Effect of PRBS Pattern Length on Data-Dependent Jitter

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1. Outline

The trend towards increasingly large-capacity data communications is driving rapid progress in smaller and lower-cost optical modules. As a result, we are starting to see market standardization on SFP+ modules with a wider bandwidth than SFP modules. The current SFP+ MSA uses a short PRBS 2^9-1 pattern with a length of 511 bits as the test pattern for evaluating Data-Dependent Jitter (DDJ) at the Tx side. This is the specification for TWDP evaluation, but when these devices are installed in transmission equipment, the final jitter in the actual SDH/SONET/OTN signal is evaluated. Consequently, with the increasing number of SFP+ modules in the market, there is some concern that it may not be possible to use the results of stand-alone device jitter evaluation to adjust the amount of jitter when the device is installed in equipment. This white paper examines the theoretical degree of difference in jitter amounts generated by the device under test (DUT) using PRBS patterns of different lengths. To quantify the degree to which this difference is impacted by the DUT parameters, we performed the evaluation using numerical simulation, modeling the DUT and jitter measurement method.

2. Simulation Model

The jitter components of a data signal can be classified into deterministic jitter (DJ) and random jitter (RJ). DJ can be subdivided further into data dependent jitter (DDJ) and periodic jitter (PJ). Of these, DDJ is impacted directly by the data pattern. As a result, this numeric simulation only considers DDJ. The cause of DDJ is thought to be waveform distortion due to the DUT frequency bandwidth as well as reflection of the transmitted signal, etc. [1]. In this simulation, DDJ is generated according to the frequency bandwidth of the DUT and jitter measurement method and the difference in the size of the DDJ is quantified according to the data pattern length. In the first evaluation, the degree of the difference in the DDJ measurement error for the jitter measurement method used by most SDH/SONET/OTN jitter testers (data signal converted to clock signal and jitter in clock signal measured) was quantified using the measurement system shown in Fig. 1. Then, in the second evaluation, the theoretical degree of difference in the jitter of the DUT output signal with the data pattern length was quantified using the measurement system shown in Fig. 2. Here, the DUT frequency bandwidth due to AC coupling and high-frequency cutoff are represented by a high-pass filter (HPF) and low-pass filter (LPF); the impact on the DDJ was investigated by changing these cutoff frequencies.

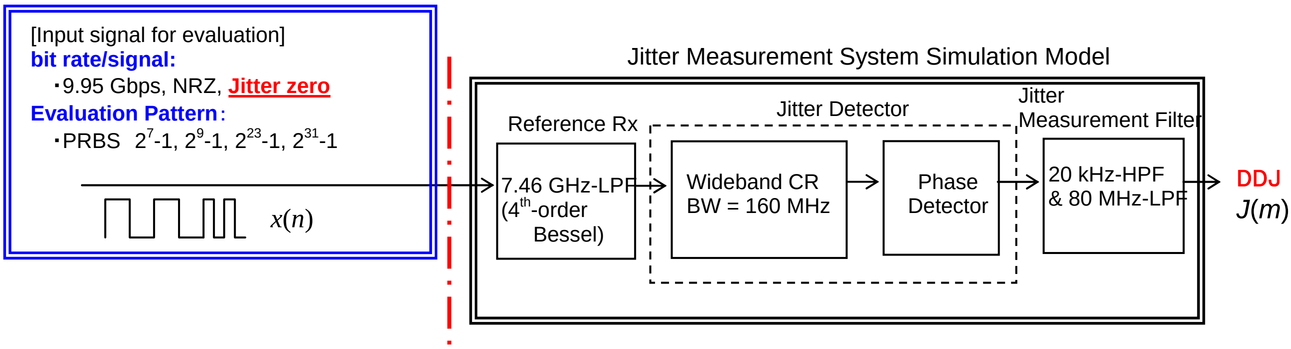

Fig. 1 Evaluation 1: Data Dependent Jitter Error of Jitter Measurement Method used by SDH/SONET/OTN Jitter Testers

