivalent to Test Signal Structure 1 (TSS1) defined in Annex C/O.181 [19].

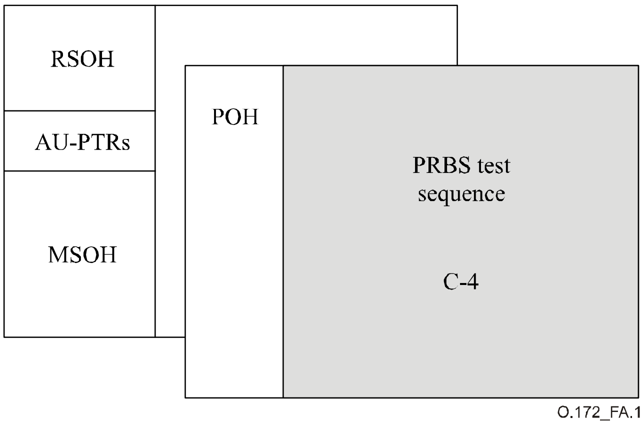

Figure A.1/O.172 – Test signal structure for jitter testing of STM-1 interface

A.2.2 STM-N signal (N ≥ 4)

The test signal TSS1 described in A.2.1 shall be used.

The (N–1) C-4 payload containers which do not contain the test signal shall contain an all "0" or all "1" fixed byte pattern or may contain an unequipped VC-4 as defined in ITU-T Rec. G.783 [6].

A.2.3 STM-0 signal

The STM-0 test signal structure illustrated in Figure A.2 consists of a PRBS test sequence of length $2^{23} - 1$ bits according to ITU-T Rec. O.150 [17], which is applied to all bytes of the C-3 container.

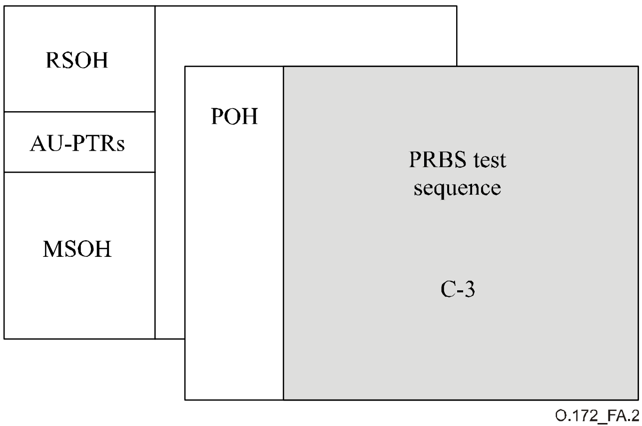

Figure A.2/O.172 – Test signal structure for jitter testing of STM-0 interface

A.3 Test signal structure for concatenated STM-N signals

A.3.1 STM-N signal (N ≥ 4)

The STM-N test signal structure illustrated in Figure A.3 is a PRBS test sequence of length $2^{23} - 1$ or $2^{31} - 1$ bits for STM-N (N ≥ 64) according to ITU-T Rec. O.150 [17], which is applied to all bytes of the C-4-Xc concatenated container.

NOTE – This is equivalent to Test Signal Structure 9 (TSS9) defined in Annex C/O.181 [19].

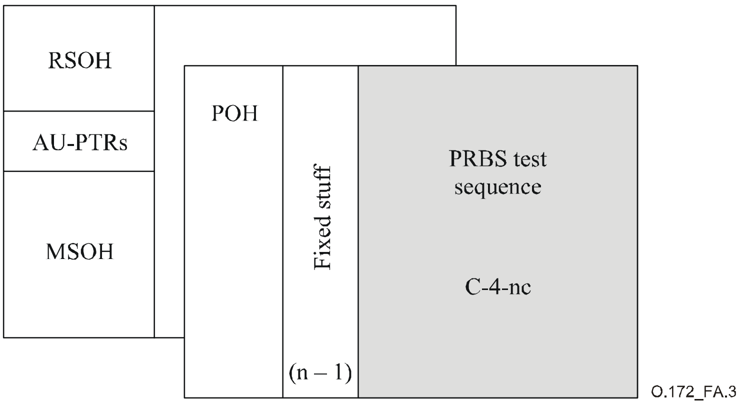

Figure A.3/O.172 – Test signal structure for jitter testing of concatenated STM-N interface

Annex B

Definition of band-limited peak-to-peak phase slope error

When sinusoidal phase modulation is used to stress a phase-locked loop (PLL), the stress is proportional to the peak-to-peak phase when the modulation frequency is greater than the PLL bandwidth, and the stress is proportional to the peak-to-peak phase slope when the modulation frequency is less than the bandwidth. Distortion in the generated sinusoidal modulation can cause additional error of the phase slope. Clause 8.6.2 specifies limits for the phase slope error.

The phase slope is measured by a procedure functionally equivalent to that illustrated in Figure B.1. The differentiator finds the slope of the phase, and the low-pass filter is first-order with a cut-off frequency f_{3dB}, where $f_{3dB} = 2 \cdot f_3$ ±10%, and f_3 is defined in Table 3 for SDH line signals and in Table 3a for SDH tributary signals.

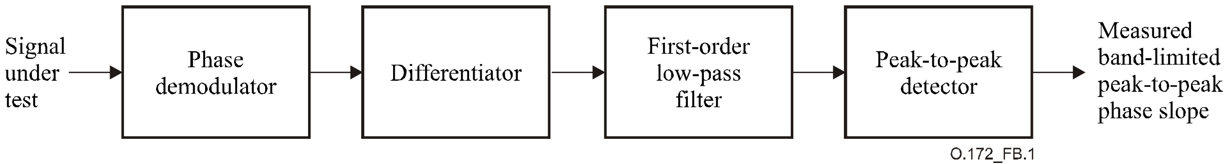

Figure B.1/O.172 – Phase slope measurement function

If the jitter/wander generation were a perfect sinusoid with peak-to-peak phase amplitude (in UIpp) exactly equal to the "setting" and a modulation frequency of f_m, then the peak-to-peak phase slope as measured through a first-order low-pass filter would be:

$$\text{ideal band-limited peak-to-peak phase slope} = \frac{(\text{setting}) \cdot 2\pi f_m}{\sqrt{1 + (f_m / f_{3\text{dB}})^2}}$$

Because the actual phase amplitude is not, in general, equal to the phase amplitude setting, the actual modulation frequency is not equal to f_m, and the modulation is not a perfect sinusoid, the measured band-limited peak-to-peak phase slope will not equal the ideal band-limited peak-to-peak phase slope given above. The difference between the measured band-limited peak-to-peak phase slope and the ideal band-limited peak-to-peak phase slope is defined as the band-limited peak-to-peak phase slope error.

Annex C

MTIE upper limit for TDEV wander noise

This annex describes the MTIE upper limit for TDEV wander noise required for the wander tolerance test and the wander transfer test specified in ITU-T Recs G.812 and G.813. The MTIE for TDEV wander noise should be below the MTIE upper limit to prevent application of excessive MTIE stress to the device under test.

The MTIE(τ) for the test signal output from the TDEV noise generator shall satisfy the following relationship:

$$MTIE(\tau) \leq 7\sqrt{4K_1 \int_{K_2/\tau_{max}}^{K_2/\tau_{min}} \left(TDEV\left(\frac{K_2}{f}\right)\right)^2 \frac{\sin(\pi\tau f)}{f} df}$$

where, $K_1 = 0.84$ and $K_2 = 0.42$, $\tau_{min} \leq \tau \leq \tau_{max}$ and $T \geq 12\tau_{max}$, where τ is the observation interval and T is the measurement period. τ_{min} and τ_{max} are the smallest and the largest observation interval specified for the corresponding TDEV mask. The TDEV(τ) of the corresponding TDEV mask is substituted for TDEV(K_2/f) on the right side of the equation.

Figures C.1 and C.2 show examples of TDEV masks and the corresponding MTIE upper limits for TDEV wander noises. For reference, the MTIE tolerance mask specified for the same equipment is also shown by the broken line in each figure.

