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SERIES O: SPECIFICATIONS OF MEASURING
EQUIPMENT

Equipment for the measurement of digital and
analogue/digital parameters

**Jitter measuring equipment for digital systems
based on XG-PON**

Recommendation ITU-T O.175



ITU-T O-SERIES RECOMMENDATIONS
SPECIFICATIONS OF MEASURING EQUIPMENT

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Recommendation ITU-T O.175

Jitter measuring equipment for digital systems based on XG-PON

Summary

Recommendation ITU-T O.175 specifies test instrumentation that is used to generate and measure timing jitter in digital systems based on the XG-PON.

History

Edition	Recommendation	Approval	Study Group
1.0	ITU-T O.175	2012-10-29	15

FOREWORD

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Recommendation ITU-T O.175

Jitter measuring equipment for digital systems based on XG-PON

1 Scope

The test instrumentation consists principally of a jitter measurement function and a jitter generation function. Measurements can be performed at the physical layer of XG-PON systems. A bit-error rate test (BERT) 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 in digital systems based on synchronous digital hierarchy (SDH) is specified in [ITU-T O.172].

It is recommended that [ITU-T G.987.2] should be read in conjunction with this Recommendation.

2 References

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

- [ITU-T G.703] Recommendation ITU-T G.703 (2001), *Physical/electrical characteristics of hierarchical digital interfaces*.
- [ITU-T G.783] Recommendation ITU-T G.783 (2006), *Characteristics of synchronous digital hierarchy (SDH) equipment functional blocks*.
- [ITU-T G.810] Recommendation ITU-T G.810 (1996), *Definitions and terminology for synchronization networks*.
- [ITU-T G.987] Recommendation ITU-T G.987 (2012), *10-Gigabit-capable passive optical network (XG-PON) systems: Definitions, abbreviations, and acronyms*.
- [ITU-T G.987.1] Recommendation ITU-T G.987.1 (2010), *10-Gigabit-capable passive optical networks (XG-PON): General requirements*.
- [ITU-T G.987.2] Recommendation ITU-T G.987.2 (2010), *10-Gigabit-capable passive optical networks (XG-PON): Physical media dependent (PMD) layer specification*.
- [ITU-T G.987.3] Recommendation ITU-T G.987.3 (2010), *10-Gigabit-capable passive optical networks (XG-PON): Transmission convergence (TC) specifications*.
- [ITU-T G-Sup.48] ITU-T G-series Recommendations – Supplement 48 (2010), *10-Gigabit-capable passive optical networks: Interface between media access control with serializer/deserializer and physical medium dependent sublayers*.
- [ITU-T O.3] Recommendation ITU-T O.3 (1992), *Climatic conditions and relevant tests for measuring equipment*.
- [ITU-T O.172] Recommendation ITU-T O.172 (2005), *Jitter and wander measuring equipment for digital systems which are based on the synchronous digital hierarchy (SDH)*.

[IEEE 802.3] IEEE Standard 802.3-2008, *Information technology – Telecommunications and information exchange between systems – Local and metropolitan area networks – Specific requirements – Part 3: Carrier Sense Multiple Access with Collision Detection (CSMA/CD) Access Method and Physical Layer Specifications.*

3 Definitions

This Recommendation uses the following terms defined elsewhere:

3.1 (timing) jitter: [ITU-T G.810].

3.2 10-gigabit-capable passive optical network (XG-PON): [ITU-T G.987].

3.3 XG-PON1: [ITU-T G.987].

3.4 XG-PON2: [ITU-T G.987].

Note that [ITU-T G.987] provides additional definitions and abbreviations used in timing and synchronization Recommendations. They also provide background information on the need to limit phase variation and impairments on digital systems.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

BER	Bit Error Ratio
BERT	Bit Error Rate Tester
B-PON	Broadband Passive Optical Network
FEC	Forward Error Correction
FTTx	Fibre to the x (B – building, business; H – home; C – cabinet, curb, P – premises)
G-PON	Gigabit-capable Passive Optical Network
HEC	Hybrid Error Correction
LOB	Loss Of Burst
LODS	Loss Of Downstream Synchronization
LOS	Loss Of Signal
NRZ	Non Return to Zero
OLT	Optical Line Terminal
ONT	Optical Network Terminal
ONU	Optical Network Unit
PLL	Phase-Locked Loop
PON	Passive Optical Network
ppm	parts per million
PRBS	Pseudo Random Binary Sequence
RMS	Root Mean Square
TIE	Time Interval Error
TJ	Total Jitter

UI	Unit Interval
UI _{pp}	Unit Interval, peak-to-peak
UNI	User Network Interface
XG-PON	10-Gigabit-capable Passive Optical Network, ITU-T G.987-series Recommendations.

