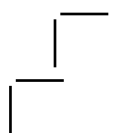
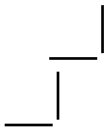


Performing RIN and RIN OMA Measurements on the DSA8300 Sampling Oscilloscope

Application Note

Tektronix[®]



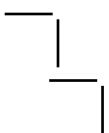


Application Note

A general consideration on measurements of RIN with an optical, equivalent time sampling oscilloscope is given here. Detailed information on the measurement of the RIN OMA for the purpose of 10 Gb/s Ethernet, IEEE 802.3ae and similar specifications is presented.

Table of Contents

1. Definition of RIN and RINxOMA.....	3
2. Procedure, Example Calculation	7
3. Oscilloscope Noise Contribution.....	9
4. Conclusion.....	9
5. Bibliography.....	9





1. Definition of RIN and RINxOMA

In the most basic definition RIN (Relative Intensity Noise) is a ratio of the laser's intensity noise to power. This is then typically expressed over the bandwidth of interest:

$$RIN = 10 \cdot \text{LOG} \frac{P_N}{BW \cdot P_C} \quad \text{Equation 1}$$

Where:

RIN = Relative Intensity Noise referred to optical high amplitude,

P_N = Noise power in watts (no modulation)

P_C = power of continuous wave (no modulation),

BW = Low-pass bandwidth of an optical-electrical receiver system, or of the measuring system in [Hz].

This measurement can be performed with a spectrum analyzer (for the value of noise power; the spectrum analyzer is AC-coupled) and a power meter (for the value of power of the laser with continuous high level).

In actual optical transmitter the behavior of the laser alone is of less interest than a measure of the noise on the modulated signal relative to optical signal amplitude of the modulated light.

Several measures of optical signal amplitude can be considered, for example AOP (average optical power) or OMA¹.

There are some advantages to considering OMA as the measure of the optical signal's power, and since this is used in a very common standard (802.3ae Ethernet - since 2002, and several follow-on standards) such measurement became the common way to evaluate the relative intensity noise in data communication transmitters. This measurement is then referred to as RINxOMA measurement and is performed as defined below.

Another consideration is that since the laser's relative intensity noise is a function of the optical return loss of the system the laser is connected to, the RIN should be measured with particular reflection magnitude in mind. The reflection coefficient is in this case by convention labeled x .

RINxOMA therefore is the Relative Intensity Noise with OMA as the measure of signal power and while the laser experiences x dB of return loss from the fiber.

The IEEE 802.3ae, e.g. 10GBASE-LR gives the method in electrical domain (after a photo-diode optical detector).

$$RINxOMA := 10 \cdot \log \left(\frac{P_{N_e}}{BW \cdot P_{M_e}} \right) \quad \text{Equation 2}$$

Where:

RINxOMA = Relative Intensity Noise referred to optical modulation amplitude measured with x dB reflection,

P_{N_e} = electrical noise power in watts with modulation off²,

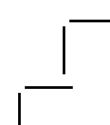
P_{M_e} = electrical power in watts of the modulated signal²,

BW = (Low-pass bandwidth of filter) –
(high-pass bandwidth of DC blocking capacitor)
[noise bandwidth of the measuring system (Hz)].

Figure 1 (see next page) contains the diagram of the measurement setup from the IEEE 802.3 clause 52.

¹OMA, optical modulation amplitude, is the difference between the high level and the low level, each level measured in a particular part of the waveform.

²The IEEE 802.3ae uses the symbol P_N resp. P_M ; in this paper we've added the subscript extension $_e$ to emphasize the fact that this parameter is electrical, not optical.



