THE IMPORTANCE OF CALIBRATION STANDARDS IN JITTER MEASUREMENTS

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When the International Telecommunication Union — Telecommunication Standardization Sector (ITU-T) standardized synchronous optical network/syncrhonous digital hierarchy (SONET/SDH) in 1988, the highest speed was 156 Mb/s. The rapid growth of the Internet, as well as other factors, has increased the necessary speed of today's networks to 10 Gb/s or 40Gb/s (10G, 40G). In 2000, ITU-T Recommendation G.783 specified the maximum jitter for error-free communications on 10G and 40G networks, but there was not a standard process to verify the accuracy of jitter measurements and no reference source with a known jutter amount.

ITU-T Recommendation G.783 specified three jitter measurements for guaranteeing error-free interconnectivity between transmission systems: *jitter generation*, *jitter tolerance*, and *jitter transfer*. Jitter generation refers to the jitter present on the output of a single device and requires that the device under test (DUT) generate a predefined amount of jitter. When measuring jitter generation, it is very important that the result not be affected by the intrinsic jitter of the measurement. Jitter tolerance evaluates the extent to which a DUT operates without causing an error when the jitter amplitude is increased. Jitter transfer evaluates to what extent the jitter amplitude is transferred to the output side when a modulation signal is input to the DUT. This is a critical measurement for restricting jitter accumulation.

In order to hold jitter from the transmission system below the jitter tolerance value, ITU-T Recommendation G.783 determined the acceptable jitter generation to be less than 0.1 UIp-p (peak-to-peak amplitude, user interface) from 4 to 80 MHz. The jitter limits established at various rates can be seen in Table 1. To guarantee this specification, it is very important to evaluate the in-band jitter correctly.

In general, two factors cause jitter in transmission systems [1]. One factor is random jitter, which is due mainly to single sideband (SSB) noise generated by the network transmission system. The amount of random jitter varies with the measurement time because the generation probability is described by a Gaussian distribution. As a result, the measurement time must be clearly defined.

On the other hand, deterministic jitter is not related to measurement time. Rather, it is generated by SONET/SDH framing. Consequently, it is important to evaluate these complex data correctly at high frequencies such as OC-192 (10G) and OC-768 (40G), because it is necessary to suppress jitter to less than 0.1 UI.

Interface	Measurement band (–3 dB frequencies) (notes 1 and 2)		Peak-peak amplitude (UI) (notes 3 and 4)
	High-pass (kHz)	Low-pass (MHz) –60 dB/dec	
STM-1 optical	0.5	1.3	0.30
	65	1.3	0.10
STM-4 optical	1	5	0.30
	250	5	0.10
STM-16 optical	5	20	0.30
	1000	20	0.10
STM-64 optical	20	80	0.30
	4000	80	0.10
STM-256 optical	80	320	0.30
(note 5)	16 000	320	0.10

Note 1 — The high-pass and low-pass measurement filter transfer functions are defined in clause 3/G.825.
Note 2 — The measurement configuration is shown in Fig. 1/ G.825.
Note 3 — For STM-1: 1 UI = 6.43 ns
For STM-4: 1 UI = 1.61 ns
For STM-16: 1 UI = 0.40 ns
For STM-64: 1 UI = 0.10 ns
For STM-256: 1 UI = 0.025 ns
Note 4 — The measurement time and pass/fail criteria are defined in clause 3/G.825.
Note 5 — Values for STM-256 are provisional and are not present in ITU-T G.825 at the time of publication of this revision of this Recommendation.

TABLE 1. Jitter generation for STM-*N* type A regenerators in 2048 kb/s based networks (ITU-T G.783).

PROBLEMS OF JITTER MEASUREMENTS

There are many test systems for measuring 10G jitter, but each piece of equipment tends to give different jitter results. Because there are no common standards for traceability, it is imperative that a sound calibration procedure is established to verify jitter measurement. ITU specifies the maximum jitter generation to make a multivendor mutual connection possible. To make accurate jitter measurements, the test system should be calibrated with a transmitter (TX) whose jitter value is already known. This known TX jitter value can be used as a golden TX to calibrate jitter testers.

When using a loopback measurement to evaluate the jitter of measurement equipment, the proportion of jitter generated individually by the transmitter and receiver must be known. It is incorrect to assume that the transmitter generates no jitter (0 UIp-p) and that the total jitter is generated by the receiver because SDH/SONET signals include the original jitter of nonscrambled framing bytes.