5 Conventions

For the purposes of this Recommendation, the following convention is adopted:

- a) The particular interface signals used are denoted either by their standardized signal formats, e.g., XG-PON1, or by their bit rate, e.g., 2.48832 Gbit/s for upstream, and 9.95328 Gbit/s for downstream. The default physical format of XG-PON interfaces is considered to be optical.

6 Functional block diagram

Figure 1 shows the general block diagram of the equipment and identify the main functions covered in this Recommendation. The figure does not describe a specific implementation.

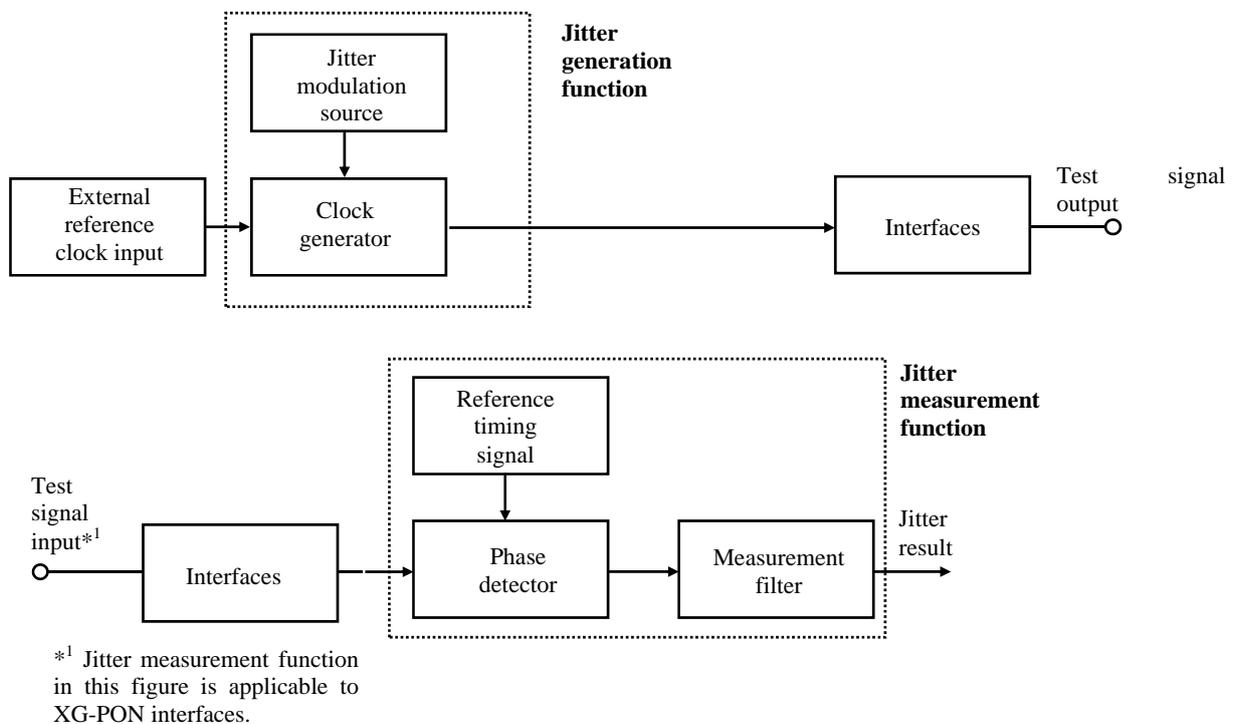


Figure 1 – Functional block diagram for jitter test set

7 Interfaces

7.1 XG-PON interfaces

The equipment shall be capable of operating at one or more of the following XG-PON interfaces. Table 9-1 of [ITU-T G.987.2] lists the interfaces supporting XG-PON.