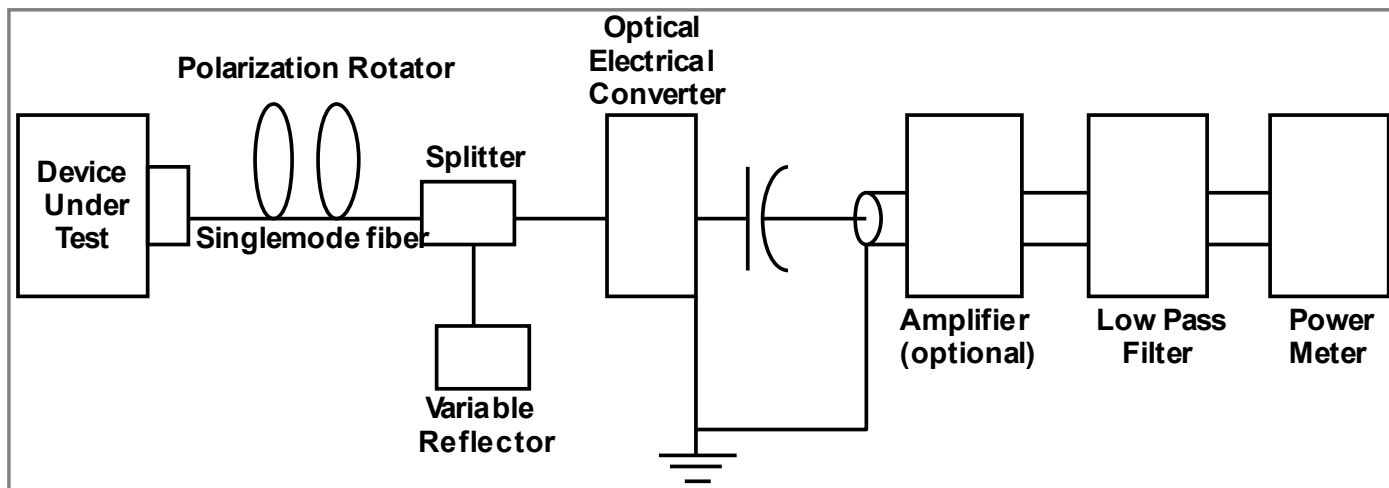


Figure 1. Setup of the RINxOMA measurement as per IEEE 802.3ae Ethernet. Refer to IEEE standard for Polarization Rotator, Splitter, and Variable Reflector information.

Again note that this definition uses electrical terms throughout – the power is the power as seen by an electrical RF power meter (right-most block in Figure 1) *after* the conversion of optical power into electrical voltage or current in the O/E (optical-to-electrical) convertor. Typical O/E converts optical power linearly to current; measuring the power generated by such current corresponds to measuring the square of optical power.

A sampling oscilloscope, such as the DSA8300, can measure all of the parameters needed to measure *RINxOMA*. The oscilloscope waveform displayed is in terms of optical power; we need to convert the waveform results into the results the Power Meter in Figure 1 would show. Two terms are needed: $P_{N_{Opt}}$ and $P_{M_{Opt}}$. Assuming the noise on the signal to be roughly Gaussian with distribution (as reported by oscilloscope's noise

measurement, or a vertical histogram)

$P_{N_{Opt}}$, the power of this noise is $P_{N_{Opt}}^2$. The power of a square-wave that is AC-coupled and swings from $P_{M_{Opt}}/2$ to $-P_{M_{Opt}}/2$, (where $P_{M_{Opt}}$ is OMA) is $(P_{M_{Opt}}/2)^2$. Substituting these terms into Equation 2 yields:

$$RINxOMA := 10 \log \left[\frac{P_{N_{Opt}}^2}{BW \cdot \left(\frac{P_{M_{Opt}}}{2} \right)^2} \right] \quad \text{Equation 3}$$

Where:

$P_{N_{Opt}}$ is optical noise power in watts; and

$P_{M_{Opt}}$ is optical OMA in watts (with modulation on)