EVALUATION OF PATTERN JITTER

Pattern-dependent jitter (PDJ) is defined as jitter generated by the unscrambled A1, A2, and J0/Z0 bytes in SONET/SDH signals. To effectively conduct a PDJ measurement, the

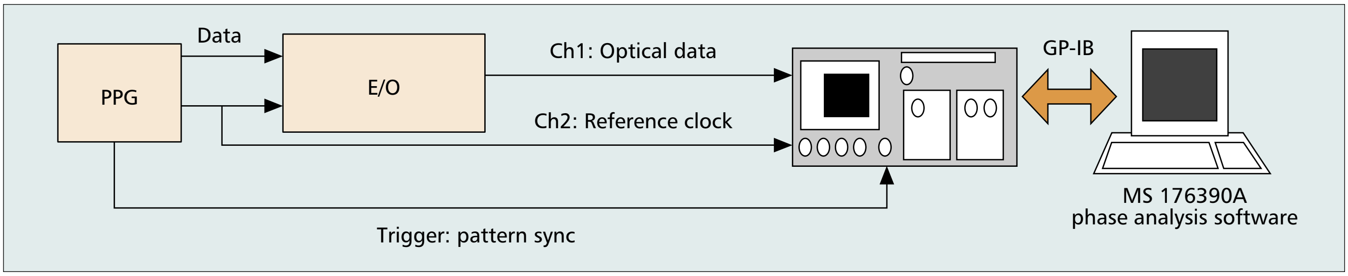

FIGURE 1. Patttern jitter evaluation system.

jitter must be measured. Figure 1 shows a PDJ evaluation system [2]. A programmable pulse pattern generator (PPG) is used to generate an OC-192 frame signal to modulate an E/O converter. The E/O converter produces an optical signal with pattern-dependent jitter, and the signal is monitored by a sampling oscilloscope. A fixed pattern is displayed by using a pattern trigger. The clock signal is also measured simultaneously as a jitter-free reference signal. The results of this jitter measurement (Fig. 2) clearly indicate the pulse jitter of the nonscrambled bytes.

It is necessary to average about 64 measurements to suppress the effect of residual jitter due to the oscilloscope's trigger circuit and allow this source of error to be ignored. The first edge of the A1 pattern and the edge of the clock are set by adjusting the delay on the sampling oscilloscope to measure the time between the data edge and clock edge (Fig. 3). After measuring the times of all edges, the pattern jitter of the transmitter can be calculated using digital signal processing and filtering technologies.

SONET/SDH framing generates pattern jitter every 125 μs on the first frame of SOH because the A1/A2 framing bytes are not scrambled, and by definition, create pattern dependent jitter. This pattern's cycle creates jitter with a 3.24 MHz central frequency. Other jitter generated by the scrambled bytes is small, so jitter generated by the nonscrambled bytes is the main cause of jitter.

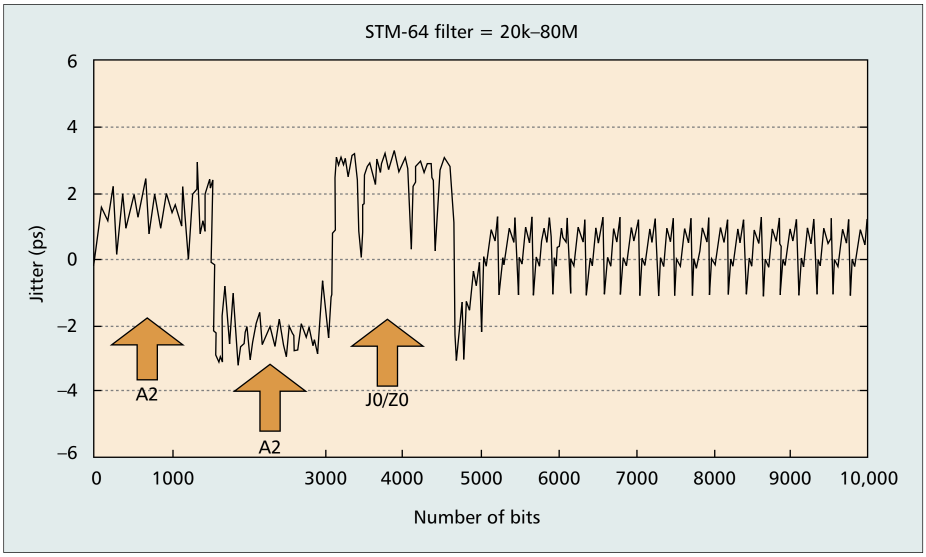

FIGURE 2. Pattern-dependent jitter test results.

