SMPTE RECOMMENDED PRACTICE

Specification of Jitter in Bit-Serial Digital Systems

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Approved
September 1, 2015

Foreword

SMPTE (the Society of Motion Picture and Television Engineers) is an internationally-recognized standards developing organization. Headquartered and incorporated in the United States of America, SMPTE has members in over 80 countries on six continents. SMPTE's Engineering Documents, including Standards, Recommended Practices, and Engineering Guidelines, are prepared by SMPTE's Technology Committees. Participation in these Committees is open to all with a bona fide interest in their work. SMPTE cooperates closely with other standards-developing organizations, including ISO, IEC and ITU.

SMPTE Engineering Documents are drafted in accordance with the rules given in its Standards Operations Manual.

SMPTE RP 184 was prepared by Technology Committee 32NF.

Intellectual Property

At the time of publication no notice had been received by SMPTE claiming patent rights essential to the implementation of this Engineering Document. However, attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. SMPTE shall not be held responsible for identifying any or all such patent rights.

Introduction

This section is entirely informative and does not form an integral part of this Recommended Practice.

This Recommended Practice (RP) defines the parameters for measuring jitter in serial digital video systems. The companion SMPTE RP 192 defines the methods and architectures of the measuring equipment. The intent of these two RPs is to allow equipment manufactures to make consistent measurements that reflect system performance, and to educate users on how to evaluate systems.

1 Scope

This Recommended Practice describes techniques for specifying jitter in self-clocking, bit-serial digital systems. It is applicable to sources, receivers, and regenerators. It is specifically intended for, but not limited to, 270 Mb/s to 12 Gb/s serial systems as defined by: SMPTE ST 259, SMPTE ST 292-1, SMPTE ST 424, SMPTE ST 435-3, SMPTE ST 2036-4, SMPTE ST 2081-1, and SMPTE ST 2082-1. Methods for measuring these specifications are found in SMPTE RP 192.

2 Conformance Notation

Normative text is text that describes elements of the design that are indispensable or contains the conformance language keywords: "shall", "should", or "may". Informative text is text that is potentially helpful to the user, but not indispensable, and can be removed, changed, or added editorially without affecting interoperability. Informative text does not contain any conformance keywords.

All text in this document is, by default, normative, except: the Introduction, any section explicitly labeled as "Informative" or individual paragraphs that start with "Note:”

The keywords "shall" and "shall not" indicate requirements strictly to be followed in order to conform to the document and from which no deviation is permitted.

The keywords, "should" and "should not" indicate that, among several possibilities, one is recommended as particularly suitable, without mentioning or excluding others; or that a certain course of action is preferred but not necessarily required; or that (in the negative form) a certain possibility or course of action is deprecated but not prohibited.

The keywords "may" and "need not" indicate courses of action permissible within the limits of the document.

The keyword “reserved” indicates a provision that is not defined at this time, shall not be used, and may be defined in the future. The keyword “forbidden” indicates “reserved” and in addition indicates that the provision will never be defined in the future.

A conformant implementation according to this document is one that includes all mandatory provisions ("shall") and, if implemented, all recommended provisions ("should") as described. A conformant implementation need not implement optional provisions ("may") and need not implement them as described.

Unless otherwise specified, the order of precedence of the types of normative information in this document shall be as follows: Normative prose shall be the authoritative definition; Tables shall be next; followed by formal languages; then figures; and then any other language forms.

3 Normative References

The following standards contain provisions which, through reference in this text, constitute provisions of this recommended practice. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this recommended practice are encouraged to investigate the possibility of applying the most recent edition of the standards indicated below.

No references are cited in this document.

4 Definitions

4.1 Alignment jitter

The variation in position of a signal's transitions relative to those of a clock extracted from that signal. The bandwidth of the clock extraction process determines the low-frequency limit for alignment jitter.

4.2 Independent Samples

For band-limited systems, samples are only independent if they are not over-sampled. By the Nyquist criteria this means that for a given bandwidth in Hz, the maximum number of independent samples per second is approximately twice the bandwidth. Any higher rate of samples will be just giving more information about the same signal components

4.3 Input jitter tolerance

Peak-to-peak amplitude of sinusoidal jitter that, when applied to an equipment input, causes a specified degradation of error performance.

4.4 Intrinsic jitter

Jitter at an equipment output in the absence of input jitter.

4.5 Jitter

The variation of a digital signal's transitions from their ideal positions in time.

4.6 Jitter transfer

Jitter on the output of equipment resulting from applied input jitter.

4.7 Jitter transfer function

Ratio of the output jitter to the applied input jitter as a function of frequency.

4.8 Output jitter

Jitter at the output of equipment that is embedded in a system or network. It consists of intrinsic jitter and the jitter transfer of jitter at the equipment input.

4.9 Probabilistic Peak-to-Peak Jitter (p-p-p, Stated as Jitter at 1 in $10^{x,}$)

This is an estimate of the most likely p-p jitter in unit intervals when measured over 10^x independent jitter samples. See Annex B for derivation.

4.10 Timing jitter

The variation in position of a signal's transitions occurring at a rate greater than a specified frequency, typically 10 Hz or less. Variations occurring below this specified frequency are termed wander and are not addressed by this practice.

4.11 Unit interval (UI)

Abbreviated UI, it is the period of one clock cycle. It corresponds to the nominal minimum time between transitions of the serial signal.

5 Jitter Specifications

Equipment jitter specifications fall into three categories: input jitter tolerance, jitter transfer, and intrinsic jitter. A fourth specification, output jitter, is a system specification and may be used to specify jitter limits at equipment interfaces.

At most device outputs in a SDI system, the observed jitter will be output jitter, consisting of the device's intrinsic jitter and any jitter transfer term from the signal driving the device. Output jitter will be at least as large as intrinsic jitter, and may be much greater in cases where there is a significant jitter transfer term. At the time of this publication, the serial interface standards SMPTE ST 259, SMPTE ST 292-1, SMPTE ST 297, SMPTE ST 424, SMPTE ST 435, SMPTE ST 2036-4, SMPTE ST 2081-1 and SMPTE ST 2082-1 only specify intrinsic jitter.