7.2 External reference clock input

The measuring equipment shall support reference data signals at bit rates of 1 544 kbit/s or 2 048 kbit/s. If 2 048 kbit/s can be accepted, the equipment shall also accept a clock signal at 2 048 kHz as a reference. The characteristics of clock signals shall be in accordance with [ITU-T G.703].

8 Jitter generation function

Tests of digital equipment may be made with either a jittered or a non-jittered 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 conforming to relevant Recommendations may be provided within the clock generator and/or digital test pattern generator, or may be provided separately. This Recommendation defines a sinusoidal modulation source for jitter generation.

The sinusoidal jitter generation functions are defined in clause 8.4.

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 and the modulating frequencies shall meet the minimum requirements of Figure 2. The generated peak-to-peak jitter and the modulating frequencies for XG-PON1 and XG-PON2 shall meet [ITU-T G.987.2]. The burst signal measurement methodology is defined in Appendix I.

8.2.1 Accuracy of clock generator

The frequency deviation of the internal clock signal from its nominal value shall be less than ± 32 ppm (stratum-4 clock) excluding locked operation.

As an option, the clock generator may provide adjustable frequency offset of sufficient magnitude to facilitate tests across the clock tolerance range of the equipment under test, e.g., ± 10 ppm to ± 50 ppm as defined for the various bit rates listed in Table 9-1 of [ITU-T G.987.1].

It shall be possible to phase-lock the generation function to an external reference clock source of arbitrary accuracy; refer to clause 7.2.

8.3 Digital test pattern generator

The jitter measurement function will normally be used in conjunction with any suitable digital test pattern generator supporting the following facility.

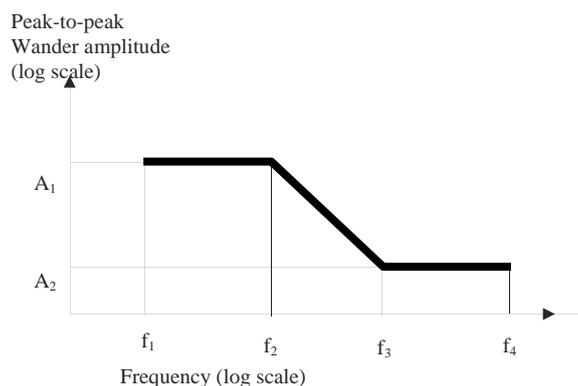
- a) XG-PON signal in accordance with [ITU-T G.987.3].

8.4 Sinusoidal jitter generation function

The ability to generate sinusoidal jitter for jitter tolerance measurements as described in [ITU-T G.987.2] may be provided. The following requirements shall be met to ensure sufficiently accurate, robust and consistent measurements.

8.4.1 Minimum sinusoidal jitter generation capability

The jitter amplitude/frequency characteristics of the generation function shall meet the minimum requirements of Figure 2 for XG-PON signals.



Signal (Gbit/s)	Minimum peak-to-peak jitter amplitude (UIpp)		Jitter frequency breakpoints (Hz)			
	A_1	A_2	f_1	f_2	f_3	f_4
2.48832	2	0.2	10	100k	1M	20M
9.95328	2	0.2	10	400k	4M	80M
NOTE – Values based on requirements of Table 9-8 of [ITU-T G.987.2]						

Figure 2 – Minimum amplitude of adjustable generated sinusoidal jitter amplitude versus jitter frequency for XG-PON signals

8.4.2 Generation accuracy

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

The generating accuracy of the sinusoidal jitter generation function depends on several factors, such as fixed intrinsic error, setting resolution, distortion and frequency response error. In addition, some error is a function of the actual setting.

8.4.2.1 Phase amplitude error

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

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

Where Q is a variable error specified in Table 1 for XG-PON signals. The frequencies f_1 and f_4 used in Table 1 are defined in Figure 2.

NOTE – This Recommendation excludes any wideband intrinsic jitter components.

Table 1 – Variable error (Q) of XG-PON signal jitter generation

Signal	Error, Q	Frequency range
XG-PON	$\pm 10\%$	f_1 to f_4
NOTE – Value of jitter range is for further study.		