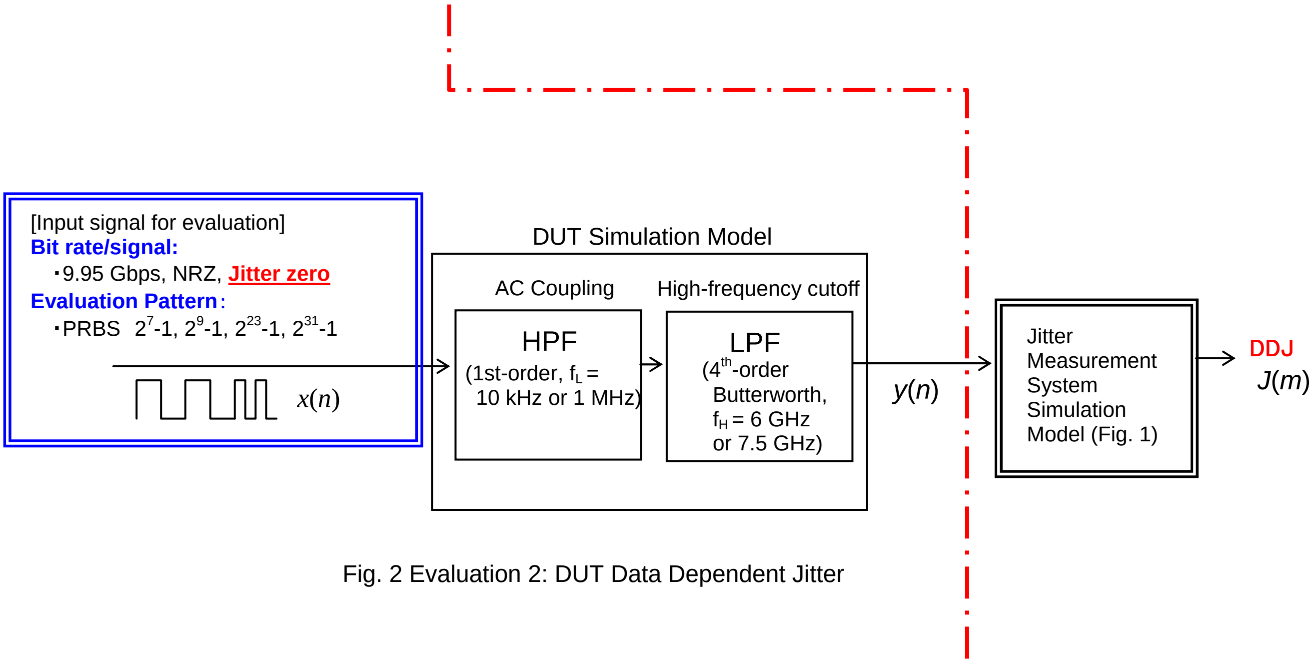

Fig. 2 Evaluation 2: DUT Data Dependent Jitter

3. Evaluation 1: Data Dependent Error using Jitter Measurement System

3.1 Evaluation 1 Simulation Method

As shown in Figure 1, a jitter-zero data signal series *x(n)* (n = 0, 1, 2…) simulating an NRZ signal with a data rate of 9.95 Gbit/s is input to the jitter measurement system as the evaluation input signal. The *x*(*n*) values are 1 (High level) and -1 (Low level). This sampling interval is 1/1000 of a 1 unit interval (1UI = 1/9.95 GHz) so as to obtain a simulation resolution for 1mUI (see Fig. 3 x(n)). PRBS 2^7-1, 2^9-1, 2^{23}-1, and 2^{31}-1 were used as the *x(n)* data patterns. Each PRBS was generated using the following polynomial equations in compliance with ITU-T T Rec. O.150, and O.151:

PRBS 2^7-1: $1+X^6+X^7$
PRBS 2^9-1: $1+X^5+X^9$
PRBS 2^{23}-1: $1+X^{18}+X^{23}$
PRBS 2^{31}-1: $1+X^{28}+X^{31}$

The transfer function of the reference receiver in the jitter measurement system used a 4th-order Bessel filter with a data rate of 0.75 times the cutoff frequency (7.46 GHz) described in ITU-T ANNEX B/G.957. The second jitter detector element in the simulation model took into consideration the phase detection method discussed by the ITU-T Q5/Study Group 4[2]. This phase detection method finds the jitter at each rising edge of the clock signal by phase detection after the input data signal is converted to a data rate clock signal (9.95 GHz) using wideband clock recovery (W-CR). In this simulation, the W-CR pass bandwidth was set to two times (160 MHz) the upper jitter band (80 MHz). The third jitter measurement filter in the jitter measurement model used filters to suppress the high and low jitter as recommend in ITU-T G.783 and G.825; a 20 kHz 1st-order HPF cut low components, and a 80 MHz 3rd-order Butterworth LPF cut high components. The DDJ series $J(m)$ (m = 0, 1, 2…) with a sampling interval equivalent to 1UI was output from the jitter measurement system.