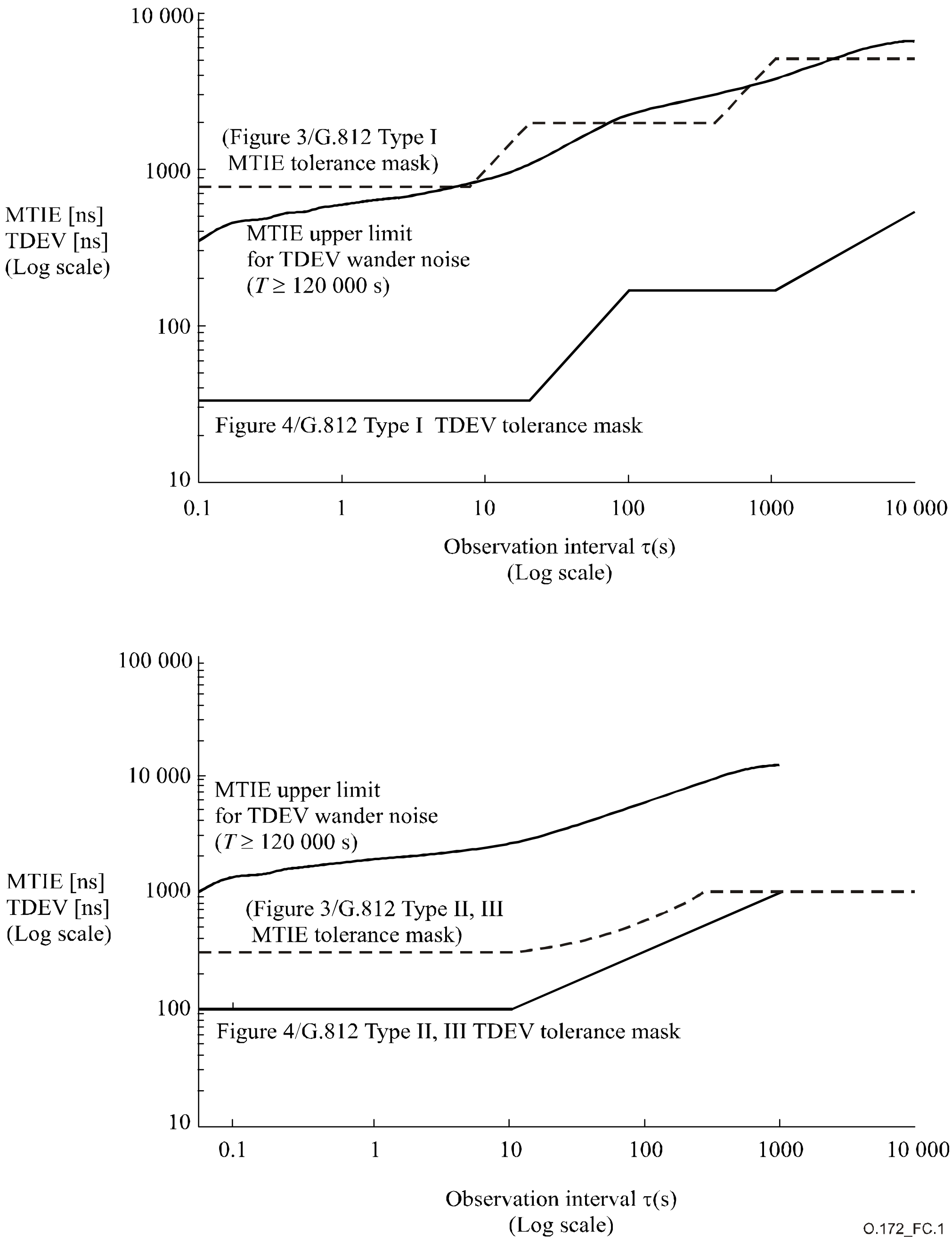

Figure C.1/O.172 – MTIE upper limit for TDEV wander tolerance test in G.812

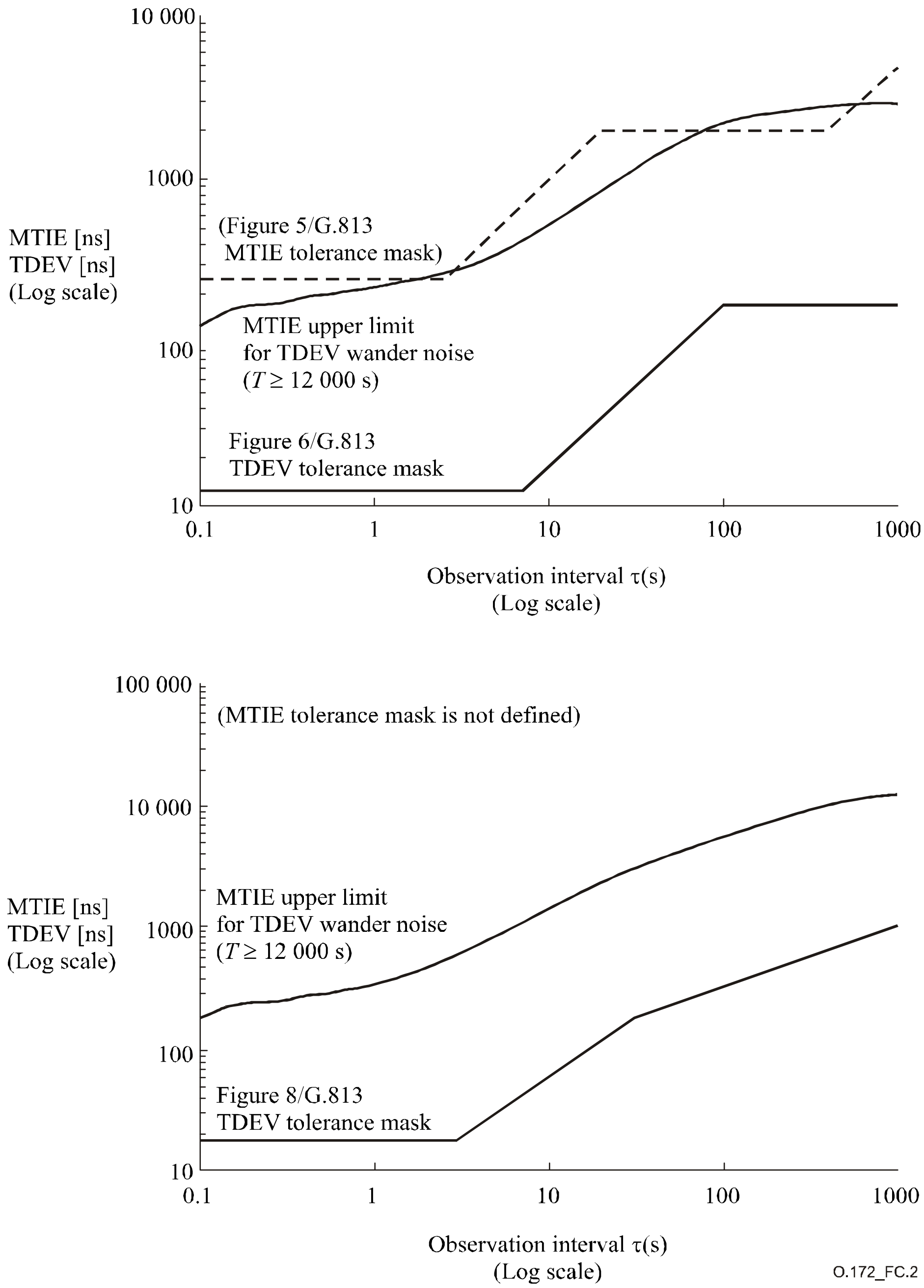

Figure C.2/O.172 – MTIE upper limit for TDEV wander tolerance test in G.813

Appendix I

Guidelines concerning the measurement of jitter in SDH systems

Appendix I/O.171 [18], "Guidelines concerning the measurement of jitter", although appropriate for PDH systems, may also be consulted for guidance on the general principles of measuring jitter in SDH systems.

Appendix II

Guidelines concerning the measurement of wander in SDH systems

II.1 Wander measurements

II.1.1 General considerations on wander measurement configurations

Due to the low frequency of the phase variations to be evaluated (refer to definition in clause 3), wander is a quantity which requires a special test configuration. When performing jitter measurements, the required reference timing signal is normally produced locally – by means of a phase-locked loop (PLL) within the test set; it is derived from the average phase of the signal to be measured. Such a PLL cannot be realized to cope with the requirements of wander measurements.

Therefore, wander measurements always require an external reference clock signal of adequate stability.

Clauses II.1.2 and II.1.3 contain information on test configurations for wander measurements that are in accordance with ITU-T Rec. G.810 [7].

II.1.2 Synchronized wander measurements

Figure II.1 shows in a very general form the functional block diagram required for the synchronized measurement of wander.

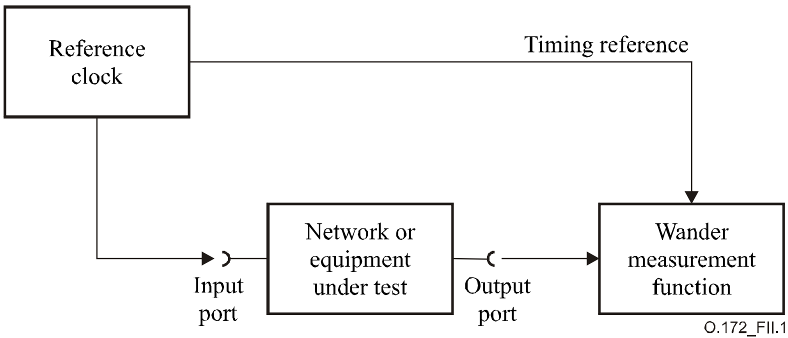

Figure II.1/O.172 – Synchronized wander measurement configuration

This configuration is applicable if the timing signals required to perform the measurement can be derived from a common reference clock. This means that only loop measurements – where input and output ports of the unit-under-test are accessible at the same location – can be carried out in this way. In this set-up, the measurement result is not affected by phase variations of the reference clock. Thus, the requirements on the stability of the reference clock are not very high and are achievable in portable test instrumentation.

II.1.3 Non-synchronized wander measurements

The block diagram for non-synchronized wander measurements is illustrated in Figure II.2.

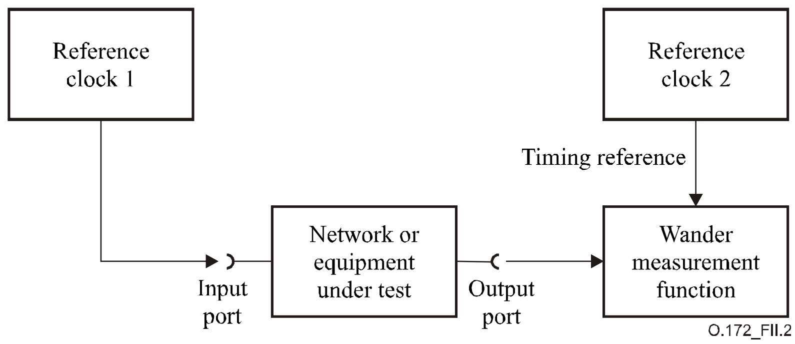

Figure II.2/O.172 – Non-synchronized wander measurement configuration

This configuration is applicable to wander measurements in cases where both input and output ports of the network or equipment under test are not available at the same location (e.g., end-to-end measurements). In this set-up, the measurement result is affected by any frequency/phase drift of the two clocks involved in the measurement. This means that the stability of the two clocks has to be at least one order of magnitude better than the quantity to be measured. Such reference clocks may not be provided in portable test instrumentation in which case synchronization to an external reference is required.

II.2 Clock stability measurements

If the stability of a clock is to be measured, the measurement set-up is similar to that described above in II.1.3. It is illustrated in Figure II.3.

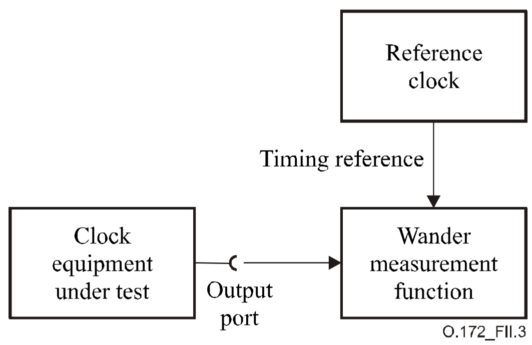

Figure II.3/O.172 – Clock stability measurement configuration

Also in this configuration, the measurement result is affected by any frequency or phase drift of the reference clock involved in the measurement. The same considerations as described in II.1.3 apply in this case.

Appendix III

Guidelines concerning the generation of pointer test sequences

The following functional block diagram of Figure III.1 and text outline a method for generating the pointer test sequences defined in ITU-T Rec. G.783 [6] and which are described in 8.4.1. This figure does not describe a specific implementation.