8.4.2.2 Intrinsic jitter of generation function

The intrinsic jitter of the jitter generation function measured in the bandwidth f_1 - f_4 , as defined in Figure 2 with the amplitude set to zero, shall be less than:

0.04 UIpp for test signal defined in clause 8.3.

9 Jitter measurement function

The jitter measurement methodology for XG-PON interfaces is defined in [ITU-T G.987.2]. Burst signal assumes that there are essentially two jitter mechanisms: deterministic jitter and random jitter. Separate requirements are specified for transmitters and receivers. The burst jitter measurement for XG-PON according to Appendix IV of [ITU-T G.987.2] is defined in Appendix I.

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 3 and Table 3 for XG-PON signals. The frequencies f_1 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_1 to f_4 is optional.

Table 3 – Minimum amplitude of measured jitter versus jitter frequency

XG-PON Signal (Gbit/s)	Minimum peak-to-peak jitter amplitude [UIpp]		Jitter frequency breakpoints [Hz]			
	A_1	A_2	f_1	f_2	f_3	f_4
2.48832	2	0.2	10	50 k	500 k	20 M
9.95328	2	0.2	10	400 k	4 M	80 M

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

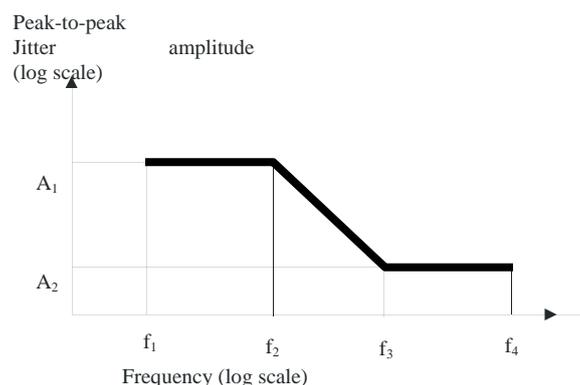


Figure 3 – Measured jitter amplitude versus jitter frequency

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 of the jitter measurement function shall be in accordance with Table 4 for XG-PON signals.

Table 4 – Jitter measurement function bandwidth for XG-PON signals

XG-PON signal (Gbit/s)	Jitter measurement bandwidth (-3 dB cut-off frequencies)		
	f_1 [Hz] high-pass	f_3 [Hz] high-pass	f_4 [Hz] low-pass
2.48832	5 k	1 M	20 M
9.95328	20 k	4 M	80 M

9.3.1 Frequency response of jitter measurement function for XG-PON 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 clause 9.4).

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

- The high-pass measurement filter with cut-off frequency f_1 has a first-order characteristic and a roll-off of 20 dB/decade.
- The nominal f_1 cut-off frequency for each bit rate is specified in Table 4 and the nominal -3 dB point of the measurement filter shall be at a frequency $f_1 \pm 10\%$.
- 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.
- The nominal f_4 cut-off frequency for each bit rate is specified in Table 4 and the -3 dB point of the measurement filter shall be at a frequency $f_4 \pm 10\%$.
- The maximum attenuation of the measurement filters shall be at least 60 dB.

These jitter measurement functional requirements are compatible with [ITU-T G.987.2].

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 G.987.2].

The measurement accuracy is specified using an input signal with structure defined in clause 8.3 for XG-PON signals and physical characteristics of either:

- a) an electrical signal in conformance with [ITU-T G.987.2] having the nominal terminated signal level and with no additional frequency-dependent loss; or
- b) an optical signal in conformance with [ITU-T G.987.2] and with a nominal power in the range -10 dBm to -12 dBm. Operation at higher input power levels may be permitted at 2.5G and 10G in accordance with the mean launch powers specified in [ITU-T G.987.2].

The total measurement error shall be less than:

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

where R is the variable error specified in Table 6 and W is the fixed error of Table 5, which includes any contribution from the internal timing extraction function.

9.4.2 Fixed error of XG-PON jitter measurements

For the XG-PON bit rates and for the indicated digital signals, the fixed error of the jitter measurement function shall be as specified in Table 5 within the frequency ranges f_1 - f_4 indicated. Frequencies f_1 , and f_4 used in Table 5 are defined in Table 4.

