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Jitter Specifications Made Easy:

A Heuristic Discussion of Fibre Channel and Gigabit Ethernet Methods

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A Heuristic Discussion of Fibre Channel and Gigabit Ethernet Methods

1. Jitter Overview

The jitter working group of the Fibre Channel Industry Association[1], after countless cups of high-octane coffee, produced a groundbreaking report: “Methodologies of Jitter Specification.” Within this report is probably the most approachable and self-consistent strategy for jitter measurement and specification of any standards effort.

A central observation addressed here is the consistent use, within Fibre Channel standards, of a simple, single-pole weighting for all jitter measurements in a serial link (channel) based on receiver performance.

But, first, let’s define a few terms.

In a digital communications channel, *jitter* is the time deviation from ideal timing of a signal transition through a decision threshold. See the signal eye-diagram display in Figure 1. Note the horizontal time offsets due to jitter at each threshold crossing (of the horizontal center line).

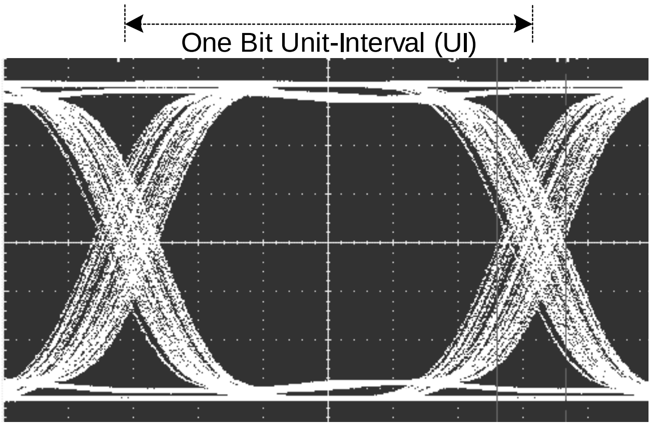

Figure 1. Eye diagram

Of course, data errors can result from sufficiently large time deviations from ideal (e.g., closing of the eye diagram).

Two general types of jitter are characterized: *deterministic jitter* and *random jitter*. Because each type accumulates differently in the channel, they are characterized independently.

Deterministic jitter is generally bounded in amplitude, non-Gaussian, and expressed in units of time, peak to peak. These are examples of deterministic jitter:

1) Duty-cycle distortion—e.g., from asymmetric rise/fall times
2) Intersymbol interference (ISI)—e.g., from channel dispersion or filtering
3) Sinusoidal—e.g., from power-supply feedthrough
4) Uncorrelated—e.g., from crosstalk by other signals

Random jitter is assumed to be Gaussian in nature and accumulates from thermal noise sources. Because peak-to-peak measurements take a long time to achieve statistical significance, random jitter is measured as an RMS (root mean square) value.

Multiple random-jitter sources add in an RMS fashion, but a peak-to-peak value is needed when adding random jitter to deterministic jitter to get total jitter, peak to peak. Although Gaussian statistics imply an “infinite” peak-to-peak amplitude, a useful peak-to-peak value can be calculated from the RMS value after you choose a probability of exceeding the peak-to-peak value. For example, the peak-to-peak random jitter having less than 10^{-12} probability of being exceeded is 14.1 times the RMS value. See Table 1.

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[1] The T11.2 technical committee of the Fibre Channel Industry Association drafts standards of Fibre Channel gigabit rate serial link physical layer (PHY) specification and methods.

Table 1 Random Jitter (pk to pk) vs. BER

Probability of Data Error (BER)	Peak to Peak = N * RMS
10^{-10}	Pk–Pk = 12.7 * RMS
10^{-11}	Pk–Pk = 13.4 * RMS
10^{-12}	Pk–Pk = 14.1 * RMS
10^{-13}	Pk–Pk = 14.7 * RMS
10^{-14}	Pk–Pk = 15.3 * RMS

The expected bit-error rate (BER) is the probability of causing a bit error when the total jitter (random jitter plus deterministic jitter), peak to peak, exceeds the jitter budget. Figure 2 displays the jitter distribution (probability density function) of the eye-diagram threshold crossings. (Note that the horizontal axis is time and the two histograms correspond to the two threshold crossing regions of an eye diagram, as seen in Figure 1.) The relative area under the overlapping tails is the probability of a data error at the sampling time.