Note: System designers are encouraged to define the desired system jitter margin and the allowed output jitter at each point in the system, given the jitter transfer and input jitter tolerance of the devices being used, so that the desired system error performance is reliably achieved. Cascading serial devices can lead to jitter accumulation. The characteristic of the jitter accumulation depends on the architecture of the serial devices:

- Many devices implement a reclocker with a very low frequency loop bandwidth, or use an internal or external frequency reference to effectively prevent all input jitter from passing through to the output.
- Other reclocking devices have a moderate loop bandwidth for the reclocking function, they attenuate jitter well above this bandwidth and pass through any jitter well below this bandwidth. At jitter frequencies near the loop bandwidth, reclockers may peak up and amplify input jitter. In addition, reclockers have a jitter contribution of their own that may add to the low frequency jitter they pass through from the input, and which is typically the main source of high-frequency jitter on the reclocker output.
- Devices without reclocking pass all input jitter and can add jitter at any frequency.
- Cascading multiple devices of the same type can lead to exaggerated effects; e.g., if several reclockers have peaking at the same frequency. Some devices are not prone to this behavior.

5.1 Input Jitter Tolerance

Input jitter tolerance is the peak-to-peak amplitude of sinusoidal jitter that, when applied to an equipment input, causes a specified degradation of error performance. Input jitter tolerance is applicable to most serial inputs.

Input jitter tolerance requirements are specified with a jitter template that covers a specified sinusoidal amplitude/frequency region (see Figure 1). This template represents the minimum amount of jitter that the equipment must accept without causing the specified degradation of error performance. Equipment meeting a jitter tolerance requirement must have an actual jitter tolerance greater than the requirement (see Figure 2).

Input jitter tolerance requirements are specified with the parameters given in Table 1.

Frequency band f1 to f2 forms the low-frequency jitter tolerance bandpass. At least A1 UI of peak-to-peak sinusoidal jitter shall be tolerated over this bandpass without exceeding the specified error criterion.

Frequency band f3 to f4 forms the high-frequency jitter tolerance bandpass. At least A2 UI of peak-to-peak sinusoidal jitter shall be tolerated over this bandpass without exceeding the specified error criterion.

A1 and A2 shall be specified in UI.

The slope of the jitter tolerance requirement between f2 and f3 shall be 20 dB/decade. Frequencies f2 and f3 are related as follows: F2 = f3/(A1/A2).

The criterion for reaching the onset of errors shall be specified. Either a BER limit or a maximum number of errored seconds over a specified measurement interval should be used.

The test signal used for the measurement (to which sinusoidal jitter is added) shall be specified.

Numerical input jitter tolerance values are provided in the appropriate SMPTE standards which reference this practice. The terminology shall comply with Table 1.

Table 1 – Input jitter tolerance

Parameters	Units	Description
Data rate	(bits/s)	(Serial bit rate)
f1	(Hz)	(Low-frequency specification limit)
f2	(Hz)	(Upper band edge for A1, low-frequency jitter tolerance)
f3	(Hz)	(Lower band edge for A2, high-frequency jitter tolerance)
f4	(Hz)	(High-frequency specification limit)
A1	(UI)	(Low-frequency jitter tolerance, f1 to f2)
A2	(UI)	(High-frequency jitter tolerance, f3 to f4)
Error criterion		(Criterion for onset of errors)
Test signal		(Test signal used for measurement)