Table 5 – Fixed error (W) of XG-PON jitter measurements

XG-PON signal (Gbit/s)	Maximum peak-to-peak jitter error [UIpp] for given digital signals	
	Structured signal	Clock signal
	f_1 - f_4	f_1 - f_4
2.48832	0.1	0.05
9.95328	0.1	0.05

NOTE 1 – Structured digital signals are defined in clause 8.3.
NOTE 2 – Clock interfaces are optional.

9.4.3 Variable error of XG-PON jitter measurements

The variable error R shall be as specified in Table 6 for XG-PON signals. Frequencies f_1 and f_4 used in Table 6 are defined in Table 4.

Table 6 – Variable error (R) of XG-PON jitter measurements

XG-PON signal (Gbit/s)	Error, <i>R</i>	Frequency range
2.48832 9.95328	±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

9.4.4 Digital test signal-dependent error

The accuracy requirements stated in previous subclauses shall be met when digital test signals defined in clause 8.3 are used to perform the jitter measurement. When using other structured signals, pseudo-random or random signals, larger measurement errors could be expected.

9.5 Additional facilities

9.5.1 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 Operating environment

The performance requirements shall be met when operating within the climate conditions specified in clause 2.1 of [ITU-T O.3].

Appendix I

Jitter evaluation methods for an optical network unit burst mode transmitter

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

This appendix describes the methods for evaluating jitter in the burst upstream signal output from an optical network unit (ONU).

I.1 Introduction

The specifications for jitter performance at the XG-PON interface described in clause 9.2.9.7 of [ITU-T G.987.2] are derived from the jitter performance at the SDH interface described in [ITU-T G.783]. Therefore, the jitter measurement equipment specified in [ITU-T O.172] for the SDH interface might seem suitable for evaluating jitter performance at the XG-PON interface. However, much SDH jitter measurement equipment cannot work properly with the burst signal transmitted from an ONU, because the internal clock recovery circuit is designed for a continuous signal. Therefore, to evaluate jitter performance for an ONU transmitter using existing SDH jitter measurement equipment, Appendix IV.4 of [ITU-T G.987.2] specifies configuring the ONU to transmit in the continuous mode.

However, in actual operation, the ONU burst signal might include additional jitter components. For example, a transient jitter component might be added at the start of the burst frame. This appendix explains how to evaluate the total jitter including any additional components in the burst data signal. The evaluation uses either a wideband real-time oscilloscope, a sampling oscilloscope, or a bit error rate tester (BERT). Each method is explained below.

I.2 Evaluation using wideband real-time oscilloscope

I.2.1 Apparatus

The following apparatus are required:

- 1) Real-time oscilloscope
 - Sampling rate $\geq 40\text{G}$ sample/s
 - Capture length $\geq 25\ \mu\text{s}$
 - Jitter analysis software according to Annex 48B.3 of [IEEE 802.3] and chapter 10 of [b-INCITS TR-35].
- 2) O/E converter
 - With transfer function specified in clause B.2 of [b-ITU-T G.975].

I.2.2 Set-up

Figure I.1 shows the measurement set-up. The ONU optical burst signal is converted to an electrical data signal by the O/E converter and is input to the real-time oscilloscope. The ONU also outputs the TX_DIS signal [ITU-T G Suppl.48] from its internal SERDES. Although this TX_DIS is a control signal for the internal physical medium dependent (PMD) of the ONU to transmit an optical signal, the real-time oscilloscope can use this TX_DIS as a timing trigger to capture the entire burst signal. The ONU can be connected with an OLT to control the ONU transmission.

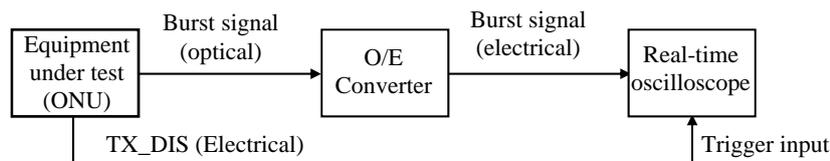


Figure I.1 – Measurement set-up using wideband real-time oscilloscope

Figure I.2 shows the timing of the signals in Figure I.1.