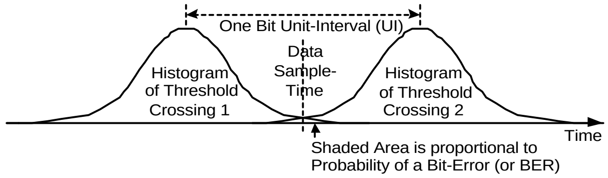


Figure 2. Time distribution of eye-diagram threshold crossings showing jitter profile

2. Referencing Jitter Measurements to Receiver Jitter Tolerance

A great simplification results in specifying or measuring jitter anywhere in the channel when the receiver jitter tolerance is used as the common frequency domain weighting filter for all measurements. First, let's define jitter tolerance:

Jitter tolerance is a measure of the capability of the receiver's clock/data recovery (CDR) circuits to recover data with a specified bit-error rate (BER), or better, in the presence of jitter. It is a function of frequency and has the general characteristic shown in Figure 3. Conceptually, it can be thought of as the maximum jitter permissible, at any frequency, before data errors occur (see Figure 2). In practice, sinusoidal jitter is added to worst-case channel jitter to test the margin of the receiver's jitter tolerance.

Note the single inflection point in the curve. This comes from the dominant pole in the receiver's CDR PLL loop filter implementation. The result is increasing tolerance to jitter below this pole frequency. In general terms, the receiver's sampling time tracks jitter below this frequency, making it more immune to low-frequency jitter. It doesn't track jitter above this frequency; thus, it is more vulnerable to high-frequency jitter.

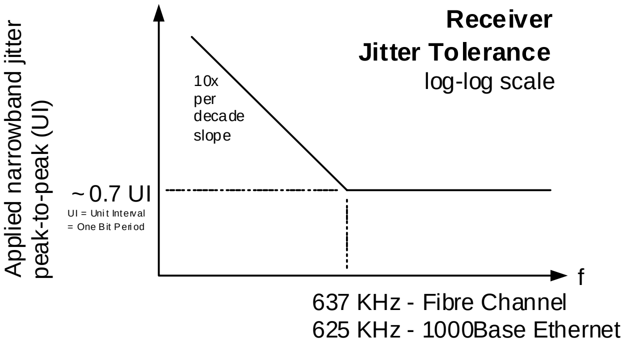


Figure 3. Characteristic receiver jitter tolerance

When measuring jitter in the channel, anywhere between the transmitter and the receiver, it would be logical to use a jitter metric that relates directly to the receiver's ability to tolerate jitter. This, in fact, is the approach chosen by the Fibre Channel working group: Invert the receiver jitter tolerance curve to yield the weighting filter for total-jitter measurement anywhere in the channel. Note the weighting response in Figure 4.

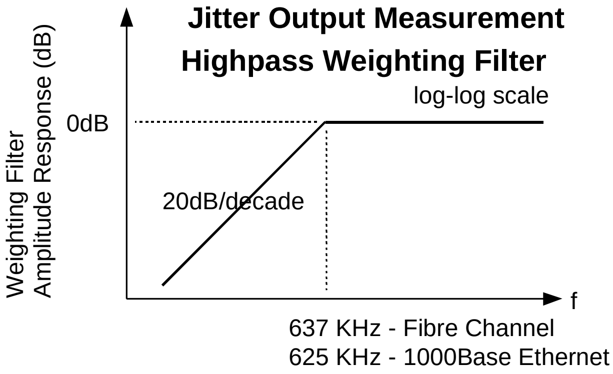


Figure 4. Jitter output measurement using a highpass weighting filter

This is a highpass filter with a pole at the same frequency as the pole in the receiver CDR PLL lowpass filter. The results in weighted measurements have reduced sensitivity at lower frequencies. This complements the receiver jitter tolerance, increasing tolerance at lower frequencies. Therefore, this weighted total-jitter measurement is a consistent metric upon which a jitter budget can be made for the entire channel.

3. Jitter Budget in the Channel

Both Fibre Channel and Gigabit Ethernet standards include jitter budgets for the channel, from transmitter to receiver, for each data rate and transmission media type. Both copper and optical channel links are shown in Figures 5 and 6.

The four channel locations are as follows:

TP1—Transmitter Electrical Output

TP2—Physical Media Tx Connection

TP3—Physical Media Rx Connection

TP4—Receiver Electrical Input

For the 1Gbps class of interfaces, Table 2 summarizes the jitter budgets specified by Fibre Channel and Gigabit Ethernet.

