

Stressed Receiver Sensitivity Testing

for 10 Gigabit Ethernet and 10 Gigabit Fibre Channel

Introduction

10 Gigabit Ethernet's stressed receiver sensitivity (SRS) is a parameter that describes the minimum input optical power at which a receiver is required by the IEEE standard to operate with a bit error ratio (BER) of better than or equal to 10^{-12} at system level. It specifies a receiver's capability to recover traffic when its input signal contains physical degradations. Failure to meet this requirement may result in delay in service provisioning for carriers and even redesign of hardware for equipment manufacturers. Therefore SRS testing is one of the most important tests for network operators, equipment manufacturers and transceiver manufacturers. Since the eye diagram of a test signal shows signs of stress through vertical eye closure and jitter, an SRS test is sometimes referred to as 'stressed eye' test. Figure 1 below shows the eye diagram of a stressed signal that contains vertical eye closure and jitter.

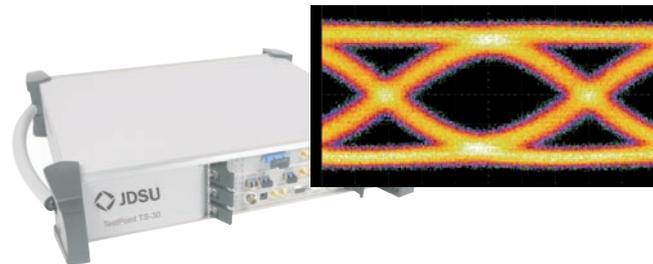


Figure 1 Eye diagram of a stressed signal

Unlike many other communications standards which specify sensitivity in terms of average optical power, the 10 Gigabit Ethernet standard specifies its SRS requirement in terms of optical modulation amplitude (OMA), which is the difference in optical power for the nominal "1" and "0" levels of the input optical signal. Jitter tolerance is usually a separate requirement for other standards, such as SONET/SDH; it is incorporated into the requirement for the test signal and not listed as a separate requirement. Differences in describing the requirements mandate that different measurement instrument are used in testing receiver sensitivities for Ethernet and SONET/SDH technologies.

Requirement of stressed receiver sensitivity testing

The IEEE standard has specified the requirements for 850nm, 1310nm and 1550nm wavelengths. The requirements on the test signal for SRS evaluation are listed in Table 1. An SRS tester must be able to produce the correct amount of stress for each wavelength it supports as specified below.

	Wavelength (nm)		
	850	1310	1550
OMA (dBm)	-7.5	-10.3	-11.3
VECP (dB)	3.5	2.2	2.7
Jitter (UI pk-pk)	0.3	0.3	0.3

Written by:

Gaoyao Tang

Applications Engineer, JDSU

Table 1 Conditions for SRS testing

To produce such degradation, the standard recommends, as described in Figure 2, the use of a fourth-order Bessel-Thomson filter to create inter-symbol interference (ISI)-induced vertical eye closure penalty (VECP), a sinusoidal amplitude interference (SI) source to add additional eye closure and deterministic jitter, and phase modulator to add sinusoidal jitter (SJ). The combined effect should result in the required stress as is listed in Table 1.

Over-stressing or under-stressing the signal should be avoided.

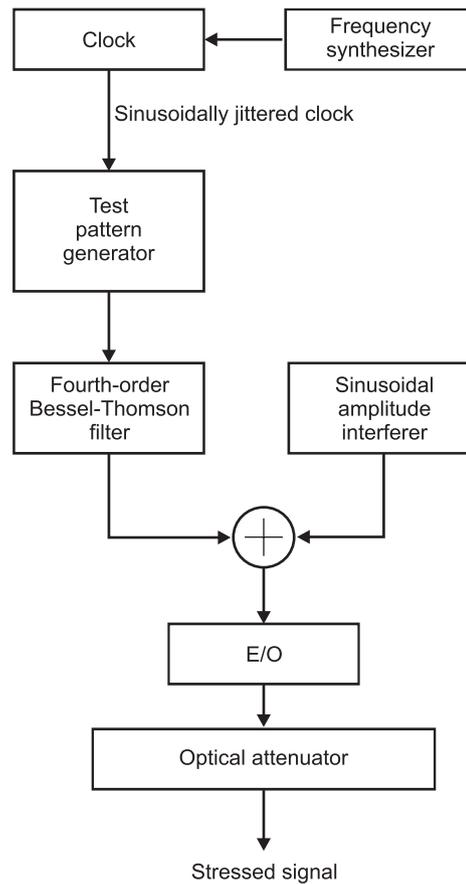


Figure 2 Generation of stressed signal

Characterization of the test signal

An optical power meter is not used to characterize the test signal as it does not measure the OMA of a signal. Instead, a digital communications analyzer (DCA) is used for the measurement of the specified parameters: extinction ratio, OMA, VECP and jitter.

The standard requires that the OMA of a signal must be measured with a square wave, as shown in Figure 3, not a PRBS, before ISI, SI and SJ are applied.