Performing RIN and RIN OMA Measurements on the DSA8300 Sampling Oscilloscope

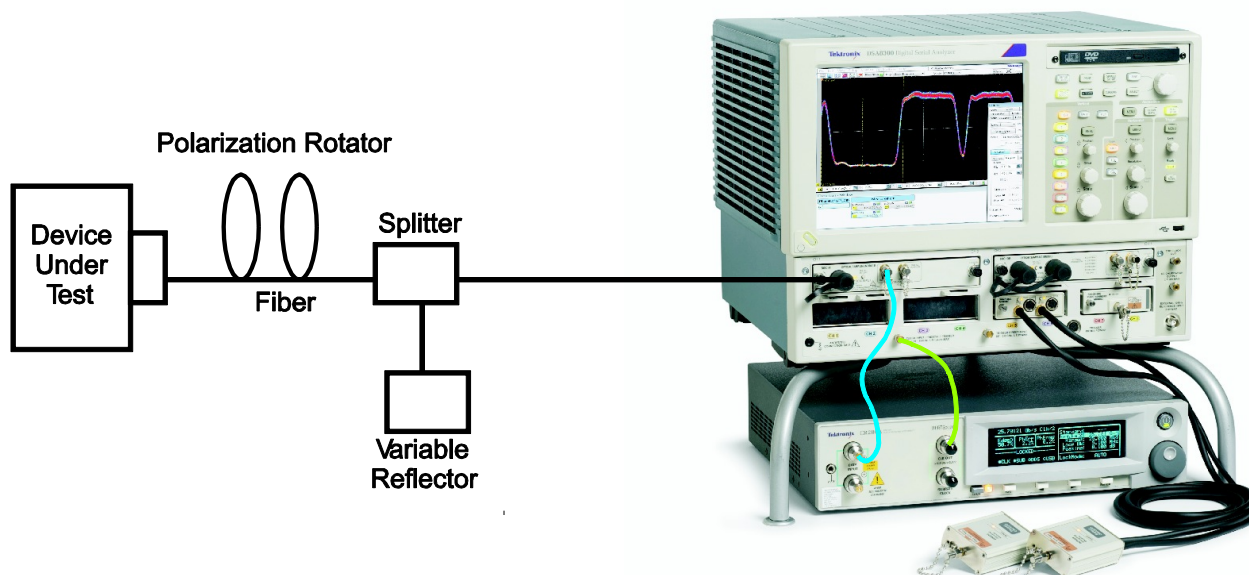
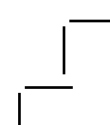


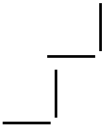
Figure 2. Setup of the RINxOMA when using an optical oscilloscope.

Figure 2 shows a setup for the RINxOMA measurement following the IEEE 802.3ae Ethernet when using a DSA8300 oscilloscope.

Refer to IEEE standard for Polarization Rotator, Splitter, and Variable Reflector information, noting that only a subset is used in the test of a multi-mode device. The loss $\langle x \rangle$ dB of reflection loss in “optical path and detector combination” must be configured for a single dominant reflection with an optical return loss specified by the standard; $RIN_{21}OMA$ for example is specified for 10GBASE-E.

The IEEE document also mentions that Optical return loss may be determined by the method of FOTP-107; and the length of the test cable is not critical but should be in excess of 2 m. Clock Recover is optional (depends on DUT Clock availability) and for some speeds can even be built into the optical module.





Application Note

It is common for optical transmitters to present lower noise power in the optical low state than in optical high state. It is then pessimistic to simply use the noise power at high level as in Equation 2; accounting for that yields:

$$\text{RINxOMA} := 10 \log \left[\frac{\left(\frac{P_{N_Opt_H_meas} + P_{N_Opt_L_meas}}{2} \right)^2}{\text{BW} \cdot \left(\frac{P_M}{2} \right)^2} \right]$$

Which simplifies to:

Equation 4

$$\text{RINxOMA} := 10 \log \left[\frac{\left(P_{N_Opt_H_meas} + P_{N_Opt_L_meas} \right)^2}{\text{BW} \cdot \left(P_{M_Opt_OMA} \right)^2} \right]$$

Where:

RINxOMA_1 = Relative Intensity Noise referred to optical modulation amplitude measured with x dB reflection,

$P_{N_Opt_H_meas}$ = Optical noise power in watts at high level, as measured (with oscilloscope's own noise included)

$P_{N_Opt_L_meas}$ = Optical noise power in watts at low level, as measured (with oscilloscope's own noise included)

$P_{M_Opt_OMA}$ = Optical OMA in watts with modulation on,

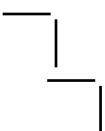
BW = Bandwidth of the low-pass filter in case of an *optical reference receiver* (ORR) mandated by optical standard,

$\text{BW} := \text{BW}_{\text{ORR}} * 1.05$; where BW_{ORR} is the Optical Reference Receiver bandwidth, typically $\text{BW}_{\text{ORR}} := 0.75 * \text{bit_rate_frequency}$ [Hz; Hz], so

$\text{BW} := 1.05 * 0.75 * \text{bit_rate_frequency}^3$ [Hz; Hz]

Also see "Section 3: Oscilloscope Noise Contribution" for even more accurate calculation that includes accounting for the oscilloscope's own noise, a step that is important if the oscilloscope optical plug-in noise is close in size to the noise of the optical signal.

³bit_rate_frequency = 1/UI [Hz; s] e.g. 10 GHz for 10 GBd, i.e. 10 Gb/s PAM2.