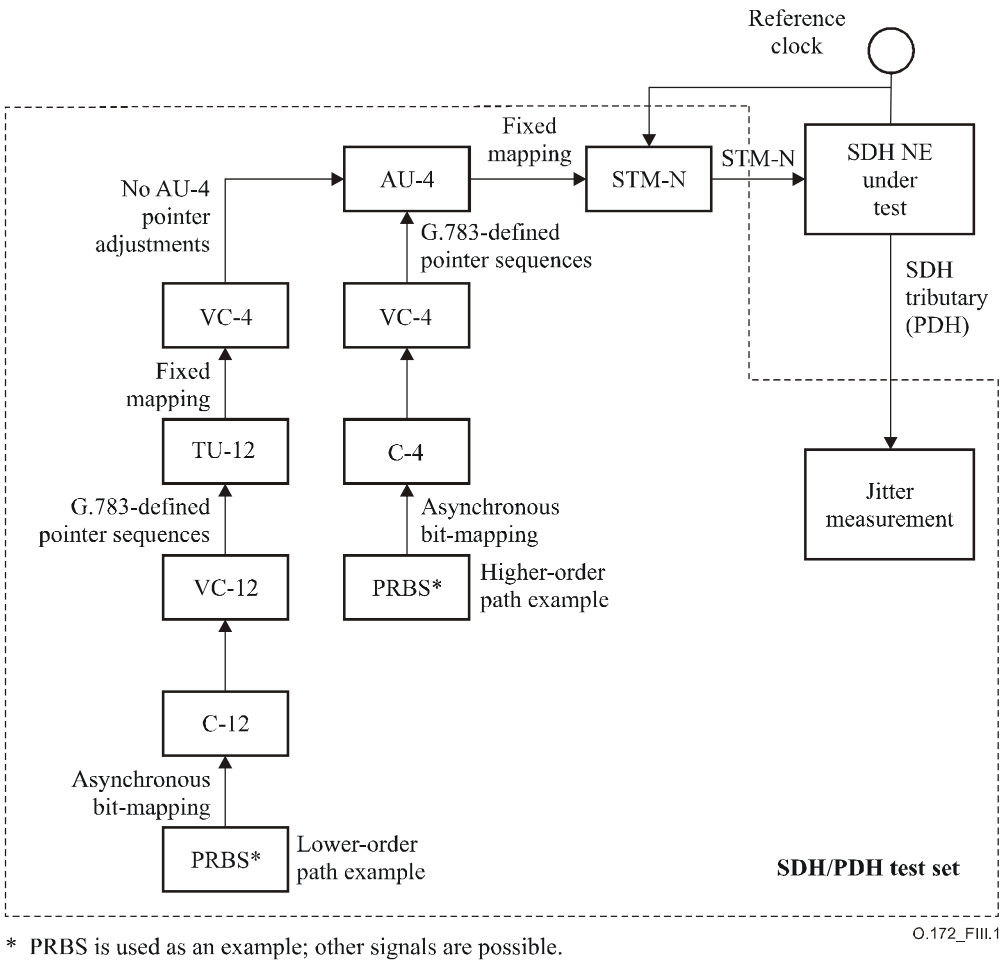

Figure III.1/O.172 – Functional block diagram of pointer test sequence generation

In order to generate an ITU-T Rec. G.783 [6] pointer test sequence, the following considerations shall be taken into account by the test set capabilities, the test configuration and the user of the test set:

a) The SDH/PDH test set and the network element should be synchronized from the same reference clock, to eliminate any uncontrolled pointer justification events that would interfere with the results.

b) To measure combined pointer and mapping jitter, it should be possible to set the frequency of the PDH PRBS within the PDH offset ranges defined in ITU-T Rec. G.703 [3].

c) To measure only mapping jitter, it should be possible to suppress pointer justification actions.

d) To generate the bit-stuffing sequence for asynchronous bit-mapping, justifications of a single polarity should be generated at regular intervals. The mapping process shall be in accordance to 15.2.3.1/G.783[6].

e) The generation of pointer justification events should be independent of the mapping process.

f) To create lower-order TU-m pointer test sequences, the higher-order AU-n pointer should be fixed.

g) The "pointer sequences" and the "bit-mapping" functions imply frequency offsets between the clocks which drive the various functional blocks.

Appendix IV

Total jitter measurement function response

IV.1 Introduction

Clause 9.3.2 specifies filters for SDH tributary jitter measurement. These specifications are in terms of limits on individual filter parameters such as −3 dB cut-off frequency, gain tolerance, pass-band ripple, etc.

These parameters imply that some equivalent limits on the total frequency responses of the jitter measurement functions exist. This appendix illustrates how the individual filter parameters can be combined into a single frequency response, whose characteristic is bounded by mask limits.

IV.2 Measurement filter parameters

Table IV.1 summarizes the measurement filter parameters and their definitions. In the following descriptions of mask limits, if the value of a particular parameter is not specified in a filter description, then the default value given in Table IV.1 should be used.

Table IV.1/O.172 – Summary of measurement filter specification parameters

Measurement filter parameter	Parameter definition
n	Order of the filter (n = 1 is first-order, n = 3 is third-order).
f_x	Nominal −3 dB cut-off frequency or bandwidth.
a	Fractional cut-off frequency tolerance (±). Default: no specification.
f_p	Second filter pole frequency. Default: 0 for high-pass, ∞ for low-pass.
g	Fractional gain tolerance of 9.3.2 c).
r	Pass-band ripple (±) in dB. Default: 0.
c	Minimum maximum attenuation in dB. Default: no specification.

IV.3 Mask limits for high-pass measurement filter response

The upper and lower mask limits for the frequency response are *Upper*(f) and *Lower*(f) as defined below. These masks apply to the frequency range $f < 10\,f_x$.

$$U = \begin{cases} U(f) + r, & f > f_x \\ -c, & U(f) < -c \\ U(f), & \text{otherwise} \end{cases}$$

where:

$$U(f) = 20 \cdot \log\left[\frac{(1-g)f^n}{\sqrt{f^{2n} + \left((1+a)f_x\right)^{2n}}}\right] \qquad \text{(IV-1)}$$

$$Lower(f) = \begin{cases} L(f) - r, & f > f_x \\ -\infty, & L(f) < -c \\ L(f), & \text{otherwise} \end{cases}$$

where:

$$L(f) = 20 \cdot \log\left[\frac{(1-g)f^n}{\sqrt{f^{2n} + \left((1+a)f_x\right)^{2n}}} \frac{f}{\sqrt{f^2 + f_p^2}}\right] \qquad \text{(IV-2)}$$

IV.3.1 SDH tributary jitter measurement high-pass filter

As an example, the SDH tributary jitter measurement filter specified for 2048 kbit/s has parameters $n = 1$, $f_x = 20$ Hz, $a = 0.1$, $f_p = 0.1$ Hz, $g = 0.07$, $r = 0$, and $c = 60$ dB. Then the upper and lower mask limits for the jitter measurement function frequency response are as illustrated in Figure IV.1.

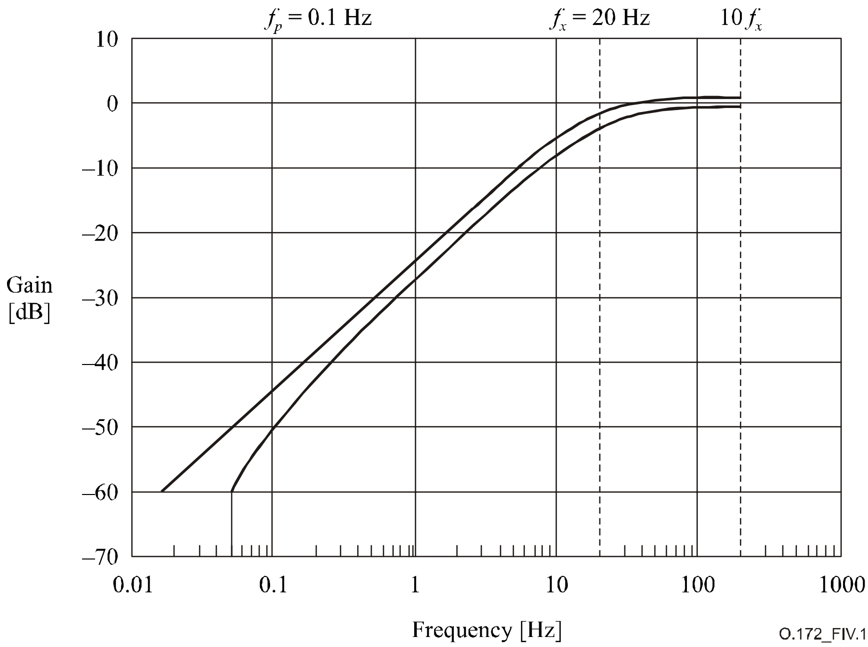

Figure IV.1/O.172 – Mask limits for 2048 kbit/s jitter measurement high-pass filter at 20 Hz

In general, when the jitter measurement function response of a test set lies on the Upper or Lower mask, the error of the measurement (peak-to-peak or rms) is at its maximum magnitude; other measurement function responses will yield less error. The superposition of $g = -0.07$ with $a = +0.10$ or to $g = +0.07$ with $a = -0.10$ leads to an extension of the cross-over points of the mask limits with the –3-dB level. Therefore the mask limits for the –3-dB level may exceed the $a = \pm 10\%$ limits specified for the nominal –3-dB cut-off frequency.

Appendix V

Verification of MTIE and TDEV calculation algorithms

V.1 TIE noise source functional description

In order to verify the accuracy of stand-alone MTIE and TDEV calculation algorithms (refer to 10.4.2 and 10.5.2), a defined TIE noise source can be used.

The MTIE and TDEV calculation algorithm accuracy specifications (refer to 10.4.2 and 10.5.2) nominally apply to all possible TIE waveforms from which MTIE and TDEV are calculated. Since it is impractical to test for many waveforms, a simple TIE pattern generator can be used for the evaluation. This pattern should have a $1/f^2$ power spectral density and a probability distribution function that is approximately Gaussian (satisfies the criteria of Annex C).

V.2 First example of TIE noise generator

One TIE generator that meets these criteria is shown in Figure V.1. It is based on a pseudo-random binary sequence (PRBS) generator that is 31 stages long. The output of the PRBS generator is a pseudo-random sequence of 1s and 0s. The output of the TIE generator is a series of numbers x_i at a rate f_s, where the numbers are given some weight in nanoseconds (ns) by the algorithm under test, and f_s is the reciprocal of the sampling interval expected by the algorithm (not less than 30 Hz).