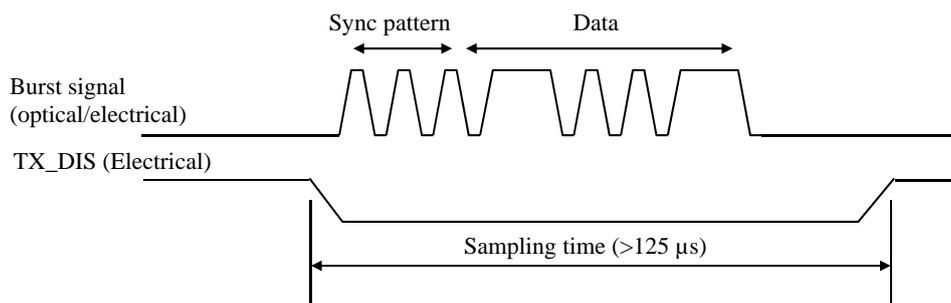


Figure I.2 – Timing of signals in Figure I.1

I.2.3 Procedure

- 1) Set the ONU to output a burst signal. Here, the burst length is 125 μs or less.

NOTE 1 – The pattern of the burst signal is FFS.

- 2) Capture the entire burst signal at the real-time oscilloscope.
- 3) Calculate the total jitter (TJ) at $\text{BER}=10^{-12}$ using the jitter analysis software.

NOTE 2 – The jitter analysis software of many existing oscilloscopes does not support the jitter measurement bandwidth specified in clause 9.3. Therefore, the TJ in step 3 does not correspond exactly to the peak-to-peak value of the jitter measurement result according to the measurement bandwidth in clause 9.3. To match the measurement bandwidth to the specification in clause 9.3, follow steps 4 and 5 below instead of step 3.

- 4) Calculate the time interval error (TIE) sequence, x_k , which is the timing error sequence between the timing of the rising/falling edge of the input data signal and the ideal timing shown in Figure I.3, using the jitter analysis software. Next, interpolate the TIE samples where there is no corresponding data signal edge to create a TIE sequence with a constant interval. Refer to clause VIII.2.1 of [ITU-T O.172] for this interpolation method. In addition, use high-pass and low-pass filtering for the interpolated TIE sequence, according to the measurement bandwidth specified in clause 9.3. As a result, the interpolated and filtered TIE sequence, y_k , is obtained.
- 5) Calculate the TJ at $\text{BER}=10^{-12}$ for the sequence y_k using the jitter analysis software.