3.2 Evaluation 1 Simulation Results

Table 1 lists the DDJ peak-to-peak values of the DDJ time series $J(m)$ (m = 0, 1, 2, …., M -1) obtained using the evaluation system shown in Fig. 1. DDJ occurs in the jitter measurement system irrespective of whether the input signal is jitter zero because when the data signal is converted to a clock signal by the phase detector W-CR, timing errors occur in the recovered clock signal, depending on the length of the High and Low levels in the data signal. From Table 1, it is clear that the maximum data pattern dependent error of the jitter measurement method used by most current SDH/SONET/OTN jitter testers is 5mUIpp. This is much smaller than the 100mUIpp maximum permissible jitter limit for measurement equipment specified in ITU-T Rec. G.783.

Table 1 DDJ Error of Jitter Measurement Systems using Evaluation 1 Simulation

Units: mUIpp

Data Pattern			
PRBS 2^7-1 (M = 127)	PRBS 2^9-1 (M = 511)	PRBS 2^{23}-1 (M = 8,388,607)	PRBS 2^{31}-1 (M = 20 x10^6)
1	2	4	5

However, the value of M in the *J(m)* series used in the DDJ evaluation ranged from 127 (2^7-1) to 8,388,607 (2^{23}-1) for PRBS patterns of 2^7-1 to 2^{23}-1, respectively. In the case of PRBS 2^{31}-1, computation of the maximum pattern length requires an exceptionally long time because M is 20 x 10^6. Moreover, a sample size of 20 x 10^6, includes 31UI of consecutive High levels for PRBS 2^{31}-1. Consequently, despite using a 20 x 10^6 sample, we think it is possible to obtain approximately the same DDJ as in evaluation using the maximum pattern length. However, strictly speaking, DDJ is not due only to the maximum length of High and Low levels in the pattern and is also affected by adjacent patterns, so it is probable that different results will be obtained from those in Table 1 when using other polynomial equations to generate the PRBS.

4. Evaluation 2: DUT Data Dependent Jitter

4.1 Evaluation 2 Simulation Method

The laser driver in an actual optical transmitter sometimes has AC coupling at the input and output sections[3]. AC coupling cuts low-frequency components including DC, degrading the data signal waveform. In Fig. 2, the DUT AC coupling was modeled ideally using a 1^{st}-order HPF with a cutoff frequency f_L of 10 kHz or 1 MHz.

On the other hand, a 4^{th}-order Butterworth LPF with a cutoff frequency f_H of 6 GHz or 7.5 GHz was used to model the optical transmitter high-frequency cutoff.

Generally, it is believed that the primary factor generating DDJ is the HPF cutting DC components, but the LPF distorting the data signal waveform is also a main cause of DDJ [3]. A Butterworth filter is used as the LPF, because some frequency characteristics of actual optical transmitters are like a Butterworth filter.

The same four PRBS patterns as used in Evaluation 1 were used as the DUT input signal $x(n)$. The DDJ of the DUT output signal $y(n)$ was detected using the same jitter measurement system simulation model as in Fig. 1. Figure 3 is an example of the DUT input and output signals $x(n)$ and $y(n)$ obtained by the simulation shown in Fig. 2.