Note that although the system clock is 6.4 kHz, the numbers x_i are generated at a lower rate of f_s through sub-sampling. The pattern of this TIE noise generator repeats after 671 000 seconds. The numbers z_i before scaling have a dynamic range of 99 123 peak-to-peak. The Scaling factor in Figure V.1 is chosen to match the LSB weighting of the algorithm under test so the dynamic range of the output x_i corresponds to 50 000 ns peak-to-peak.

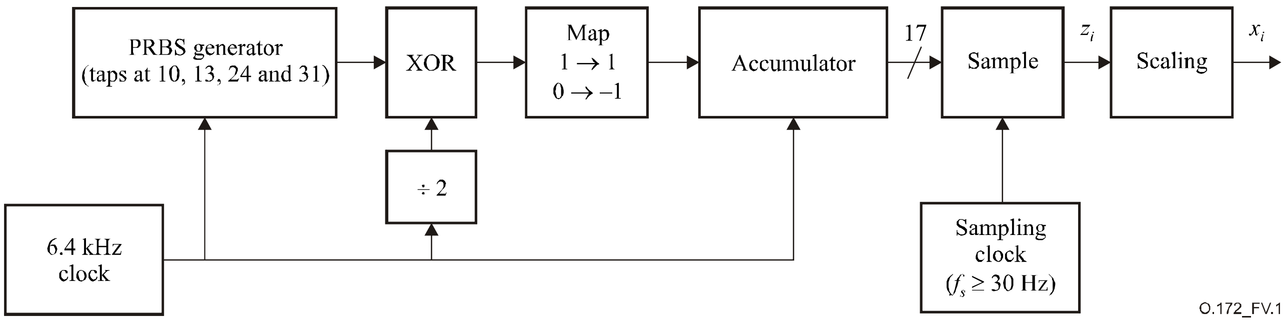

Figure V.1/O.172 – TIE noise source used for verifying MTIE and TDEV calculation algorithms

V.3 Second example of TIE noise generator

An alternative TIE generator for testing MTIE and TDEV calculation algorithms is shown in Figure V.2. It differs from that in Figure V.1 principally in the Mapping function, where the $w(n)$ are floating-point numbers from –2.884 to 2.884 defined by:

$$\frac{n+0.5}{256} = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{w(n)} e^{-0.5t^2}\, dt$$

The output pattern x_i has a repetition period of 335 500 seconds, and the dynamic range of z_i before scaling is 64 167 peak-to-peak. The Scaling factor in Figure V.2 is chosen to match the LSB weighting of the algorithm under test so the dynamic range of the output x_i corresponds to 50 000 ns peak-to-peak.

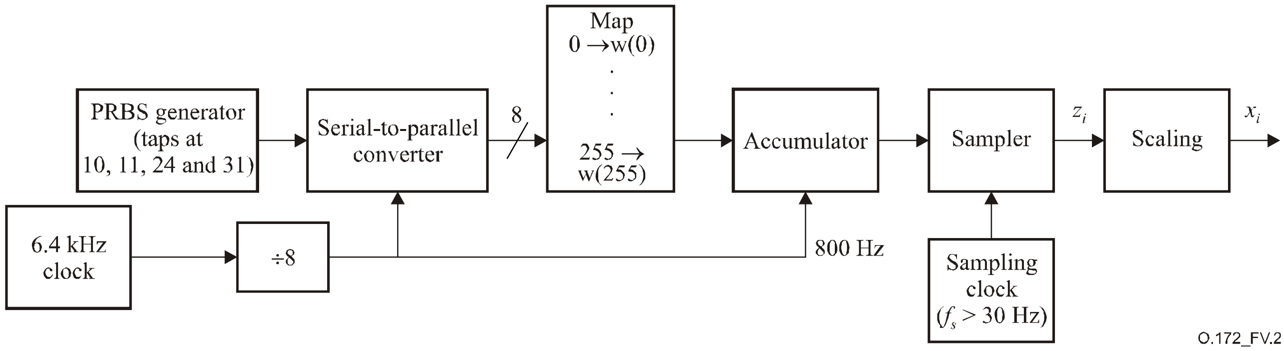

Figure V.2/O.172 – Alternative TIE noise source used for verifying MTIE and TDEV calculation algorithms

Appendix VI

MTIE generation evaluation

The requirement of MTIE wander tolerance mask generation capability of the test instrument is that the accuracy specification should be met without the attenuation of a low-pass wander measurement filter. This means that the MTIE wander tolerance generation may be as required and, within specification; however, the MTIE measurement may show attenuation effects of the wander measurement filter, typically at 10 Hz. For accurate measurement of the MTIE stress waveform, it is recommended that a bandwidth which has an effect of less than 1% of the result shall be used, this being a minimum of 500 Hz.

The examples below show 2 MTIE waveforms, both of which are compliant with this Recommendation and both generating the correct amount of MTIE stress for the given network interface (Table 10/G.812).

Figure VI.1 shows the first waveform and the effect of a 10-Hz wander measurement filter, and Figure VI.2 the corresponding MTIE. Figure VI.3 shows the second waveform and the effect of a 500-Hz wander measurement filter, and Figure VI.4 the corresponding MTIE. The 500-Hz result is within 1% of the MTIE stress at the interface, while the 10-Hz measurement shows up to 50% error.

Figure VI.5 shows a modified waveform used to generate the same MTIE stress. Figure VI.6 shows the result this time within 1% measured with a 10-Hz wander measurement filter, for $\tau > 0.1$ s.

The difference between the 2 MTIE stress waveforms is the minimum bandwidth needed to measure correctly the maximum MTIE stress each produces. Both give the correct MTIE stress, but the potential error, when measuring the first waveform in a 10-Hz bandwidth, indicates to the user that a 500-Hz minimum bandwidth be used to ensure accurate characterization of the test equipment.

Figure VI.1-a and -b show a test pattern $x(t)$ for Table 10/G.812. Here, the repetitive transients in Figure VI.1 are three superimposed triangular waveforms, $w_1(t)$, $w_2(t)$ and $w_3(t)$. Their amplitudes are $A_1 = 0.3$, $A_2 = 0.7$ and $A_3 = 0.097$ µs and their rise times are $\tau_1 = 0.05$, $\tau_2 = 280$ and $\tau_3 = 10\,000$ s, respectively. The dotted line in Figure VI.1-b is the $u(t)$ output from the 10-Hz wander measurement filter. In Figure VI.1-b, the peak-to-peak value of $u(t)$ is decreased because the fundamental frequency of $w_1(t)$, which is one component of $x(t)$, is equal to the cut-off frequency of the wander measurement filter.

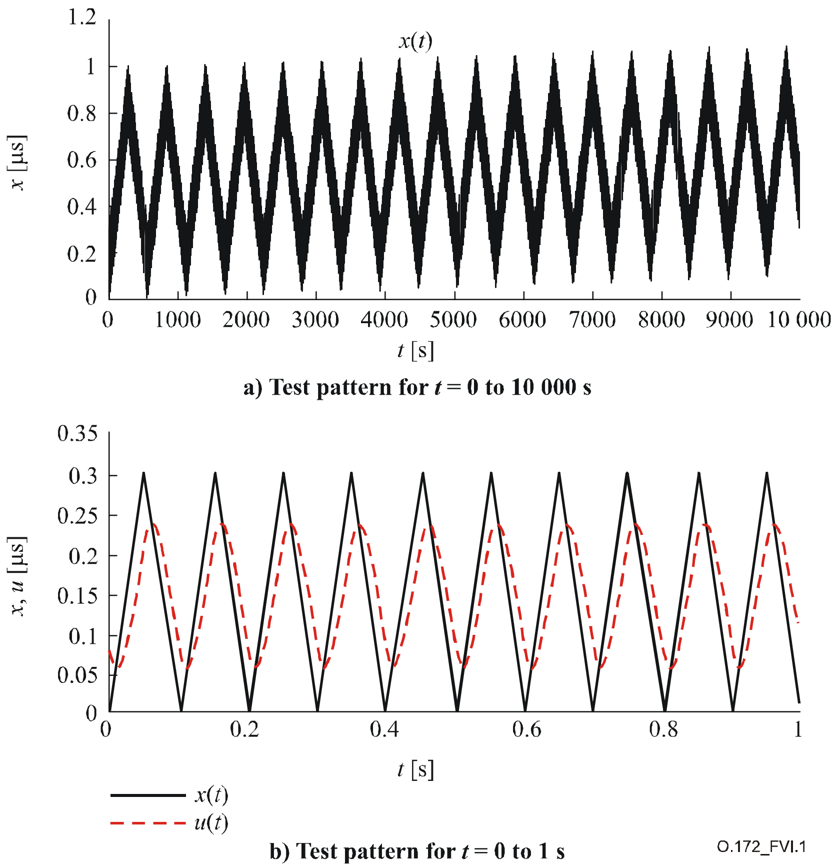

Figure VI.1/O.172 – Test pattern for Table 10/G.812 MTIE mask generated by repetitive transient (10-Hz low-pass measurement filter)

The calculated MTIE for $x(t)$ and $u(t)$ in Figure VI.1 is shown in Figure VI.2. The MTIE of $x(t)$ matches the MTIE mask. However, the MTIE of $u(t)$ is lower than the MTIE mask. Since the wander measurement function can only calculate the MTIE of $u(t)$, it is not possible to confirm whether the MTIE of the test pattern $x(t)$ matches the MTIE mask.

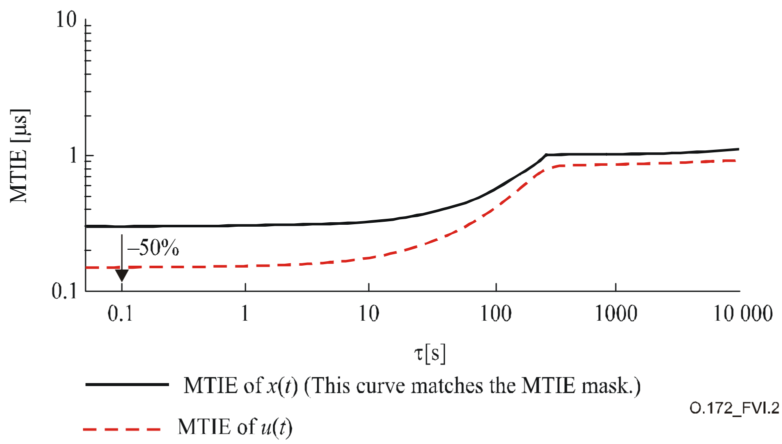

Figure VI.2/O.172 – MTIE of $x(t)$ and $u(t)$ in Figure VI.1

Figure VI.3 below shows the same signal $x(t)$ when filtered with a 500-Hz wander measurement filter, and Figure VI.4 the resultant MTIE. The MTIE stress, when measured in a 500-Hz filter, is now shown as less than 1% different from the MTIE being generated.