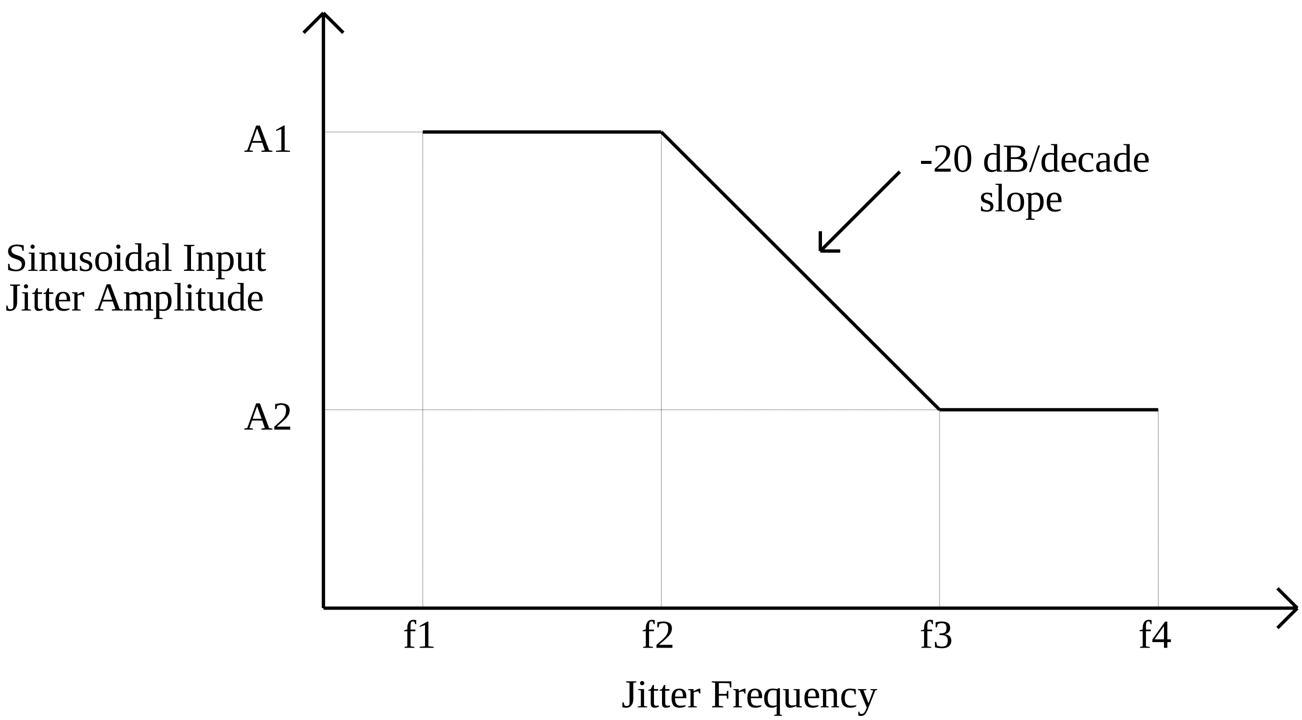

Figure 1 – Input jitter tolerance template

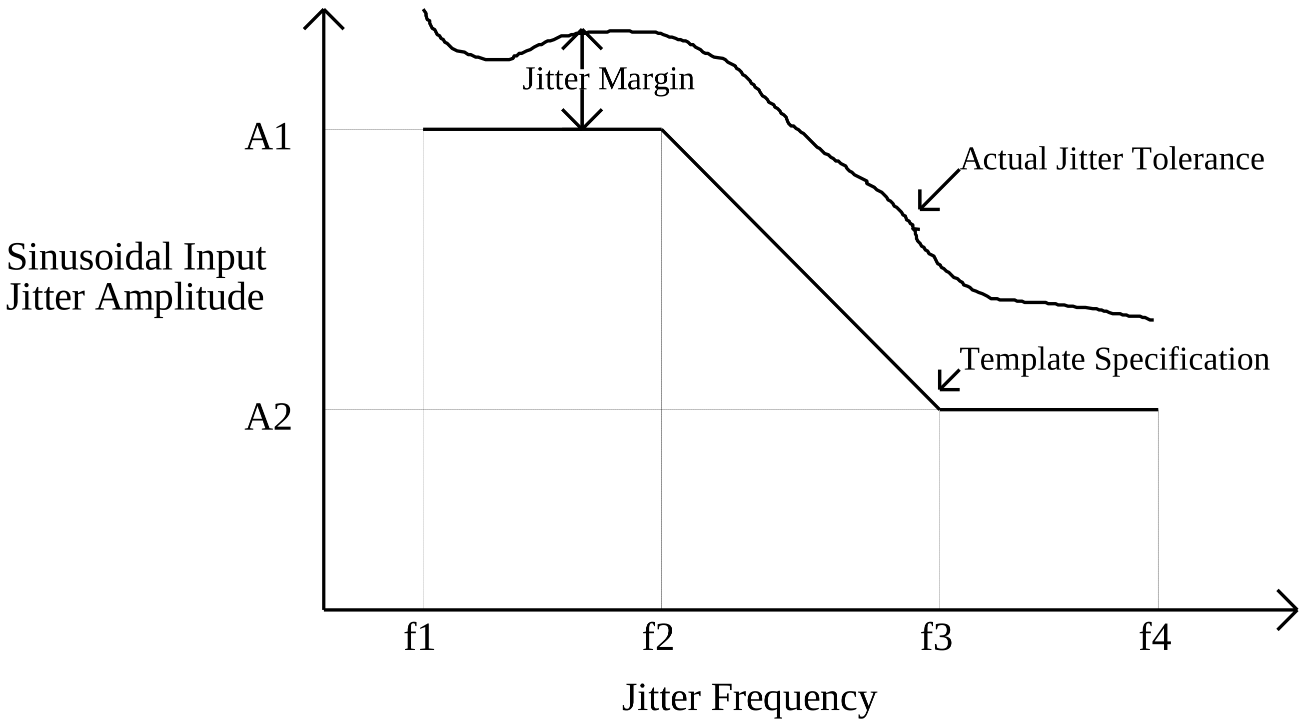

Figure 2 – Jitter tolerance specification and a compliant jitter tolerance

5.2 Jitter Transfer

Jitter transfer is jitter on the output of equipment resulting from applied input jitter. Jitter transfer is applicable to a device which produces a serial output from a serial input, such as a regenerator.

Jitter transfer can also occur from reference signals applied to equipment, such as analog black burst. The jitter transfer templates described below are intended for serial input to serial output jitter transfer.

Jitter transfer requirements are specified with a template showing the maximum jitter gain as a function of frequency (see Figure 3). Equipment meeting a jitter transfer requirement will have a jitter transfer function that lies within this template (see Figure 4).

Jitter transfer requirements are specified with the parameters given in Table 2.

Frequency band f1 to fc forms the jitter transfer bandpass. The maximum jitter gain over this bandpass shall be P.

From frequency fc to at least 10 (fc), the jitter transfer template shall decrease at 20 dB/decade.

P shall be specified in decibels.

The test signal used for the measurement (to which sinusoidal jitter is added) shall be specified.

Jitter Transfer shall be measured as probabilistic peak-to-peak quantities on the input and output of the device.

Numerical jitter transfer values are provided in the appropriate SMPTE standards which reference this practice. The terminology shall comply with Table 2.