Note that both deterministic and total jitter are specified. The difference between them is the random-jitter amplitude. The amplitude of random jitter has been chosen by the standards committees to be that which yields a bit-error rate (BER) of 10^{-12}.

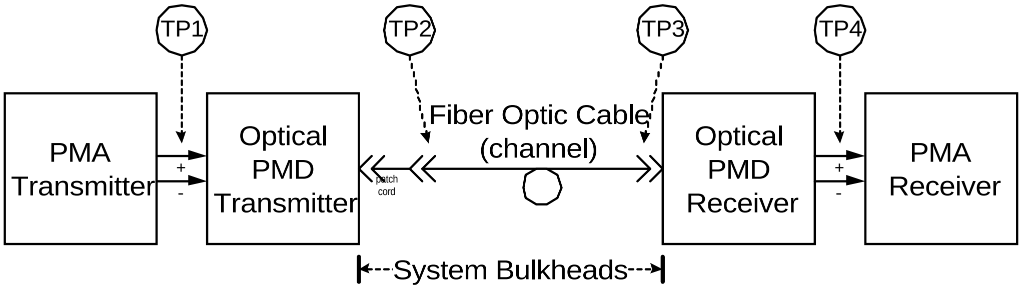


Figure 5. Serial link using fiber optic cabling

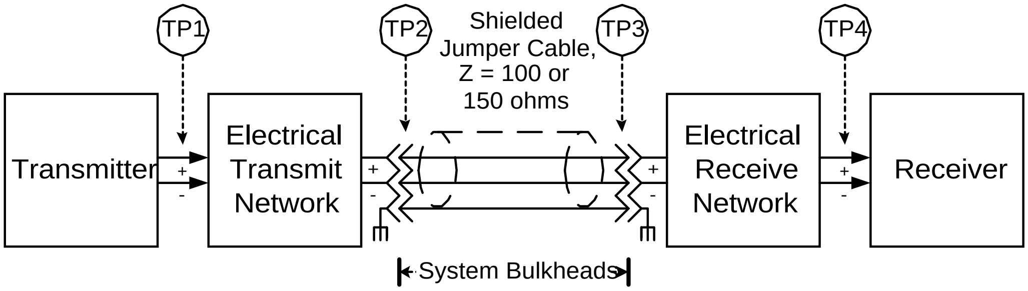


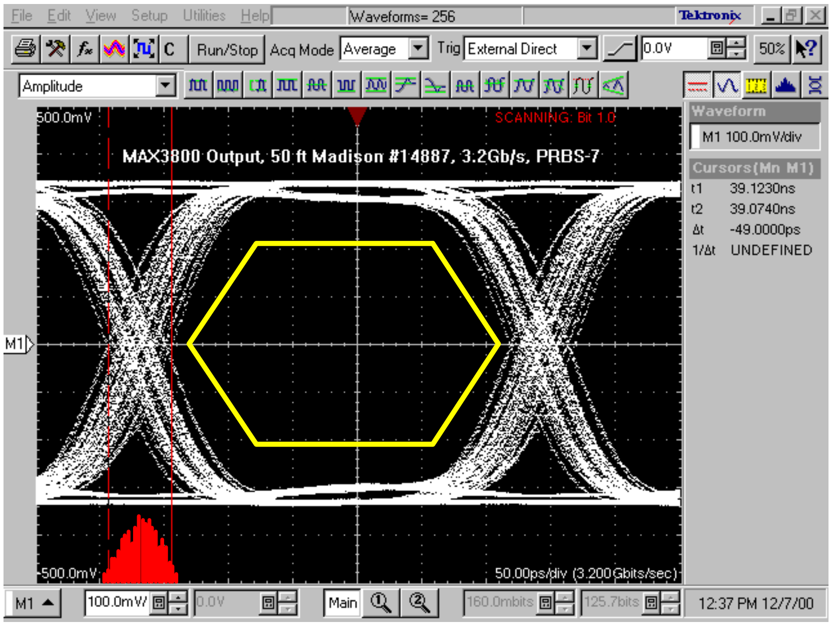
Figure 6. Serial link using shielded jumper cable