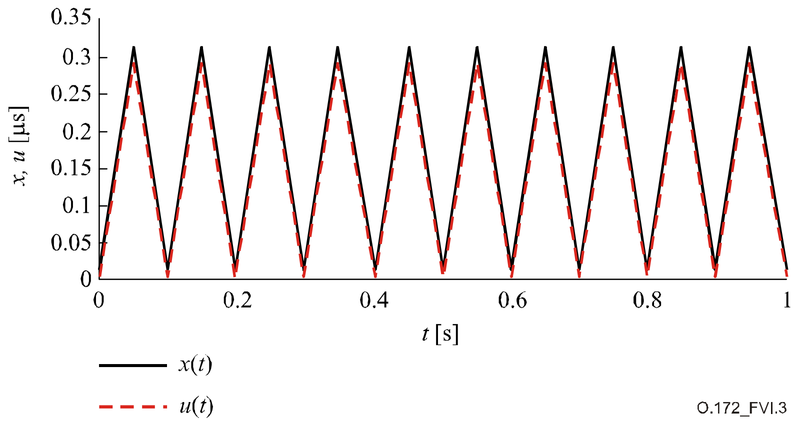

Figure VI.3/O.172 – Test pattern for Table 10/G.812 MTIE mask generated by repetitive transient (500-Hz low-pass measurement filter)

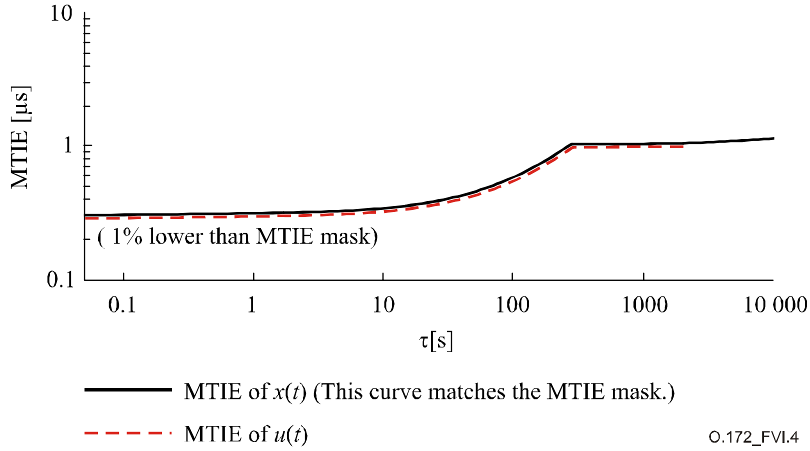

Figure VI.4/O.172 – MTIE of $x(t)$ and $u(t)$ in Figure VI.3

The modified $x(t)$, which uses a trapezoid waveform, is shown in Figure VI.5 as a solid line. The dotted line, $u(t)$, shows the waveform when filtered in a 10-Hz bandwidth.

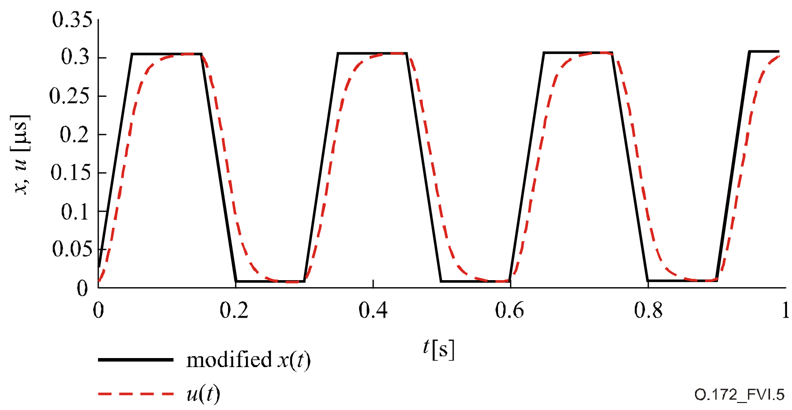

Figure VI.5/O.172 – Modified test pattern for t = 0 to 1 s with repetitive transient $w_1(t)$ in Figure VI.1-b (10-Hz low-pass measurement filter)

The MTIE of the modified test pattern $x(t)$ and the MTIE of $u(t)$ are shown in Figure VI.5. The MTIE of $u(t)$ matched the MTIE mask within 0.1% for $\tau > 0.1$ s.

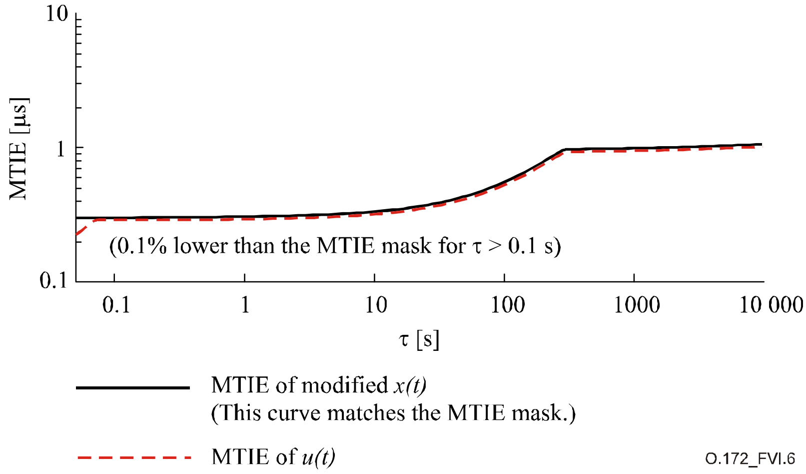

Figure VI.6/O.172 – MTIE of $x(t)$ and $u(t)$ in Figure VI.5

Appendix VII

Method for verification of measurement result accuracy and intrinsic fixed error

VII.1 Verification description and application

This appendix recommends a method and example implementations to verify and characterize the measurement result accuracy specified in 9.4.1. This method allows the user to effectively de-embed error contributions of the test equipment from the signal being measured. It provides a high-quality reference transmitter with the capability to add pulse transient sinusoidal modulation. The pattern dependent jitter contribution of the reference transmitter can be considered as negligible and therefore may be removed from the error calculation.

The scheme uses a high-quality optical transmitter and pattern generator with minimal pattern dependent jitter at the line rate under test. A target would be less than 10 mUI peak-peak measured in bandwidth f_1-f_4. A generic jitter modulator is also described with the capability to generate pulse sinusoidal jitter. Both techniques can be verified with general purpose test equipment. The method described in Appendix VIII may be used to verify the intrinsic jitter of the optical pattern generator.

The application is to allow test equipment vendors and users the ability to accurately characterize jitter measurement equipment.

VII.2 System implementation

The block diagram of the system is shown in Figure VII.1. The calibration section is used to set up and verify the jitter clock and optical data signals. This is intended to be a low jitter amplitude test and as such is suited to generate up to 100 mUI, transient sinusoidal, for jitter measurement testing. The modulation frequencies to be generated are typically from f_1 to f_4.

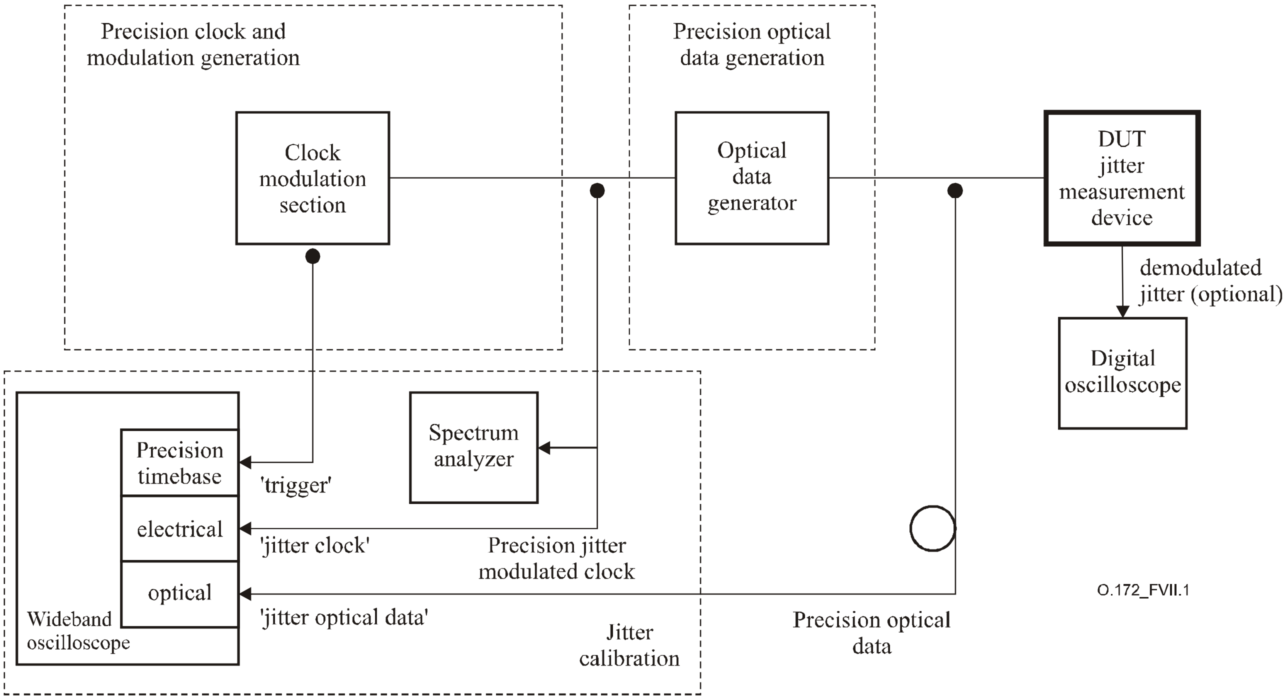

Figure VII.1/O.172 – Verification system block diagram

Figures VII.2, VII.3 and VII.4 are example implementations of the generic test system in Figure VII.1. These illustrate potential means to produce independently verifiable bursts of clock jitter and a means of eliminating data jitter from an optical pattern, these do not restrict other implementation methods.

The block diagram of the clock section is shown in Figure VII.2. This is implemented using two high-quality synthesisers, Oscillator 1 and 2, to generate the line rate clock and sinusoidal jitter phase modulation. The relative amplitude levels of these oscillators will determine the jitter amplitude generated, the relative frequencies the jitter modulation. For example the Oscillator 1 is the line rate clock, Oscillator 2 is set to the line rate plus (or minus) an offset – sinusoidal phase modulation will be generated at the offset frequency, on the line clock.