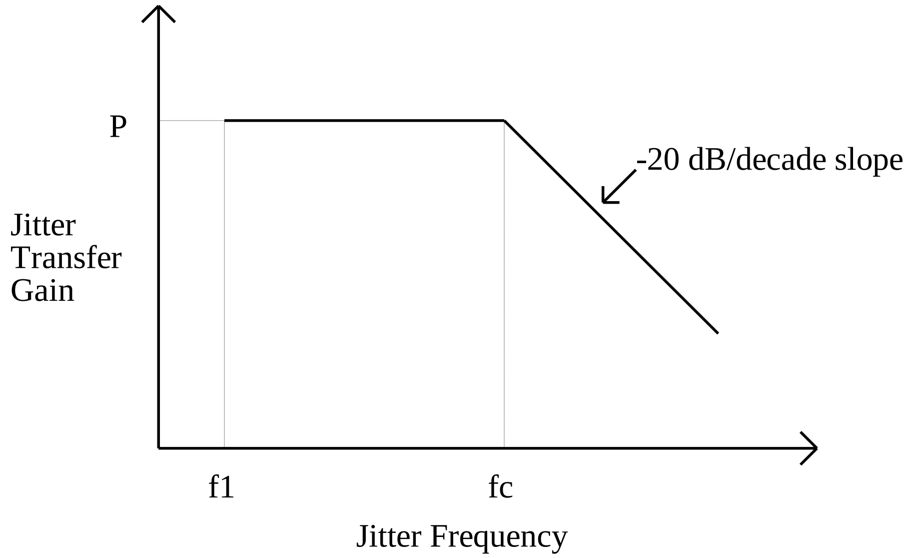

Figure 3 – Jitter transfer template

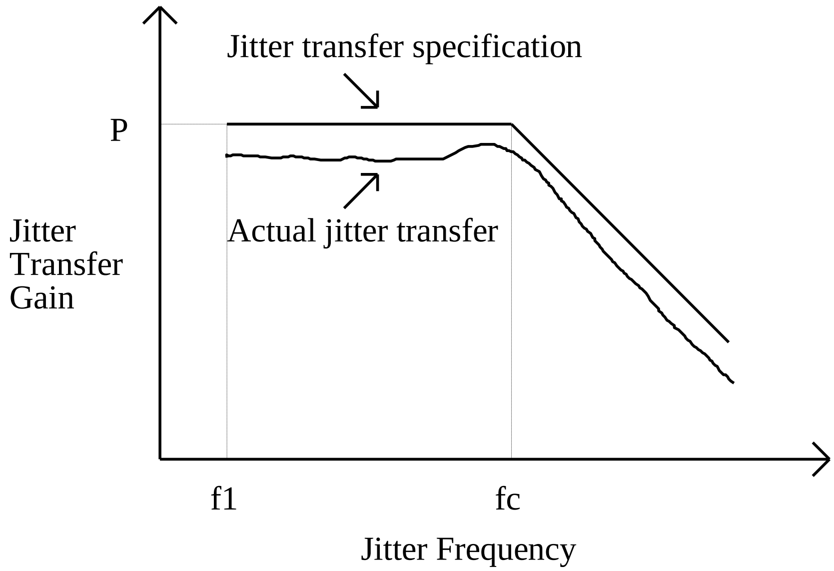

Figure 4 – Jitter transfer specification and a compliant jitter transfer function

Table 2 – Jitter transfer requirements

Parameters	Units	Description
Data rate	(bits/s)	(Serial bit rate)
f1	(Hz)	(Low-frequency specification limit)
fc	(Hz)	(Upper band edge of jitter transfer bandpass)
P	(dB)	(Maximum jitter gain, f1 to fc)
Test signal		(Test signal used for measurement)

5.3 Intrinsic Jitter and Output Jitter

Intrinsic jitter and output jitter are both measurements of jitter at an equipment output. They differ in the specification of the input signal to the equipment. Except for this, they are measured identically.

Intrinsic jitter is defined as the amount of jitter at an equipment output when a jitter-free input signal is applied. It is a measure of the amount of jitter generated in the equipment, independent of any jitter transfer. Intrinsic jitter applies to most serial outputs.

Output jitter is the amount of jitter at the output of equipment that is embedded in a system or network. It consists of intrinsic jitter and the jitter transfer of jitter at the equipment input. Output jitter is a system specification, not an equipment specification. Individual equipment should be specified in terms of intrinsic jitter, jitter transfer, and input jitter tolerance. System interface specifications may use output jitter.

Intrinsic and output jitter shall be specified as probabilistic peak-to-peak (p-p-p) quantities and measured over defined jitter frequency bands. Two measurement bands are specified, one is a subset of the other (see Figure 5).

Intrinsic and output jitter shall be specified with the parameters given in Table 3.

The timing jitter measurement bandpass is formed by f1 to f4. The maximum peak-to-peak jitter allowed over this bandpass is specified as A1.

The alignment jitter measurement bandpass is formed by f3 to f4. The maximum peak-to-peak jitter allowed over this bandpass is specified as A2.

A1 and A2 shall be specified in unit intervals.

Bandpass slopes shall be at least 20 dB/decade and have a minimum phase response unless otherwise specified. Stop band rejection shall be at least 20 dB. Pass band ripple shall be less than ± 1 dB.