2. Procedure, Example Calculation

Measurement procedure: we recommend that the instrument should be compensated (the thermometer gauge in the bottom right of the oscilloscope screen should be green). Please follow the instruction manual if this is not the case.

- **2.1.** Setup the optical test system as per the Figure 2. In case of an multi-mode system remove the polarization rotator. Optical return loss should match the requirement of particular standard. Lower optical return loss will give pessimistic results.
- **2.2.** Set the optical channel that will be used for the measurement (e.g. ch1) for the correct wavelength. See Figure 3.
- **2.3.** Set the optical ORR (optical reference receiver), i.e. set the Vert → Signal Conditioning → Filter for the appropriate bit-rate. For example if testing a 10 Gb/s system, the Filter should be set to an 10Gb/s ORR (optical Reference Receiver), such as 10GBASE-R⁴.
- **2.4.** With the Transmitter (DUT) disconnected, measure the noise of the oscilloscope alone, P_{N_scope} . Use RMSN⁵ measurement.

This is equivalent to the IEEE 802.3 clause 52.9.6.3 (a), although with a small change (the oscilloscope doesn't need to 'zero' the result as it's using the RMSN measurement).

Store the residual noise power, P_{N_scope} (e.g.: around 1.8 μ W in a 10Gb/s system with 80C08C sampling module in the DSA8300 oscilloscope).

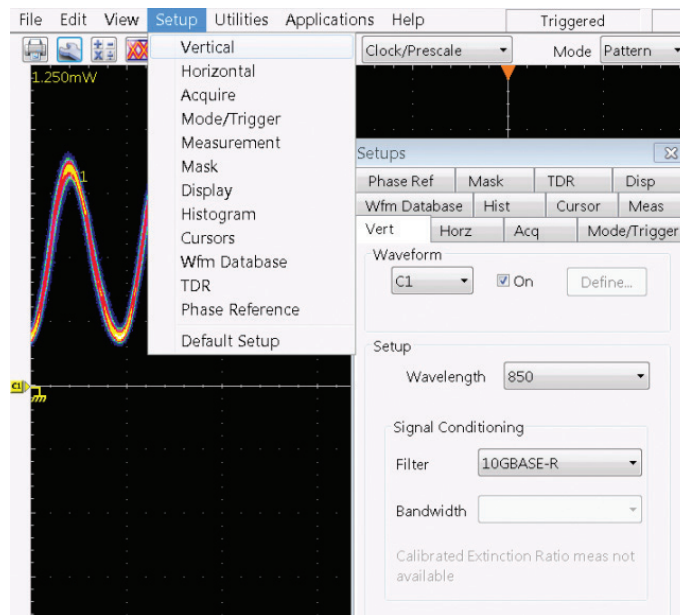
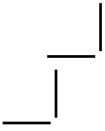


Figure 3. Setting/verifying the Optical Channel's wavelength and Filter selection.

⁴Note that the 10 Gb/s standard requires an ORR (opt. ref. receiver) with about 10 GHz bandwidth. Such ORR is specified for historical reasons at a 1/4 optical power bandwidth at $0.75 * \text{bit_rate_frequency}$, which is the -3 dB of the *electrical* power (after O/E) at $0.75 * \text{bit_rate_frequency}$.

⁵Alternatively it is also fine to use the DSA8300's histogram measurement, in which case read the StdDev readout.



Application Note

- **2.5.** With the DUT transmitting a pattern⁶, connect the transmitter DUT; enable the DSA8300 pattern trigger, lock the pattern on the screen. Find a sequence of several consecutive high level UIs.

Setup measurements as documented by Figure 4:

- **2.6.** Find a flat area in the sequence of several consecutive high UIs; use Setup → Meas to setup a measurement on RMSNoise. Setup two such measurements, measurement 1 and measurement 2.
- **2.7.** Setup → Meas → Region to gate the measurement 1 the logic high level and Setup → Meas → Region to gate the measurement 2 the logic zero level.
- **2.8.** Setup measurement 3 by selecting the OMA measurement and gating with left gate just slightly before the fall of the last pulse before the flat logic zero area.

OMA should be measured on a long sequence of low and high bits.