It is recommended the relative oscillator amplitudes be adjusted up to 100 mUI phase modulation, this can be calibrated using the spectrum analyser using normal FM theory techniques. The operation of the pulse generator is used to gate the Oscillator 2 clock, thus directly controlling the modulation burst time.

The synchronization of the modulation burst relative to the frame structure is for further study.

To minimize potential phase discontinuities, the modulation burst shall be either synchronized to the zero crossings of the sinusoidal modulation signal or alternatively shall have a maximum on/off transition time given approximately by the following relation.

$$t \approx \frac{0.342}{f_4}$$

As the jitter contributions of the high-quality RF synthesizer are noise like these can be estimated with phase noise analysis. It is likely the jitter contribution of a high-quality oscillator is minimal over the measurement bandwidth of interest and may be discounted from the receiver error measurements. The method described in Appendix VIII may be used to verify the random jitter contribution of the optical pattern generator.

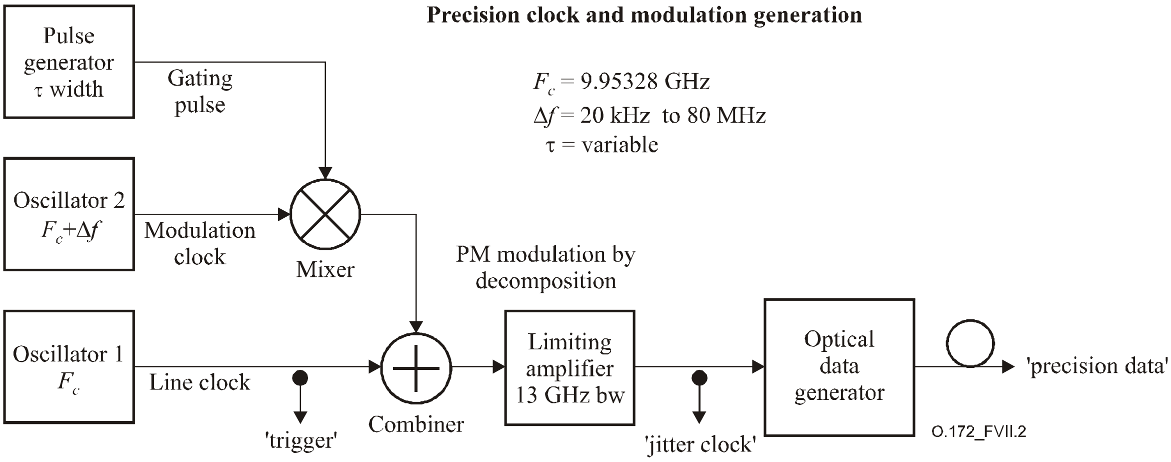

Figure VII.2/O.172 – Example clock and jitter generation block diagram

The block diagram of the data section is shown in Figure VII.3. This is implemented using a traditional pattern generator coupled to a double optical modulation scheme to perform an optical retiming function.

The data modulator operates as a traditional modulator; this has pattern-dependent jitter present. The second pulse carving modulator performs an optical retiming operation. The output is an optical AND function of the carving pulses (clock pulses of reduced width) and the NRZ data. The resultant data output has the reduced jitter properties of the retiming clock pulse – this is now an RZ data pulse. The RZ data is pulse stretched into pattern-dependent jitter-free NRZ data.

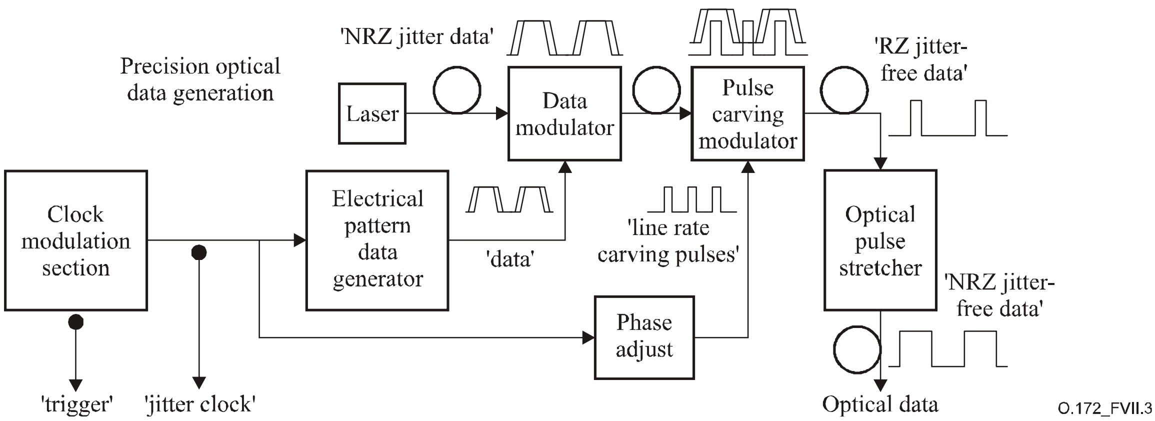

Figure VII.3/O.172 – Example optical data generation block diagram

Figure VII.4 below shows an alternative implementation of the reference transmitter. For example a good quality STM-64 optical modulator will effectively become a reference transmitter at STM-16, with negligible pattern jitter. This is also an effective technique for implementing optical data generators suitable for receiver characterization.

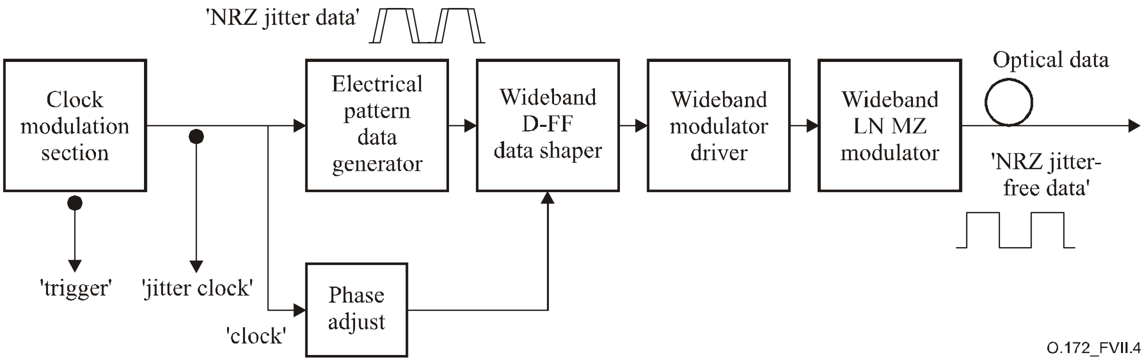

Figure VII.4/O.172 – Alternative optical data generation block diagram

VII.3 Results and interpretation

The verification system can be used to test varying modulation pulse widths and repetition rates. The user of the system has control over the area to be characterized to verify compliance with this Recommendation. It is suggested that at each modulation frequency point an accuracy map can be produced with varying transient widths and repetition rates. An example of this is given in Figure VII.5.

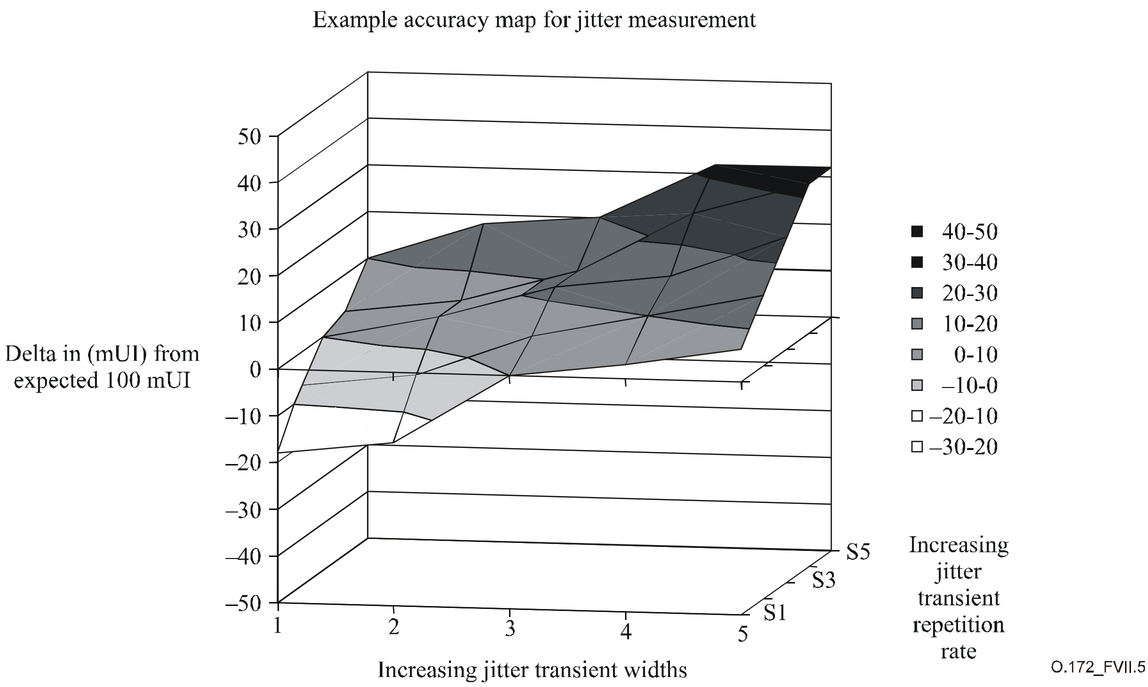

Figure VII.5/O.172 – Example jitter measurement map test result

The range of modulation frequencies, burst widths and repetition rates depend on the jitter measurement bandwidth, which is related to the applied bit rate. A possible combination of modulation frequencies, burst widths and repetition rates are given in Table VII.1 below.