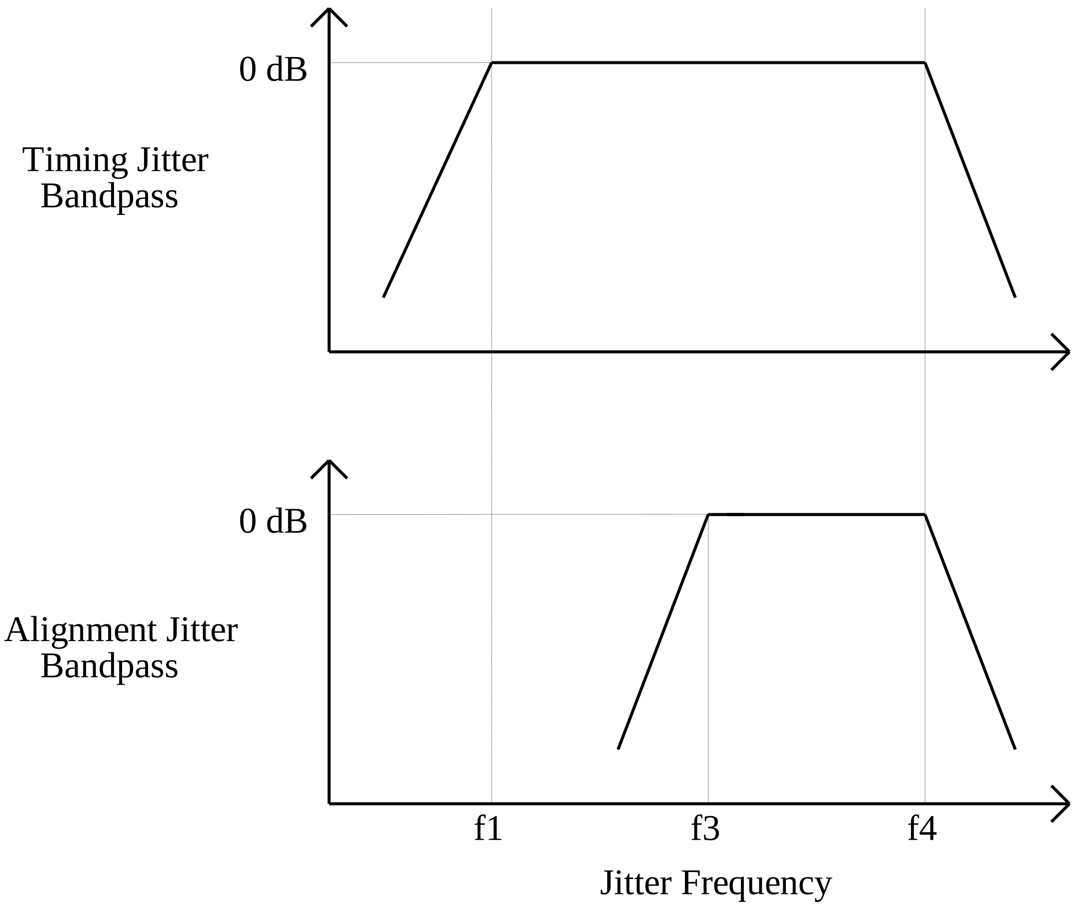

Figure 5 – Intrinsic jitter and output jitter measurement band passes

Table 3 – Intrinsic jitter and output jitter

Parameters	Units	Description
Data rate	(bits/s)	(Serial bit rate)
f1	(Hz)	(Timing jitter, lower band edge)
f3	(Hz)	(Alignment jitter, lower band edge)
f4	(Hz)	(Upper band edge)
A1	(UI)	(Timing jitter)
A2	(UI)	(Alignment jitter)
t_m	(s)	(Minimum Measurement time)
Test signal	-	(Test signal used for measurement)
Pr	-	(Probability for p-p jitter)
Note: A previous version of this practice used B1, B2, and B3 in place of f1, f3, and f4, respectively (see Annex A).		

The measurement time "t_m" shall be chosen to collect at least the specified number of independent samples needed for the probabilistic measurement. For Alignment jitter, t_m shall be at least two video frames. For Timing jitter the recommend t_m is at least 200ms (2 cycles at 10Hz). For sub-sampled methods, the interval shall be chosen to provide a high probability that jitter data has been collected from the entire video frame and lowest frequency components.

The p-p jitter specifications from the SDI standard should be interpreted by the p-p-p methodology. Other methods that use an equal or greater number of samples and measurement time, and which are mathematically equivalent, may also be used.

Note: previous versions of this document did not specify the p-p-p methodology. Measurements made by equipment conforming to the previous specification are considered to be in compliance with this recommended practice. These legacy measurements are noticeably different in that they do not indicate the probability at which the jitter is measured.

Probabilistic peak to peak (p-p-p) measurements shall use a sample size at least 10 times the denominator if the probability is stated as $1 / 10^x$. That is it shall use at least $10^{(x+1)}$ samples. For example, a p-p-p measurement to 1 in 10^6 needs to use at least 10^7 data points.

Probabilistic peak to peak (p-p-p) measurements shall be made at Pr of 1 in 10^6 to be consistent with previous methodologies.

Note: Measurement at lower probabilities for such as 1 in 10^{12} can be useful for system design.

Because of limitations on practical measurement time, extrapolations to the lower probabilities may be necessary. If extrapolations are provided, all measurements shall indicate if they are directly measured according to the criteria indicated in this recommended practice or extrapolated. If measurements are extrapolated they shall use a Dual-Dirac decomposition to separate the random and deterministic jitter components. See Annex C for references to the Dual-Dirac method.

The test signal used for the measurement shall be specified. For an intrinsic jitter measurement, the test source jitter shall be negligible compared to the intrinsic jitter specification.

Numerical intrinsic and output jitter values are provided in the appropriate SMPTE standards that reference this practice. The terminology shall comply with Table 3.

It is expected that measurement equipment conforms to the limits indicated in this recommendation. However if a jitter measurement equipment does not make measurements which conform to all the frequency limits in this recommendation, then it shall indicate the frequency range to which it does measure. For example, if a Timing jitter measurement does not extend to frequency f4 in Figure 5, then it must indicate the upper frequency to which it does measure. This may look something like: "Timing Jitter = 63ps (10Hz-5MHz)"

Annex A Terminology Changes from SMPTE RP 184-1995 to RP 184-1996
(Informative)

The 1995 version of SMPTE RP 184 described specification of output jitter in Section 3.2. The 1996 and later versions of this practice, including the current version in Section 5.3, follow the same specification format, but use different terminology for the measurement bands. This change was made to follow current jitter specification practice.

The translation of SMPTE RP 184-1995 to current SMPTE RP 184 terminology is shown in Table A.1. The current RP 184 terminology is preferred in all new equipment specifications.