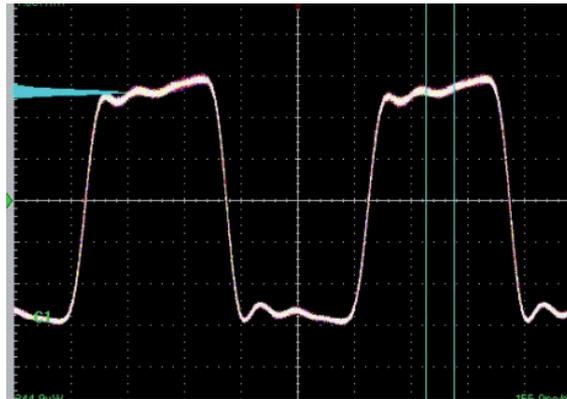


Figure 3 Input signal for OMA measurement

Without consulting the test procedure, one may tend to measure the ‘1 level’ and ‘0 level’ of an eye-diagram at the center of the eye that is generated with a PRBS. This often leads to different results than those measured with a square wave because the effect of Inter-Symbole-Interference is introduced.

When a square wave is not available, the OMA of a PRBS test signal needs to be approximated from its eye-diagram on the DCA. In such a situation, the standard recommends measuring the difference of histogram means for logical 1 and logical 0 at the point of the eye as indicated in Figure 4. Experiments have proven that errors caused by approximation are small and the resulting errors in VECP measurements are negligible. Care should be taken to ensure that the DCA has high enough sensitivity to measure the test signal in its operating range. Otherwise a good test signal may be erroneously disqualified.

The characterization of VECP involves the measurement of OMA (the nominal amplitude without ISI) and eye opening (A_o), as illustrated in Figure 4. The accuracy of OMA and A_o has direct impact on the accuracy of the calculated VECP. VECP is calculated by the standard as:

$$\text{VECP} = 10 \log \frac{\text{OMA}}{A_o}$$

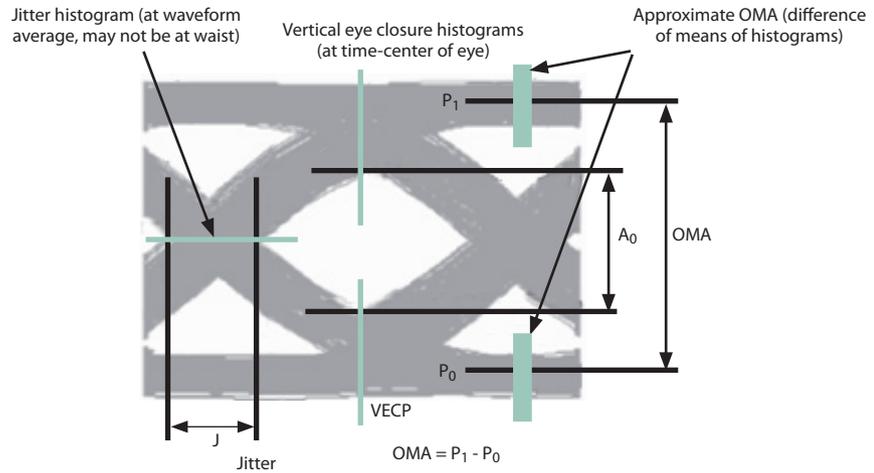
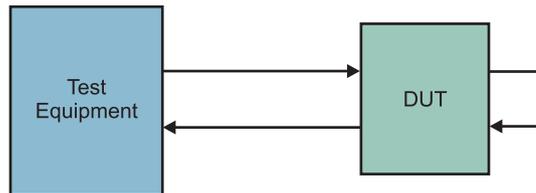


Figure 4 Stressed eye parameters

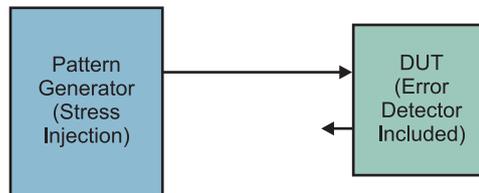
Jitter is measured at the waveform average with a DCA. The average may not necessarily be at the waist of the waveform. The use of DCA is different than for SONET and SDH which has more stringent jitter performance requirements that call for the use of more sophisticated instrument that is specifically designed for jitter and wander measurement.

Test configuration

(a)



(b)



(c)

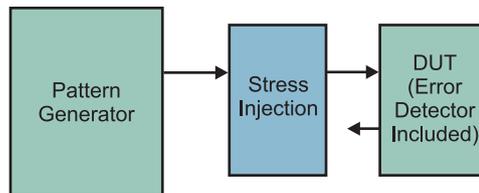


Figure 5 Test configuration

Figure 5 lists three configurations for an SRS test. Configuration ‘a’ is the most common configuration where the instrument serves as both pattern generator and error detector. The OMA of the test signal is set at the sensitivity level of the applicable wavelength that is required by the standard. The device under test (DUT) recovers the digital pattern from the degraded input optical signal and loops it back to the test instrument with a good waveform that is compliant to the requirement of the transmit standard. Any errors detected by the tester are assumed to have happened at the receiver of the DUT. At the end of the test the instrument informs the user whether the DUT meets the sensitivity requirement.