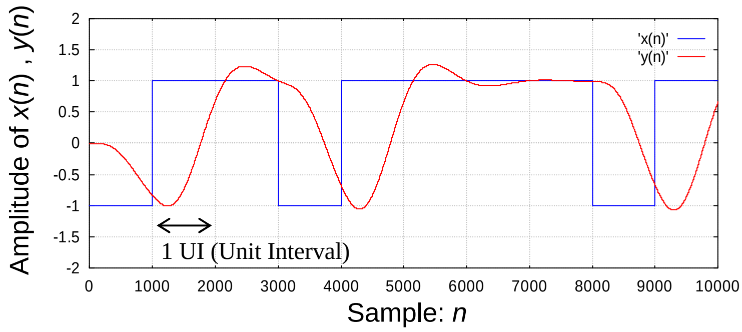

Fig. 3 Example of DUT I/O Waveforms Obtained by Evaluation 2 Simulation
(HPF: f_L = 10 kHz, LPF: f_H = 6 GHz)

4.2 Evaluation 2 Simulation Results

Table 2 shows the DDJ peak-to-peak values for the DDJ time series $J(m)$ (m = 0, 1, 2, …, M-1) obtained using the simulation model shown in Fig. 2. In simulations No. 1 to No. 8, the DUT was modeled by combining an HPF and LPF with different cutoff frequencies (f_L and f_H). The results are explained in order below.

Table 2 DUT DDJ using Evaluation 2 Simulation Units: mUIpp

Sim. No.	DUT Bandwidth Limit (“–” no filter)		Data Pattern			
			Non-frame Signal			
	f_L of HPF	f_H of LPF	PRBS 2^7-1 (M = 127)	PRBS 2^9-1 (M = 511)	PRBS 2^{23}-1 (M = 8,388,607)	PRBS 2^{31}-1 ($M = 20\times10^6$)
1	10 kHz	–	1	2	4	5
2	1 MHz	–	1	2	4	5
3	–	7.5 GHz	1	2	7	8
4	–	6 GHz	1	16	44	37
5	10 kHz	7.5 GHz	1	2	6	8
6	1 MHz	7.5 GHz	1	2	9	16
7	10 kHz	6 GHz	1	16	44	38
8	1 MHz	6 GHz	1	16	44	45

(Simulations No. 1 and No. 2)

In simulations No. 1 and No. 2, the DUT was modeled using only an HPF. The DDJ values for each data pattern are extremely small and very similar to the Jitter measurement errors in Table 1. In other words, the DDJ due to the HPF is sufficiently small that it can be ignored as measurement error.

(Simulations No. 3 and No. 4)

In simulations No. 3 and No. 4, the DUT was modeled using only an LPF. The DDJ due to the LPF increases as the PRBS stage increases. In No. 4 in particular, the large waveform distortion for *y(n)* is due to the low value of f_H as shown in Fig. 3. In No. 4, extremely large simulation DDJ values of 44mUIpp and 37mUIpp were obtained at PRBS 2^{23}-1 and PRBS 2^{31}-1.

(Simulations No. 5 to No. 8)

In simulations No. 5 to No. 8, the DUT was modeled using both an HPF and LPF. Due to the effect of both the HPF and LPF, the DDJ value at PRBS 2^{31}-1 is much larger than when only an LPF is used. For example, the DDJ for simulation No. 4 is 37 mUIpp but 45 mUIpp for simulation No. 8.

4.3 Comments on Evaluation No. 2

As shown in Table 2, the difference in DDJ generated at PRBS 2^{7}-1 and PRBS 2^{31}-1 has a gap of from 5 to 45 times. The increase in DDJ as the PRBS stage increases is thought to be due to the occurrence of long High and Low levels in the data pattern. Consequently, test patterns used at DUT jitter evaluation should generate similar lengths of High and Low levels to the lengths at the final testing stage.

5. Conclusions

DDJ is generated by the DUT low- and high-frequency cutoff. The dependency of DDJ on the send data pattern was detected by numerical simulation. Evaluation 1 clarified that the theoretical error for DDJ measured using the jitter measurement method used by most SDH/SONET/OTN jitter testers is 5mUIpp or less (@9.95 Gbit/s). Additionally, by modeling a DUT using a combination of HPF and LPF, Evaluation 2 clarified that DDJ is increased more by the effect of the LPF than the HPF. Further, the difference in DDJ for PRBS 2^{7}-1 and PRBS 2^{31}-1 patterns is dependent on the combination of HPF and LPF and ranges from 5 to 45 times. Consequently, we believe that test patterns used for jitter evaluation should generate lengths of High and Low levels similar to the actual signal and that it is appropriate to use PRBS 2^{23}-1 or PRBS 2^{31}-1.

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