Table A.1 – Terminology

Description	RP 184-1995 parameters	Current RP 184 parameters
Timing jitter lower-band edge	B1	f1
Alignment jitter lower-band edge	B2	f3
Upper-band edge	B3	f4

Annex B Derivation of Probabilistic Peak-to-Peak Jitter (Informative)

Probabilistic peak to peak (p-p-p) jitter is derived from a histogram of the jitter samples. The jitter histogram represents an empirical probability density function (PDF) of the jitter samples from the signal. To calculate p-p-p jitter this PDF is integrated to form the Cumulative Density Function (CDF). Next the Complementary Cumulative Density Function (CCDF) is calculated by subtracting the CDF from 1. (See examples in Figure B.1 thru Figure B.4 below.)

The probabilistic positive peak jitter value is the jitter at which the CCDF is equal to the desired probability. The corresponding negative peak jitter value is the jitter value at which the CDF is equal to the desired probability. The total probabilistic p-p jitter is the difference between the positive and negative peak values. (The sum of their absolute values)

The probabilistic p-p jitter is the most probable p-p measurement that would result if a series of individual measurement were made on a sample size of 1 / probability. The advantages of calculating the p-p-p from a histogram are that the sample size does not have to be fixed at 1/ probability, and that the accuracy of the measurement continues to improve as samples accumulate.

Adding the precise probabilities of each side of the probabilistic p-p jitter limits is equivalent to jitter at BER as measured with a Bit Error Ratio Tester (BERT). This implies that if a signal with symmetric positive and negative jitter is applied to a receiver which has jitter tolerance equal to the measured p-p-p jitter of that signal, then the BER or probability of a bit error is equal to 2X the probability at which the p-p jitter was measured. (The 2x is necessary since will get errors from both the positive and negative jitter excursions) In most cases the system will be designed with margin such that the jitter is well less than the input tolerance of the receiver, In this case the BER of the system will be less than the BER or probability at which the jitter was measured.

Independent jitter samples do not always have a one to one correlation to the samples taken by the various methods of measuring jitter. Refer to SMPTE RP 192 for a description of how independent jitter samples are defined.

Illustrated Example of Probabilistic Peak to Peak (p-p-p) Jitter Measurement

Figure B.1 shows a Gaussian Probability Density Function (PDF) as might be captured as a Jitter Histogram from a 1.485 Gb/s Stream.

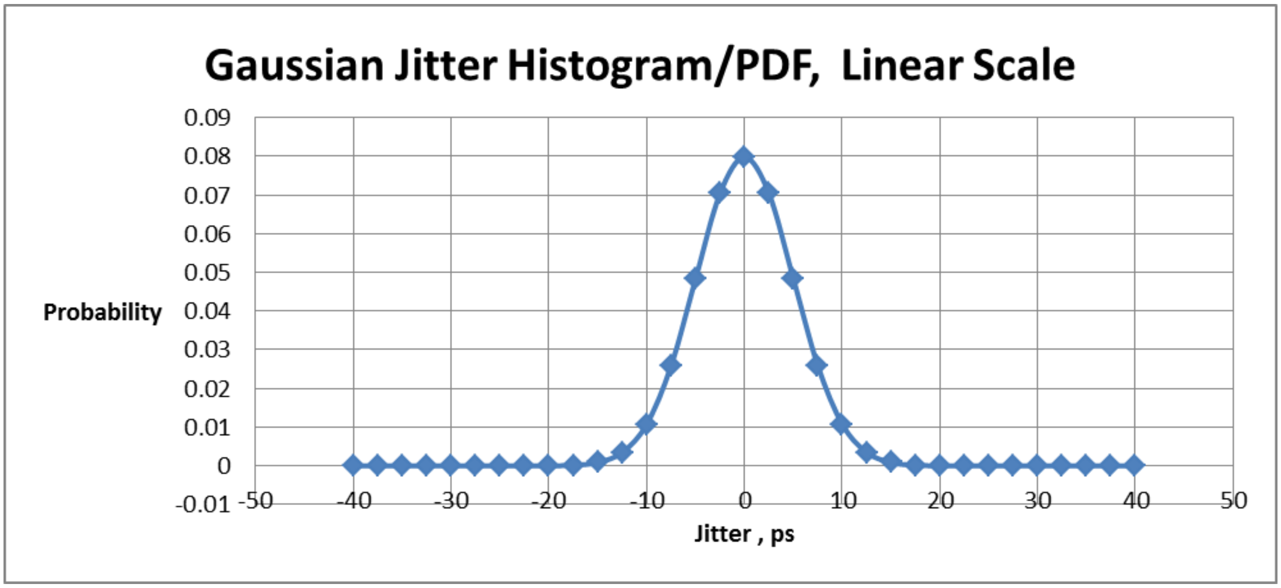

Figure B.1 – Gaussian Probability Density Function (PDF)

Figure B.2 shows the same Gaussian PDF as in Figure B.1, but with a logarithmic vertical scale to show more details on the tails.