Configuration ‘b’ is used when the DUT has a built-in error detector. The DUT is required to send traffic out of its transmitter while receiving a test signal. For this configuration, it is the DUT’s responsibility to judge whether its own receiver meets the requirement.

Configuration ‘c’ is used when the tester is required to inject only optical parameter stress to the test signal between a traffic source and a traffic sink, it is not required to generate the test pattern and detect errors. This configuration is most useful when the desired pattern can not be generated by the tester and the DUT has facilities to detect errors that may occur.

Test patterns to be used

IEEE Std.802.3-2005 section 4 defines three test patterns for 10 Gigabit Ethernet testing, as shown in Table 2. Only pattern 2 and 3 are used for SRS error testing, as listed in Table 3. They are sometimes referred to as unframed patterns.

Pattern	Pattern for 10GBASE-R	Pattern for 10GBASE-W
1	BnBiBnBi	Mixed
2	AnAiAnAi	
3	PRBS31	PRBS31

Table 2 10 Gigabit Ethernet Test patterns

Test	Pattern
OMA (modulated optical power)	Square
Extinction ratio	1 or 3
Vertical eye closure penalty calibration	2 or 3
Stressed receive conformance	2 or 3

Table 3 Test patterns for stressed eye

For system level testing, some Ethernet systems under test are not capable of receiving traffic without MAC frames. Test patterns that contain Ethernet frames, even IP packets, referred to as framed patterns, become necessary for such situations. Although not standard test patterns, framed patterns allow the evaluation of system performance which otherwise can not be evaluated. When framed patterns are used, the criteria for BER do not apply as the DUT will drop the whole frame even if only one error is detected. It is the responsibility of the user to determine in what situation the DUT passes or fails a test.

How much time is required?

To accurately determine the actual BER of the DUT when its input OMA is as listed in Table 1 requires an extended amount of time when the target bit error ratio is low, especially when it is 10^{-12} or lower. A more practical approach is to use statistical methods, set an upper limit of the measured BER and test if it is better than this limit for a specified confidence level.

To determine the amount of time needed for a test, we take a look at the statistical nature of errors in communications circuits. Assume that errors are mainly caused by noise and the occurrences of errors are independent of errors that happen at any other times. If p is the probability that an error occurs for each received bit, the probability that k errors occur for n received bits can be described by the frequency function of Poisson process, if n approaches infinity and p approaches zero in such a way that $np = \lambda$:

$$P_n(k) = \frac{(np)^k}{k!} e^{-np} = \frac{\lambda^k}{k!} e^{-\lambda}$$

The statistical mean for the number of errors detected is λ .

Based on the above equation, suppose ϵ denotes the number of errors detected within n bits, the probability that ϵ is larger than N is

$$P(\epsilon > N) = 1 - \sum_{k=0}^N \frac{(np)^k}{k!} e^{-np}$$

If $P(\epsilon > N) = 95\%$, for repeated measurement of n bits, 95% of them will produce more than N errors. If less than N errors are produced, there is 95% probability that the actual probability of error is smaller than p . This probability is the confidence level mentioned earlier. Thus,

$$CL = 1 - \sum_{k=0}^N \frac{(np)^k}{k!} e^{-np}$$

For given N , p and CL , the number of bits to be tested is:

$$n = - \frac{\ln(1 - CL)}{p} + \frac{\ln \left[\sum_{k=0}^N \frac{(np)^k}{k!} \right]}{p}$$

When $N = 0$,

$$n = - \frac{\ln(1 - CL)}{p}$$

The time required for the test can be determined from n . For 10.3125 Gbps, when $p = 10^{-12}$ and $CL = 95\%$, the time required is 291 seconds.

About 10 Gigabit Fibre Channel Testing

10 Gigabit Fibre Channel uses the same PCS and has the same physical layer specification as 10GBASE-R. Therefore, the discussion above about 10 Gigabit Ethernet stressed receiver sensitivity testing also applies to 10 Gigabit Fibre Channel testing. Please refer to the 10 Gigabit Fibre Channel standard for further information.

Summary

We have discussed SRS testing for 10 Gigabit Ethernet including how it differs from conventional sensitivity testing. Signal characterization, test configuration, and test patterns are addressed. Finally, a method to determine the number of bits to test is explained for given confidence level, BER objective and number of allowed errors. The same test applies to 10 Gigabit Fibre Channel as it has the same technical requirement for physical interface as for 10 Gigabit Ethernet. Readers are encouraged to refer to the standards for details of the test

Glossary

BER	Bit Error Ratio
DCA	Digital Communications Analyzer
DUT	Device Under Test
ISI	Inter-Symbol Interference
OMA	Optical Modulation Amplitude
PRBS	Pseudo-Random Binary Sequence
SI	Sinusoidal amplitude Interference
SJ	Sinusoidal Jitter
SRS	Stressed Receiver Sensitivity
VECP	Vertical Eye Closure Penalty

Reference

- [1] John A. Rice, 'Mathematical Statistics and Data Analysis' 2nd edition, Duxbury Press, 1995
- [2] IEEE Std. 802.3-2005 section 4.
- [3] ISO/IEC 14165-116,2005 '10 Gigabit Fibre Channel (10GFC)

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