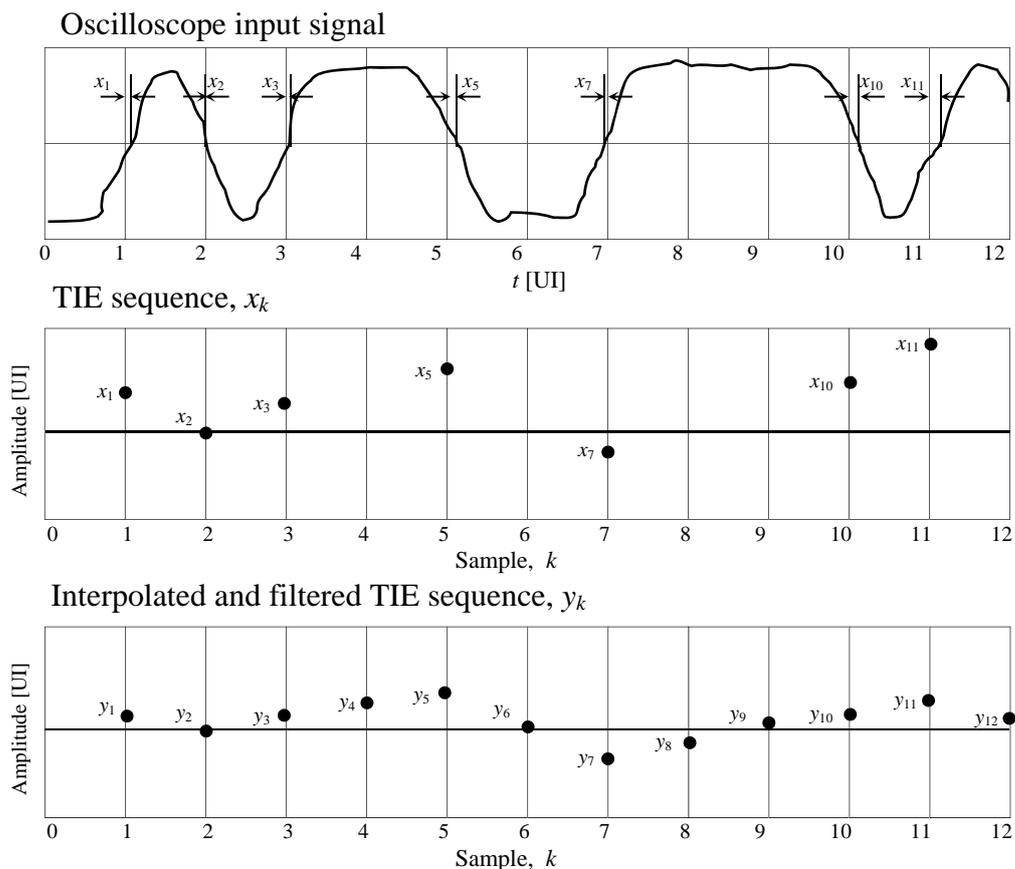


Figure I.3 – Example of interpolated and filtered TIE sequence

I.3 Evaluation using sampling oscilloscope

I.3.1 Apparatus

The following apparatus are required:

- 1) Sampling oscilloscope
 - 3 dB bandwidth $\geq 12.5\text{GHz}$
 - Jitter analysis software according to Annex 48B.3 of [IEEE 802.3] and chapter 10 of [b-INCITS TR-35].
- 2) O/E converter
 - With the transfer function specified in clause B.2 of [b-ITU-T G.975].

I.3.2 Set-up

Figure I.4 shows the measurement set-up. The burst signal output from the ONU is converted to an electrical burst signal by the O/E converter and is input to the sampling oscilloscope. The TXD signal [ITU-T G Suppl.48] output from internal SERDES of the ONU is used to obtain the clock signal for the sampling oscilloscope. Since the TXD signal continues the synchronous pattern while the burst data is stopped as shown in Figure I.5, the TXD signal can be converted to a clock signal by the clock recovery circuit. The ONU can be connected with an optical line terminal (OLT) to control the ONU transmission.

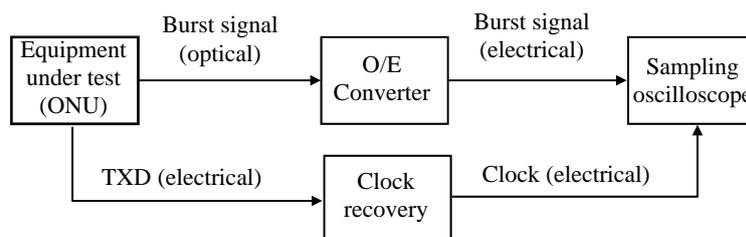


Figure I.4 – Measurement set-up using sampling oscilloscope

Figure I.5 shows the timing of the signals in Figure I.4.

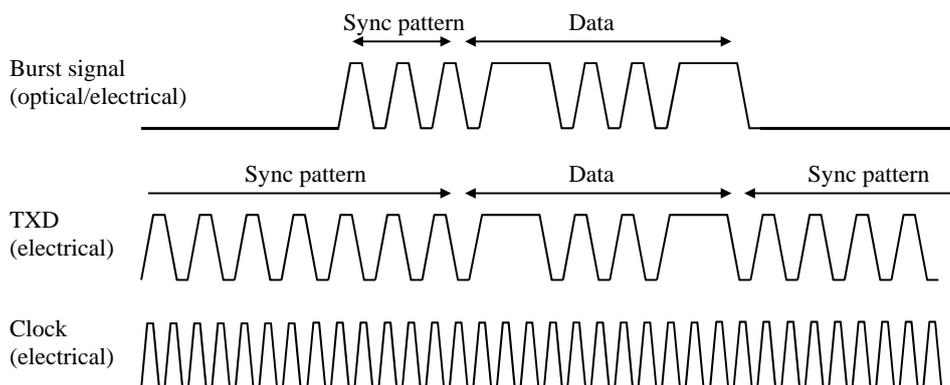


Figure I.5 – Timing of each signal in Figure I.4

I.3.3 Procedure

- 1) Set the ONU to output a burst signal. Here, the burst length is 125 μ s or less.