Table VII.1/O.172 – Combinations of modulation frequency, burst width and repetition rate

Signal	Modulation frequency f_m	Minimum burst width t_{min}	Burst widths > t_{min}				
TM-1	1 kHz [a)]	2 ms	–	–	–	–	–
	65 kHz [a)]	31 µs	–	–	–	100 µs	1 ms
	300 kHz	6.7 µs	–	–	–	100 µs	1 ms
	1.3 MHz	1.5 µs	–	–	10 µs	100 µs	1 ms
STM-4	10 kHz [a)]	200 µs	–	–	–	–	1 ms
	250 kHz [a)]	8 µs	–	–	–	100 µs	1 ms
	1 MHz	2 µs	–	–	10 µs	100 µs	1 ms
	5 MHz	400 ns	–	–	10 µs	100 µs	1 ms
STM-16	50 kHz [a)]	40 µs	–	–	–	100 µs	1 ms
	1 MHz [a)]	2 µs	–	–	10 µs	100 µs	1 ms
	5 MHz	400 ns	–	–	10 µs	100 µs	1 ms
	20 MHz	100 ns	–	1 µs	10 µs	100 µs	1 ms
STM-64	200 kHz [a)]	10 µs	–	–	–	100 µs	1 ms
	3 MHz [a)]	667 ns	–	–	10 µs	100 µs	1 ms
	20 MHz	100 ns	–	1 µs	10 µs	100 µs	1 ms
	80 MHz	25 ns	100 ns	1 µs	10 µs	100 µs	1 ms

[a)] The burst repetition rate shall be in the range from 10 Hz to 10 kHz.

NOTE 1 – Applicable only when high-pass f_1 is used for the jitter measurement.

NOTE 2 – The measurement period should be 60 seconds.

NOTE 3 – Minimum burst repetition rate of 10 Hz is chosen for measurement repeatability and is based on test pattern PRBS repetition.

NOTE 4 – Burst widths of 100 µs and 1 ms can only be used with burst repetitions less than 10 kHz and 1 kHz respectively.

The allowed measurement error is defined in 9.4. This is given as ±R% of reading ±W. For an STM-64 example point at 10 MHz R is defined as 20% and W defined as (for measurement bandwidth f_3-f_4) as 35 mUI. This means at a nominal jitter amplitude of 100 mUI the maximum error allowed is ±55 mUI (nominal measurement filter response and error of the verification system not included).

NOTE 1 – The error associated with the pattern-dependent jitter of the reference transmitter is for further study.

NOTE 2 – Appendix VII is designed specifically for use with structured test signals as defined in Annex A. Appendix VIII verification of Appendix VII pattern-dependent jitter is restricted using the specified test patterns defined in Appendix VIII.

NOTE 3 – The precision clock generation section may be used to evaluate the error of an SDH jitter measurement set when operating with electrical clock interfaces, as specified in 9.4.1.

Appendix VIII

Method for characterization of transmit intrinsic jitter

VIII.1 Verification description and application

This appendix recommends a method and implementation to verify and characterize a transmit signal with a specific jitter test pattern. This technique may be used to help de-embed transmit and receive components of jitter test equipment.

The technique requires a fixed, repeating SDH-like test frame to be used. This test frame is intended for use as a potential diagnostic tool and is not intended for use to characterize network equipment or devices under test.

This technique may be used to verify the pattern-dependent jitter and the random jitter contribution of the low jitter data source defined in Appendix VII.

This method requires the use of a high-quality pattern frame trigger.

The long-term phase drift between clock and data is recognized as a source of potential error and should be considered in any measurement.

VIII.2 Method

This is a method to accurately determine the rms and peak-to-peak values from transmit data with a defined test pattern.

VIII.2.1 Measurement of test frame pattern-dependent jitter

1) Set a transmitter to produce a framed SDH test signal as defined in VIII.3.

2) Use an oscilloscope, with measurement bandwidth equivalent to a fourth-order Bessel-Thomson filter with a 3-dB attenuation frequency at 0.75 times the bit rate, to extract the data and clock waveforms. The measurement bandwidth shall be in accordance with Annex B/G.957 and Annex A/G.691.

   NOTE 1 – The error associated with the data acquisition is for further study.

3) Set the acquisition to average over at least 64 traces to eliminate random phase noise. Adjust the phase of the clock rising edge to coincide exactly with the SDH signal edges. (This will minimize the effect of non-linearity in the oscilloscope time base.) Measure the time (in UI) between the rising edge of the clock and the corresponding SDH signal edge (within ±0.5 UI). See Figure VIII.1 This forms a sequence of pattern-dependent phase values x_i.

4) If there is no corresponding SDH signal edge for a particular i, assign to $x_i = 0$. Measure x_i to cover one period of the SDH frame, i.e., the size of the dataset, $[x_1 .. x_N]$ is $N = 125 \times 10^{-6} \times f_0$, where f_0 is the corresponding bit rate. Then generate mathematically a new sequence by using the following formulae:

$$x'_i = \frac{\sum_{n=1}^{24} x_{i-n}}{\sum_{n=1}^{24} p_{i-n}}$$

   where p_i represents the pattern density information. Assign $p_i = 1$ when an SDH edge exists, assign $p_i = 0$ when no transition data is present. See Figure VIII.2.

   Substitute x'_i values into series x_i where no measured SDH edge value exists.

   NOTE 2 – The error associated with the phase insertion algorithm is for further study.

5) Filter the sequence x_i mathematically with the appropriate high-pass and low-pass filters to form the sequence of pattern-dependent jitter values y_i.

6) Use histogram methods to determine the probability distribution function PDF_y of the sequence y_i.

7) From PDF_y, calculate the rms of the sequence y_i. This value σ_{PD} is the rms of the pattern-dependent jitter.