Table 2. Jitter Budgets

Channel Point	Jitter Component	Fiber Chan 1.0625Gbps 100-SE-EL-S SglMd Optic UI = Unit Interval	Fiber Chan 1.0625Gbps 100-SM-LC-L 75Ω Copper UI = Unit Interval	Gigabit Eth 1.25Gpbs 1000Base SX/LS Optic UI = Unit Interval	Gigabit Eth 1.25Gbps 1000Base CX Copper UI = Unit Interval
TP1—Tx Output Measured Jitter	Deterministic: TOTAL:	0.10 UI 0.21 UI	0.10 UI 0.21 UI	0.10 UI 0.24 UI	0.12 UI 0.24 UI
TP2—Media Input Measured Jitter	Deterministic: TOTAL:	0.21 UI 0.43 UI	0.13 UI 0.27 UI	0.20 UI 0.43 UI	0.14 UI 0.28 UI
TP3—Media Output Measured Jitter	Deterministic: TOTAL:	0.23 UI 0.47 UI	0.35 UI 0.54 UI	0.25 UI 0.51 UI	0.40 UI 0.66 UI
TP4—Rx Input Measured Jitter	Deterministic: TOTAL:	0.38 UI 0.65 UI	0.38 UI 0.60 UI	0.46 UI 0.75 UI	0.45 UI 0.71 UI

4. Viewing and Measuring Jitter

A sampling oscilloscope can be used to view the time-domain effects of jitter (e.g., eye-diagram display, see Figure 7). Modern sampling scopes can display the jitter histogram at the threshold crossing and "eye masks" to spot violations of jitter and amplitude noise for both Fibre Channel and Gigabit Ethernet.



Waveforms= 256

Acq Mode Average

Trig External Direct

0.0V

MAX3800 Output, 50 ft Madison #14887, 3.2Gb/s, PRBS-7

M1 100.0mV/div

Cursors(Mn M1)

t1 39.1230ns

t2 39.0740ns

Δt -49.0000ps

1/Δt UNDEFINED

Figure 7. Eye-diagram display

Figure 8 shows a sampling scope monitoring a DUT transmitter output. The “golden PLL” is used to filter the jitter to the scope trigger so that the displayed jitter is correctly weighted, thus displaying the relevant jitter amplitude and histogram.

Figure 9 shows the “golden PLL” jitter transfer. Note that the single pole once again is at the same frequency and identical response as the DUT receiver clock/data recovery (CDR) PLL response. The result: By using this lowpass weighting for the oscilloscope trigger, the resulting eye diagram displayed will show jitter with the recommended highpass weighting for jitter-output measurement.

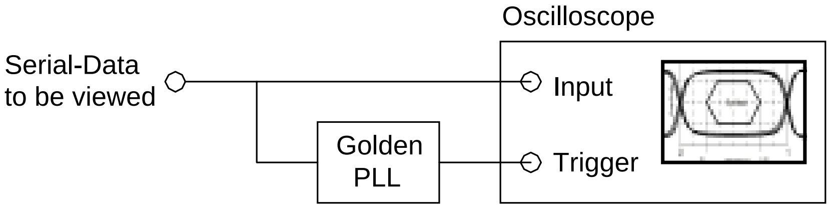


Figure 8. Viewing jitter using a sampling scope

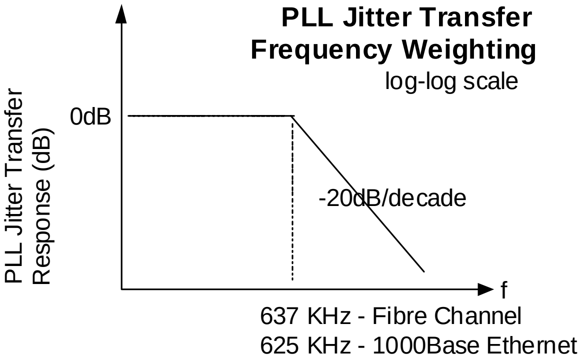


Figure 9. PLL jitter transfer using lowpass frequency weighting

References

To find out more about Fibre Channel and Gigabit Ethernet jitter methods and specifications, refer to the following documents:

1) FIBRE CHANNEL—Methodologies for Jitter Specification, T11.2/Project 1230/ Rev 10, June 9, 1999

2) FIBRE CHANNEL—Physical Interfaces (FC-PI), Rev 8.0, NCITS/Project 1235D, working draft proposed American National Standard for Information Technology, April 21, 2000

3) GIGABIT ETHERNET—PMD Sublayer, Type 1000Base-CX/SX/LX, Sections 38 and 39 of IEEE Standard 802.3, 2000 Edition