NOTE 1 – The pattern of the burst data is FFS.

- 2) Draw the Eye pattern of the burst signal using the sampling oscilloscope.
- 3) Calculate the TJ at BER= 10^{-12} using the jitter analysis software.

NOTE 2 – The jitter analysis software of many existing oscilloscopes does not support the jitter measurement bandwidth specified in clause 9.3. Therefore, the TJ in step 3 does not exactly match the peak-to-peak value of the jitter measurement result according to the measurement bandwidth in clause 9.3.

I.4 Evaluation using BERT

This method evaluates the jitter performance due to the internal PMD of the ONU for a burst signal. In general, an SFP or XFP is used for the internal PMD.

I.4.1 Apparatus

The following apparatus are required:

- 1) BERT
 - Including pattern generator, error detector and internal clock.
 - Including jitter analysis software according to Annex 48B.3 of [IEEE 802.3] and chapter 10 of [b-INCITS TR-35].
- 2) O/E converter
 - With transfer function is specified in clause B.2 of [b-ITU-T G.975].

I.4.2 Set-up

Figure I.6 shows the measurement set-up. The electrical burst signal output from the BERT Pattern Generator is input to the PMD module (SFP/XFP) used in the ONU. The optical signal output from the PMD is converted to an electrical signal by the O/E converter, and is detected by the BERT Error Detector.

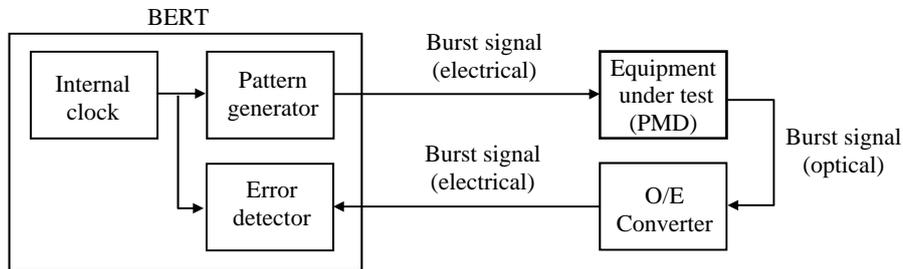


Figure I.6 – Measurement set-up using BERT

Figure I.7 shows the timing of the signals in Figure I.6.

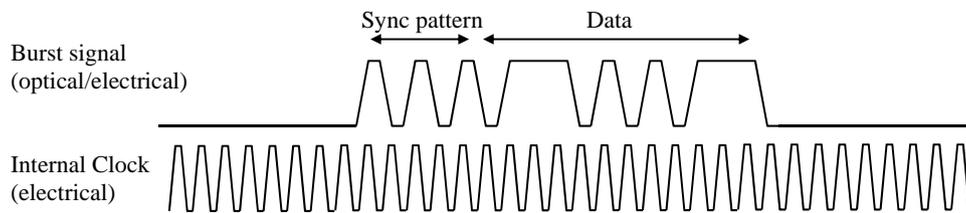


Figure I.7 – Timing of each signal in Figure I.6

I.4.3 Procedure

- 1) Set the BERT pattern generator to output the burst data. Here, the burst length is 125 μs or less.

NOTE 1 – The pattern of the burst data is FFS.

- 2) Measure the error rate of the received burst data using the BERT error detector.
- 3) Calculate the TJ at $\text{BER}=10^{-12}$ using the jitter analysis software.

NOTE 2 – The jitter analysis software of many existing oscilloscopes does not support the jitter measurement bandwidth specified in clause 9.3. Therefore, the TJ in step 3 does not exactly match the peak-to-peak value of the jitter measurement result according to the measurement bandwidth in clause 9.3.

Bibliography

- [b-ITU-T G.975] Recommendation ITU-T G.975 (2000), *Forward error correction for submarine systems*.
- [b-INCITS TR-35] INCITS TR-35-2004 (R2009), *Information Technology – Fibre Channel – Methodologies for Jitter and Signal Quality Specification (FC-MJSQ)*.

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