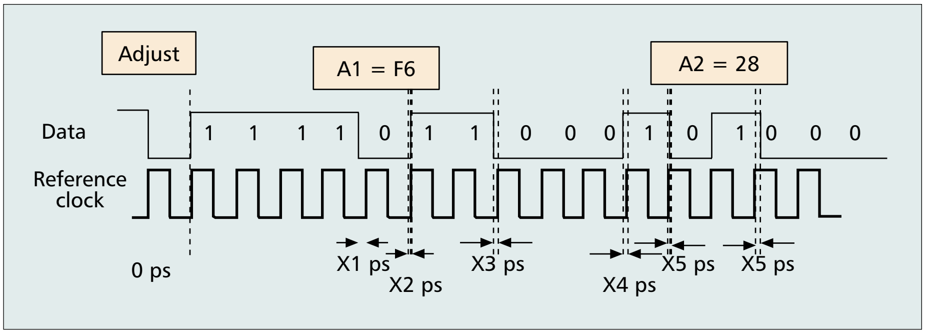

FIGURE 3. SONET/SDH jitter pattern.

The same procedure and test system can also be used to determine jitter in a GbE signal. The measurement accuracy is ensured as long as the test system is calibrated with a golden TX.

EVALUATION OF RANDOM JITTER

To analyze random jitter, the send signal SSB noise must be measured [3]. Using a send signal with an unframed 1010 pattern converted from a SONET signal, random jitter in the range of high-pass 1 (HP1) + low-pass (LP) is calculated as 0.15 mUIrms by adding a filter (HP1 + LP) to the result.

The total jitter for a 60 s period is the sum of pattern jitter and random jitter. The total jitter of the reference signal found by this method is 6.981 ps (69.47 mUIp-p) for a 10G pattern. As a result, the total jitter is almost equal to the pattern jitter when a synthesizer with very low SSB phase noise is used as a standard signal source. The SSB phase noise is only 0.15 mUIrms (HP1 + LP), so the random jitter is almost negligible. Consequently, it is clear that pattern jitter must be measured accurately when measuring jitter generation of less than 0.1 UIp-p.

SEPARATING TRANSMITTER AND RECEIVER JITTER

Although the pattern jitter of a SONET/SDH pattern consists of an infinite 8 kHz spectrum, the peak is at 3.24 MHz. Even if the standard signal is clean, there is pattern jitter of 65.8 mUIp-p because of the frame pattern. The jitter is not attenuated by the HP1 + LP jitter filter (20 kHz + 80 MHz) because it is in the jitter measurement band.

To ensure accurate jitter generation, the jitter receiver can be calibrated using an unframed 1010 pattern with a very small random jitter component and no pattern jitter. The residual jitter of the receiver can be found because the transmitter jitter is already known. For example, when the result is 80 mUIp-p, the receiver residual jitter is 14.2 mUIp-p because the transmitter jitter is 65.8 mUIp-p. Although the transmitter is the main source of residual jitter in measurement equipment, it does not affect the measurement results because it is attenuated by the DUT jitter transfer characteristics.

IMPORTANCE OF A JITTER REFERENCE WITH TRACEABILITY

The frequency of pattern jitter for OC-768 is relatively higher than that of OC-192 because of the small numbers of A1/A2 bytes for 40G. The resulting jitter frequency is around 40 MHz, but this is still in the jitter bandwidth (80 kHz–320 MHz) specified by ITU-T. Therefore, this pattern jitter must be measured accurately, especially because the specification is very strict at 40G.

The 40G specification is also strict because 0.1 UI (the maximum allowable jitter) for 40G is 2.5 ps, which is one quarter of the 10 ps permissible amount for 10G. Accurate measurements at 2.5 ps are very difficult because there is no traceability to a standard reference [4, 5].

CONCLUSION

Accurate jitter measurements at high speed are difficult because of the small times involved, but they are essential for implementing error-free networks. The method described here shows that accurate jitter measurements at 10G and above must correctly account for both pattern-dependent and random jitter. Pattern-dependent jitter is caused to a much greater extent by the transmitter than by the receiver. Incorrect assumptions about the source of pattern-dependent jitter can result in large inconsistencies in jitter measurements at high speed. The method outlined here solves those problems.

REFERENCES

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BIOGRAPHY

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