- **2.9.** Manipulate the optical polarization rotator to maximize the signal noise.
- **2.10.** Calculate RIN_xOMA from Equation 4, E.g.:

$$P_{N_scope} := 1.8\mu\text{W} \quad P_{N_Opt_H_meas} := 12.0\mu\text{W} \quad P_{N_Opt_L_meas} := 3.2\mu\text{W}$$

$$P_{M_Opt_OMA} := 633.3\mu\text{W} \quad BW := 10 \cdot 0.75 \cdot 1.05 \cdot 10^9 [\text{Hz}]$$

$$RIN_{xOMA} := 10 \log \left[\frac{(P_{N_Opt_H_meas} + P_{N_Opt_L_meas})^2}{BW \cdot (P_{M_Opt_OMA})^2} \right]$$

$$RIN_{xOMA} = -131.358 \quad [\text{dB/Hz}]$$

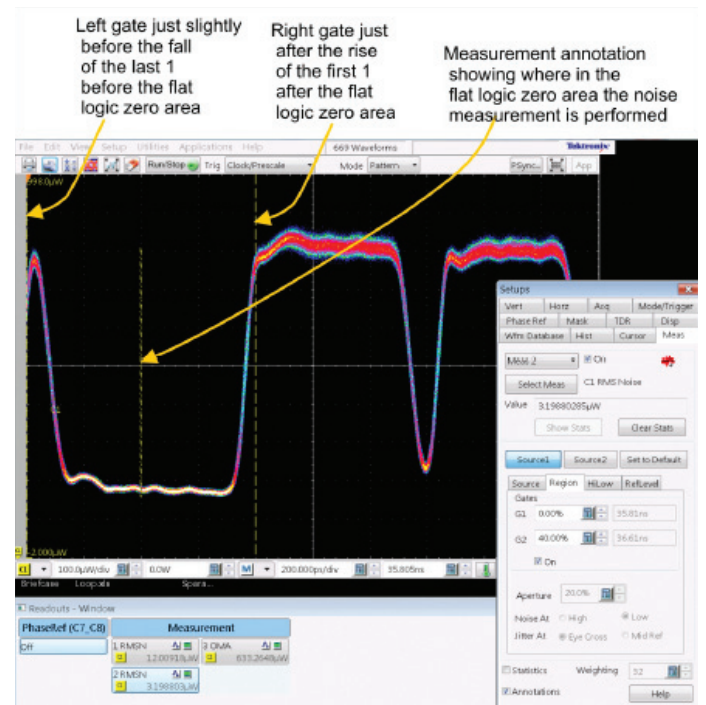
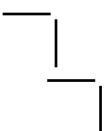


Figure 4. Measuring OMA and noise on a sequence of several zeroes and several ones.

⁶We recommend a PRBS9 pattern.





3. Oscilloscope Noise Contribution

Final improvement discussed is the removal of the oscilloscope's own noise (measured as P_{N_scope} in 2.4):

$$P_{N_Opt_L} := \sqrt{P_{N_Opt_L_meas}^2 - P_{N_scope}^2} \quad \text{Equation 5}$$

$$P_{N_Opt_H} := \sqrt{P_{N_Opt_H_meas}^2 - P_{N_scope}^2}$$

$RINxOMA_2 :=$

$$10 \log \left[\frac{\left(\sqrt{P_{N_Opt_H_meas}^2 - P_{N_scope}^2} + \sqrt{P_{N_Opt_L_meas}^2 - P_{N_scope}^2} \right)^2}{BW \cdot (P_{M_Opt_OMA})^2} \right]$$

[dB/Hz]

The Equation 5 is approximately valid if: $P_{N_Opt_L} > P_{N_scope}$ and $P_{N_Opt_H} > P_{N_scope}$, i.e. the DUT's own noise level is larger than the oscilloscope's own noise level. If this is not the case the equation theoretically still holds but practically becomes problematic – e.g. unstable – the more the inequalities above are violated, the more unstable the result will be. In the future a more precise measure for validity of the instrument noise de-embedding (Equation 5) might be developed.

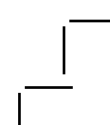
4. Conclusion

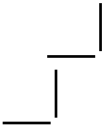
A brief discussion of measurement of RIN (Equation 1) and RINxOMA (Equation 5; or less accurate but simpler Equation 4) is given. Also given in "Section 2: Procedure" is an example procedure to measurement of RINxOMA with a DSA8300 Sampling oscilloscope.

5. Bibliography

[1] IEEE Std 802.3™; in particular the work in the IEEE 802.3ae™, section 52.9.6.*; and equation (52-1);

[2]"RIN Comment on FC-PI", <http://www.t11.org/ftp/t11/pub/fc/pi/01-456v0.pdf>





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