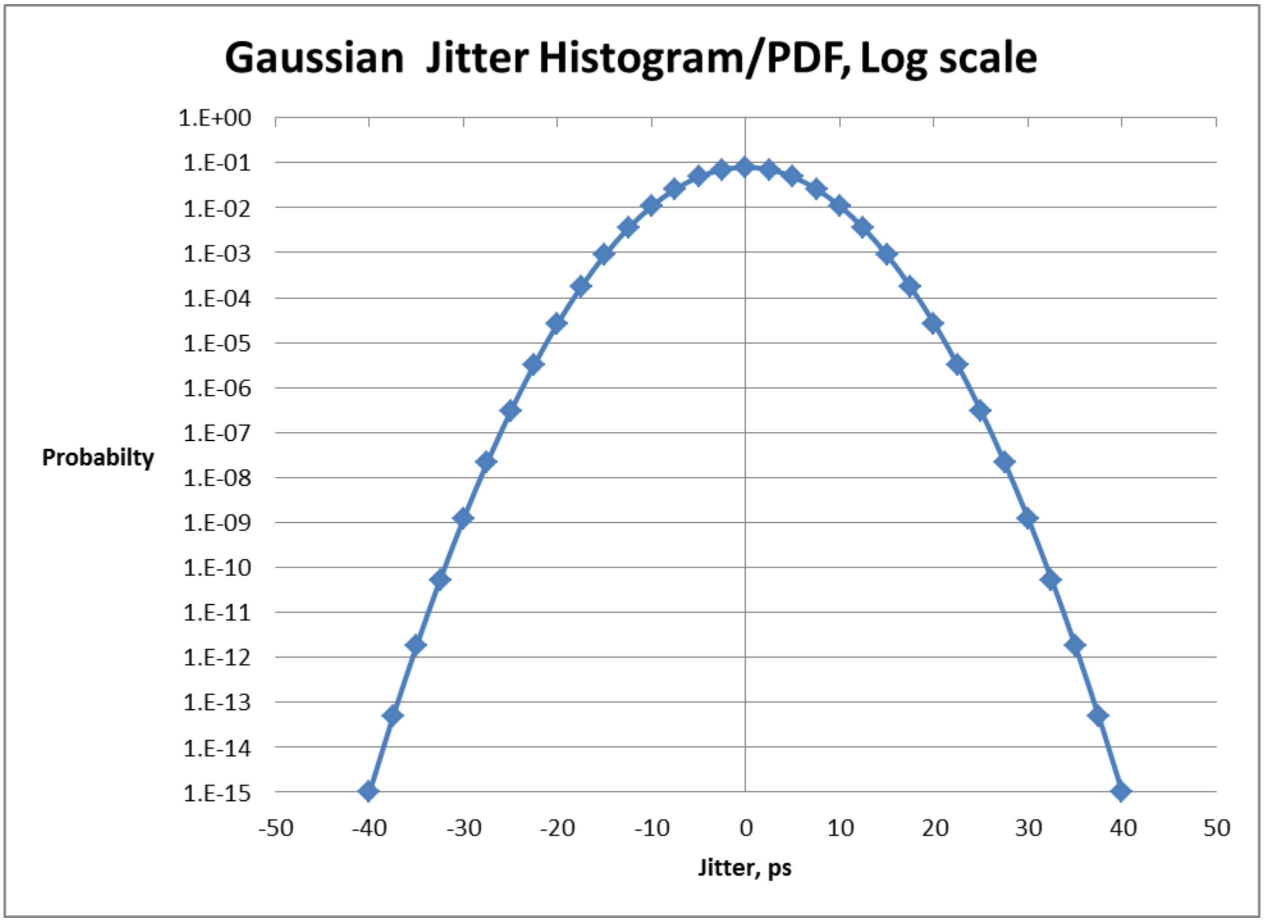

Figure B.2 – Gaussian PDF with a logarithmic vertical scale

If the PDF is integrated, it forms the Cumulative Distribution Function (CDF). This is shown with a log scale in Figure B.3. The CDF indicates the probability of jitter which is more negative or equal to a given value. The indicated line indicates the intersection of the CDF curve and the 1 in 10^6 probability graticule. This shows a negative peak jitter of about -24ps at 1 in 10^6.

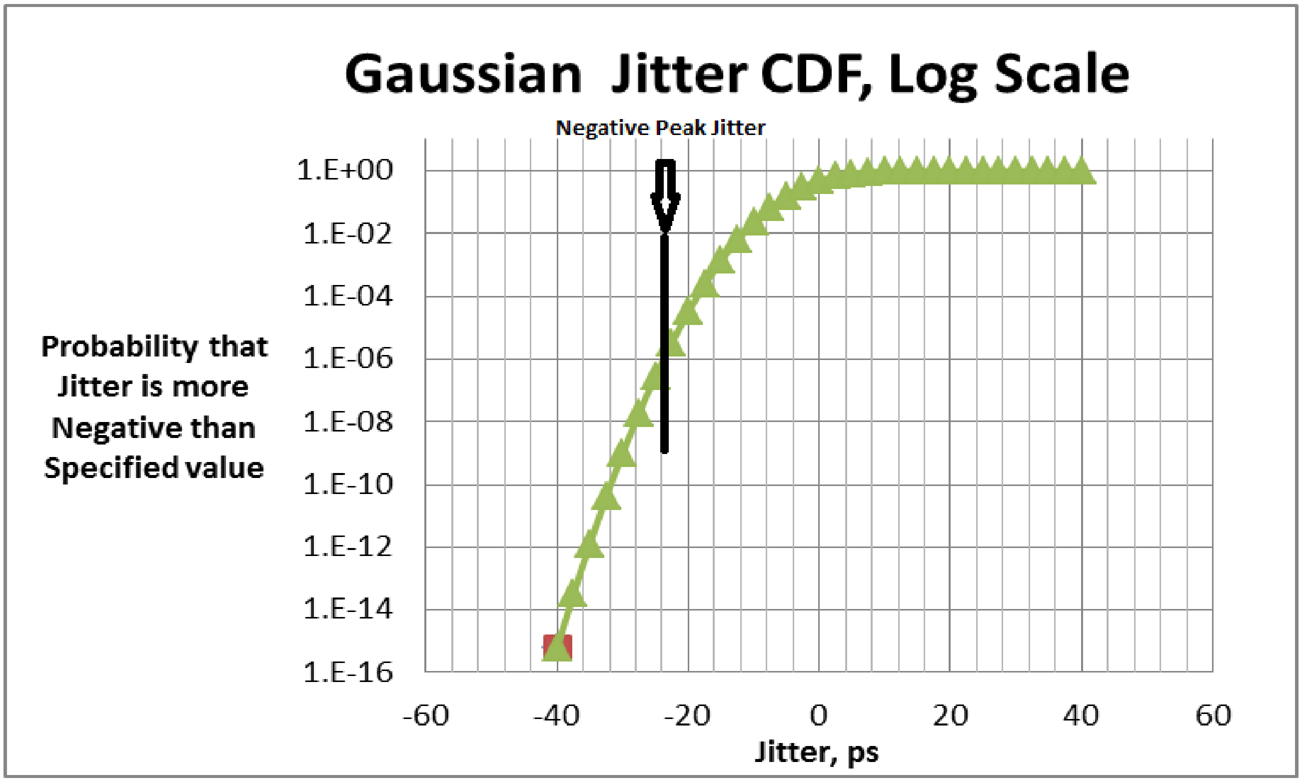

Figure B.3 – Cumulative Distribution Function (CDF)

Figure B.4 shows the Complementary Cumulative Distribution Function (CCDF) on a log scale. This is calculated by subtracting the CDF from 1. It indicates the probability of jitter that is greater than or equal to a given value. The annotated line is at the intersection of the CCDF plot and the 1 in 10^6 graticule. This shows a positive peak jitter value of about 24ps at 1 in 10^6.