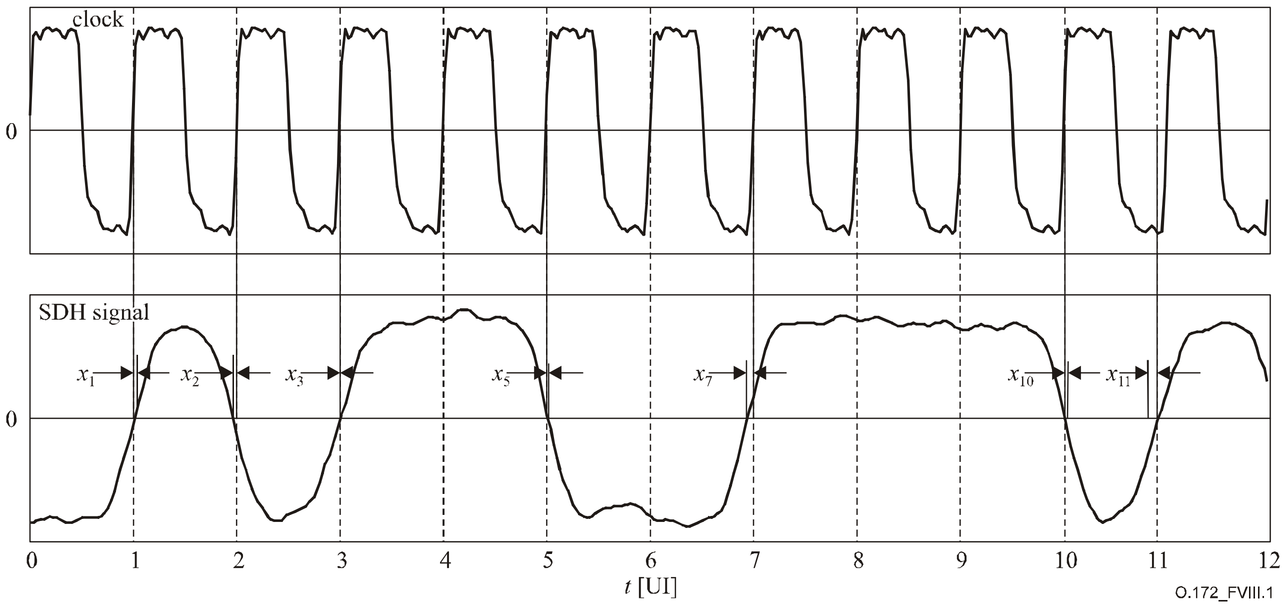

Figure VIII.1/O.172 – Measurement of the pattern-dependent phase sequence x_i

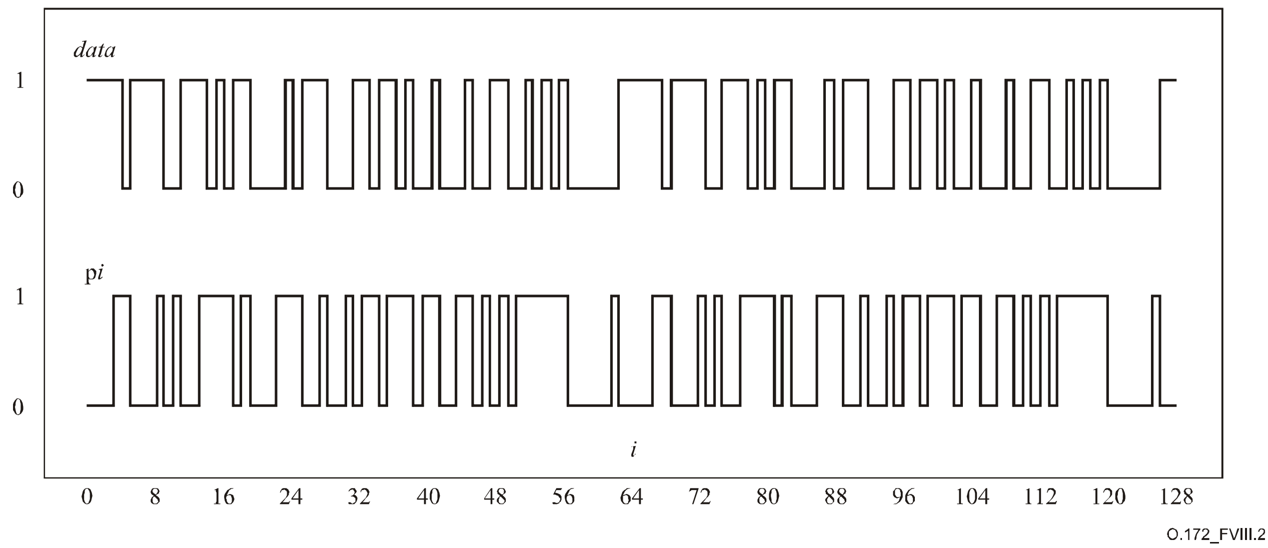

Figure VIII.2/O.172 – The data pattern and transition density p_i

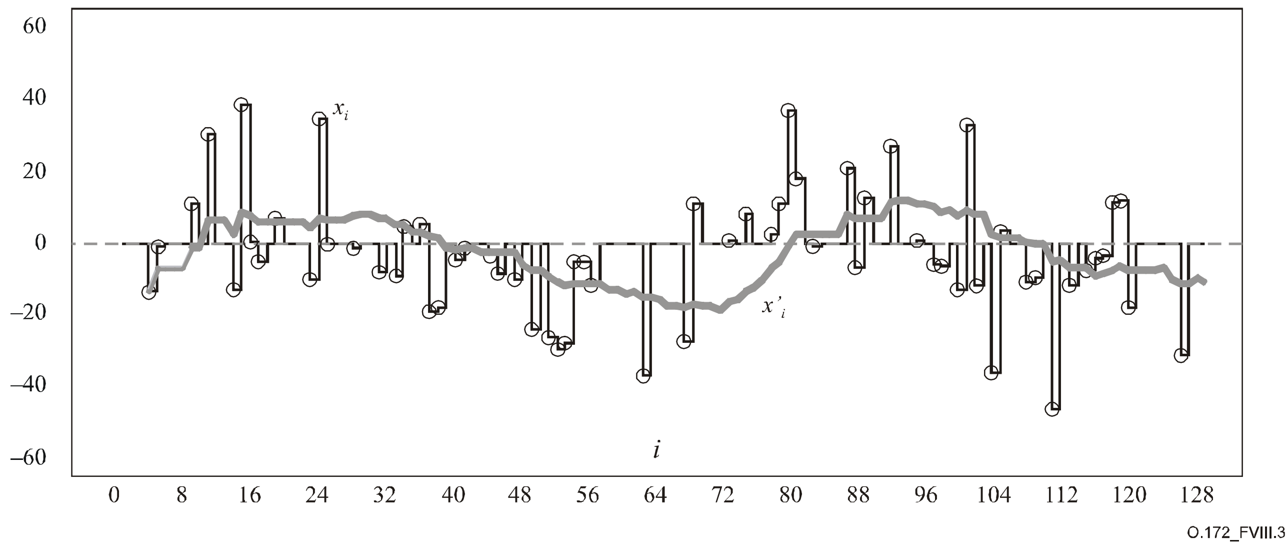

Figure VIII.3/O.172 – Unfiltered phase values x_i and x'_i

VIII.2.2 Measurement of clock random jitter

1) Set the transmitter to produce a 1010...data sequence. (This eliminates pattern-dependent jitter.)

2) Apply the signal to a spectrum analyzer, in the case of an optical signal use a wide-bandwidth O/E converter. From the SSB noise on one side of the half-baud component, determine the power spectral density PSD_{RP} of the random phase noise. (In converting the SSB noise to UI^2/Hz, remember that one cycle of the half-baud component is 2 UI.)

3) Mathematically apply the appropriate high-pass and low-pass filtering to the PSD_{RP} to get the power spectral density PSD_{RJ} of the random jitter noise.

4) Integrate PSD_{RJ} over all f and take the square root to get the rms σ_R of the random jitter noise.

VIII.2.3 Estimate of total jitter using the PDF

1) The rms of the total jitter is $\sigma_T = [\sigma_{PD}^2 + \sigma_R^2]^{0.5}$.

2) Assuming the random jitter noise is Gaussian, use σ_R to get the probability density function PDF_R of the random jitter noise.

3) Convolve the pattern-dependent PDF_y with the random PDF_R to get the probability distribution function PDF_T of the total jitter.

4) Calculate the average peak-to-peak jitter from PDF_T, from the bandwidth of the jitter, and from the measurement interval. See VIII.4 for this calculation.

VIII.3 Diagnostic test pattern

1) Figures VIII.4 and VIII.5 below define diagnostic SDH test patterns. These are suitable for use at STM-64 and STM-16.

2) STM-256 pattern is for further study.

3) Diagnostic test patterns which simulate long PRBS pattern effects are for further study.

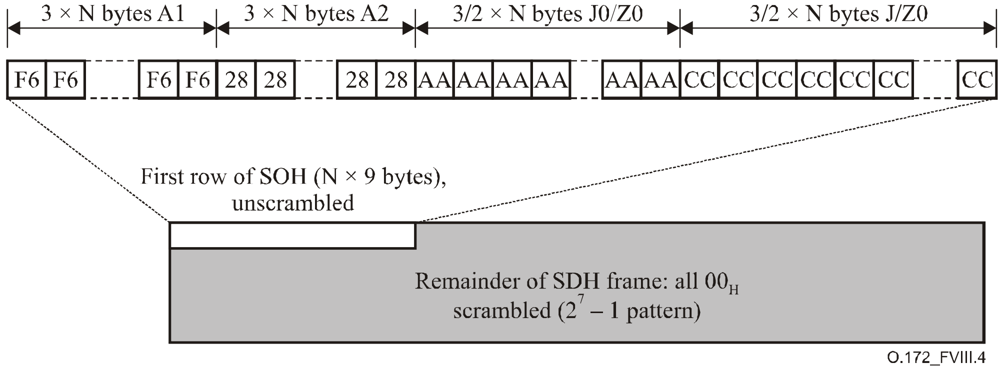

Figure VIII.4/O.172 – Test pattern 1

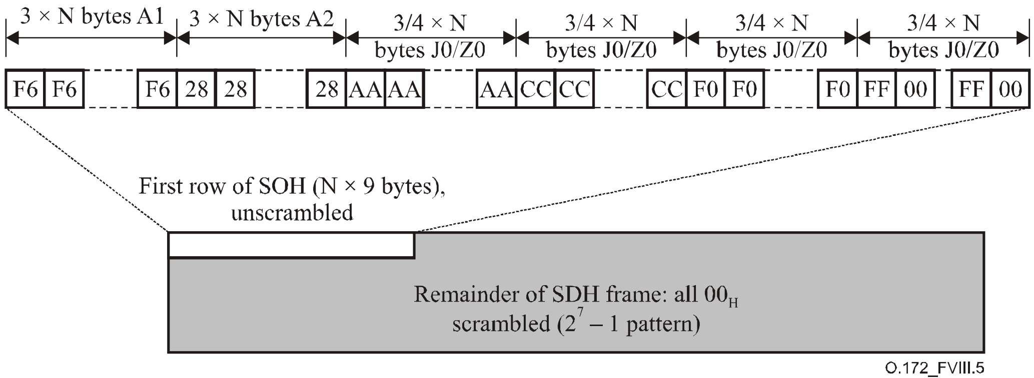

Figure VIII.5/O.172 – Test pattern 2

VIII.4 Calculation of peak-to-peak value from the probability distribution function

From the probability distribution function $p(x)$ of a time function x we want to find the expected peak-to-peak value of x, knowing that x is about white out to a bandwidth BW. The measurement interval is T.

A time function x that is white out to a bandwidth BW has about $N = 2 \cdot \text{BW} \cdot T$ independent values in the interval T. Then the probability of not exceeding some value x during the interval T is the probability of N independent values all not exceeding that x. But the probability of not exceeding x on one try is the cumulative distribution function $c(x)$, where $c(x)$ is the integral of $p(x)$. Then the probability of not exceeding x in N independent tries is $c_{\max}(x) = c(x)^N$. Since this is the probability that the maximum value will not exceed x, $c_{\max}(x)$ is the cumulative distribution function of the maximum value. Then the probability distribution function $p_{\max}(x)$ of the maximum is the derivative of $c_{\max}(x)$. The average (or expected) value of the maximum is the integral of $x \cdot p_{\max}(x)$ over all of x.

As an example, Figure VIII.6 shows these functions for the case of a Gaussian $p(x)$ with an rms of unity. If the bandwidth of x is BW = 80 MHz and the measurement interval is $T = 60$ seconds, then $N = 9.6 \cdot 10^9$. Raising $c(x)$ to this power pushes the rise of the $c_{\max}(x)$ out beyond 6. $p_{\max}(x)$ is the derivative of $c_{\max}(x)$. From $p_{\max}(x)$ we calculate the expected maximum of 6.43.

In a similar manner, the minimum of x can be found. In this symmetrical case, the expected minimum is –6.43, and the expected peak-to-peak value is 12.86.

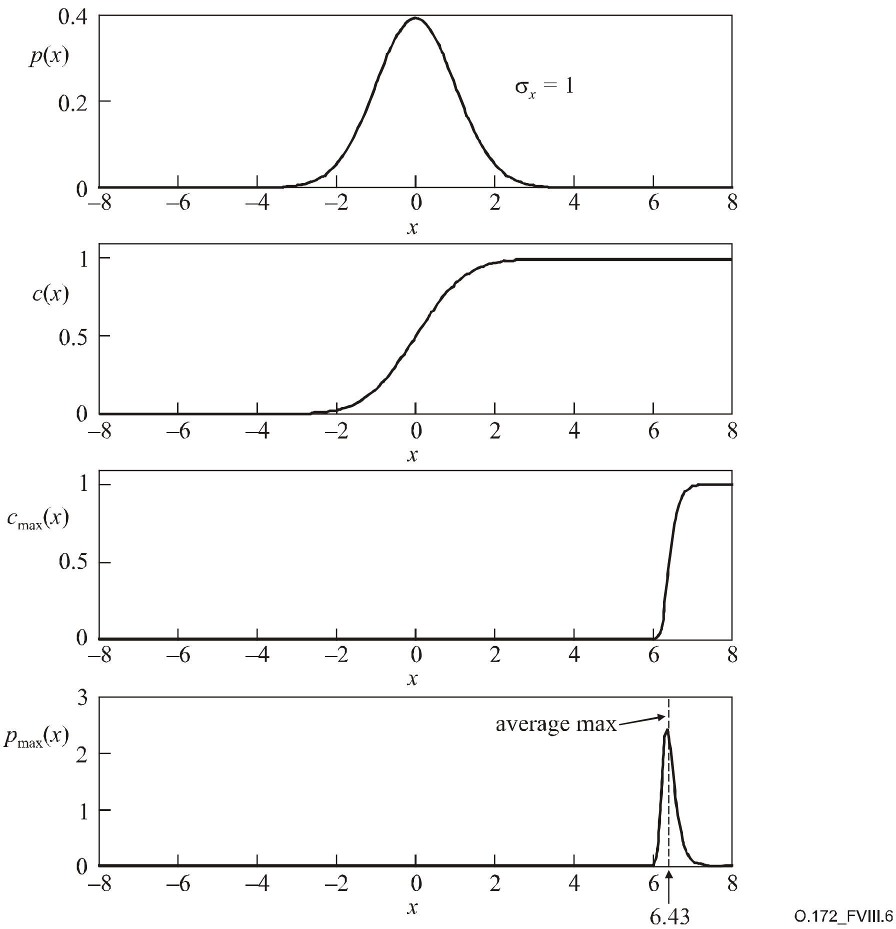

Figure VIII.6/O.172 – Gaussian example of finding the expected maximum of *x* from the PDF of *x*

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