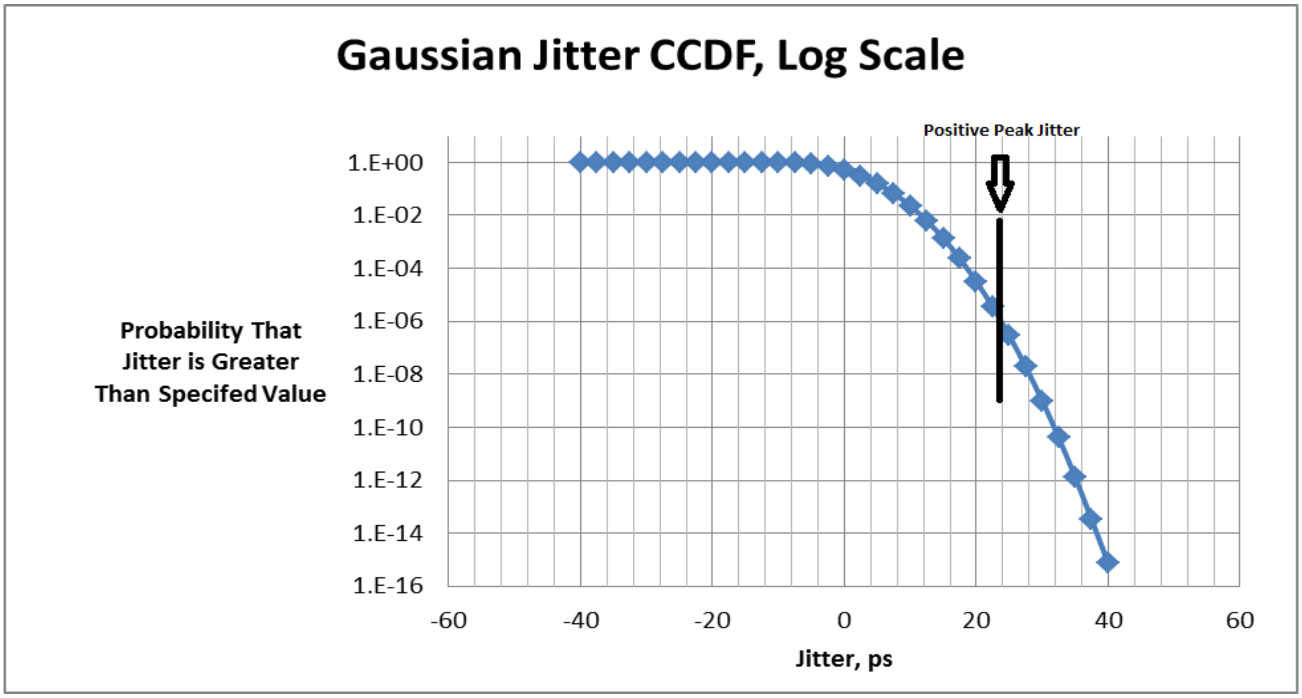

Figure B.4 – Complementary Cumulative Distribution Function (CCDF)

The Probabilistic Peak to Peak Jitter (p-p-p) is the positive peak minus the negative peak, so 24 – (-24) = 48ps at 1 in 10^6. If the same data set is evaluated at 1 in 10^{12}, then the p-p-p is about 70ps.

Annex C Bibliography (Informative)

Note: All references in this document to other SMPTE documents use the current numbering style (e.g. SMPTE ST 259:2008) although, during a transitional phase, the document as published (printed or PDF) may bear an older designation (such as SMPTE 259M-2008). Documents with the same root number (e.g. 259) and publication year (e.g. 2008) are functionally identical.

SMPTE RP 192:2015, Jitter Measurement Procedures in Bit-Serial Digital Interfaces

SMPTE ST 259:2008, Television — SDTV Digital Signal/Data — Serial Digital Interface

SMPTE ST 292-1:2012, 1.5 Gb/s Signal/Data Serial Interface

SMPTE ST 297:2015, Serial Digital Fiber Transmission System for SMPTE ST 259, SMPTE ST 344, SMPTE ST 292-1/2, SMPTE ST 424, SMPTE ST 2081-1 and SMPTE ST 2082-1 Signals

SMPTE ST 344:2000, Television — 540 Mb/s Serial Digital Interface

SMPTE ST 424:2012, 3 Gb/s Signal/Data Interface

SMPTE ST 435-3:2012, 10 Gb/s Serial Signal/Data Interface — Part 3: 10.692 Gb/s Optical

SMPTE ST 2036-4:2015, Ultra-High Definition Television — Multi-link 10Gb/s Signal/Data Interface Using 12-Bit Width Container

SMPTE ST 2081-1:2015, 6 Gb/s Signal/Data Serial Interface — Electrical

SMPTE ST 2082-1:2015, 12 Gb/s Signal/Data Serial Interface — Electrical

Stephens, Ransom. Jitter Analysis: The Dual Dirac Model, RJ/DJ, and Q-Scale. White paper from Agilent Technologies.