Technical Note

Improving Optical Transceiver
Extinction Ratio Measurement
Accuracy By Using Reference
Receiver Correction Factors

Introduction

Extinction ratio is an important measurement for characterizing the performance of optical transmitters. As design/test margins get tighter, the challenges of making accurate and repeatable extinction ratio measurements become more apparent. In addition, the variability of extinction ratio measurements made with different reference receivers has become an industry concern. This paper discusses the causes of some of the measurement variability and suggests methods for minimizing uncertainties caused by non-ideal performance of standard reference receivers.

Extinction Ratio (ER) Definition

A brief review of the definition of extinction ratio is included here for reference.

Extinction ratio, when used to describe the performance of an optical transmitter used in digital communications, is simply the ratio of the energy (power) used to transmit a logic level '1', to the energy used to transmit a logic level '0'. Most standards and typical applications define the '1' and '0' power levels as the mean of the histogram in the center 20% of the eye (0.4 UI to 0.6UI). For a graphical description, the eye-diagram is commonly used as shown in Figure 1.
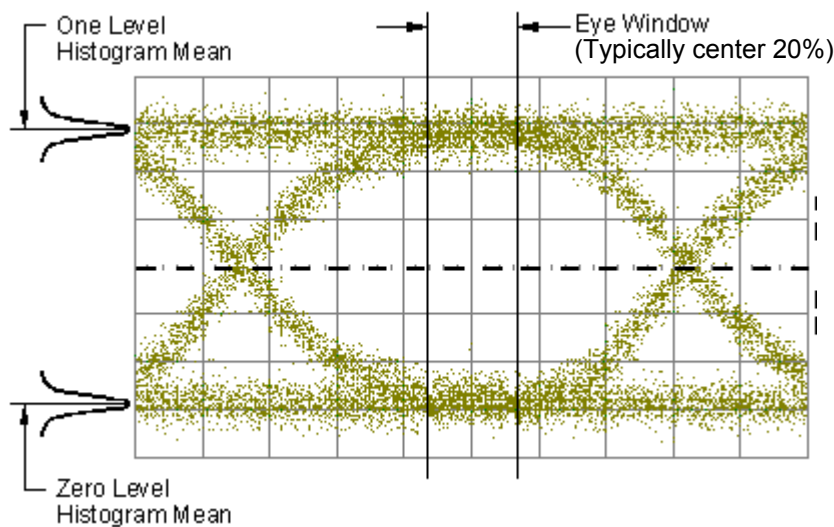

Figure 1. Definition of extinction ratio

Extinction ratio can be defined as a linear ratio, in decibels, or as a percentage:

ER linear = '1' power level / '0' power level

ER (dB) = $10 \log_{10}$(ER linear)

ER (%) = 100 X '0' power level/'1' power level

Limitations of Reference Receivers

When an instrument measures an input signal the displayed information is the combined result of the input signal and the effect of the instrument on that signal. Here we are specifically referring to discussing the effect that a reference receiver and optical oscilloscope, the measurement system, will have on the measured extinction ratio of optical transmitters.

It is important to note that all band-limited systems modify the characteristics of the input signal in some way. The observed signal on the optical oscilloscope is actually the convolution of the input signal with the impulse response of the measurement system. That is,

Observed Signal in time domain: $G(t) = data(t)**I(t)$
Observed Signal in frequency domain: $G(\omega) = FFT(data(t))*H(\omega)$

where, data(t) is the input signal and $H(\omega)$ and I(t) are defined to be the measurement system's frequency domain transfer function and the time domain impulse responses, respectively. The response of the reference receiver and optical oscilloscope measurement system typically includes contributions from the O/E converter, cables, switches, filters, amplifier and the sampling circuitry.

The key standards for optical transmitter testing typically specify the measurement receiver should have a Fourth-Order Bessel-Thompson response with a corner frequency (f_c) of _ of the bit rate. The primary attraction of the Bessel-Thompson impulse response is that it provides a "clean" time domain response. "Clean" is often perceived as being approximately critically damped and having no inter-symbol interference (ISI) or pattern dependencies. The _ bit rate Bessel-Thompson response significantly band-limits the input signal, but in such a way that has been deemed attractive by many standards organizations.

The standards also designate a range or window around the ideal Fourth-Order Bessel-Thompson response within which the measurement receiver response may vary and still be compliant. Therefore, an infinite number of responses exist which can be contained within the window and thus be compliant.

Different compliant frequency responses may have significantly different shapes and may therefore produce different eyes. If it is assumed that an ideal Fourth-Order Bessel-Thompson response would give the "correct" eye diagram and thus the "correct" answer for extinction ratio, any deviation from this response may result in a non-ideal eye and an error in the extinction ratio measurement.

Causes of Non-Ideal Reference Receiver Frequency Response
For convenience, the frequency response of a reference receiver can be considered as composed of a DC component and an AC component, both of which have to be ideal in order to produce an ideal Fourth-Order Bessel-Thompson response. Using this approach, we can look at the effects the DC response and the AC response have on the eye independently.

DC deviation in $H(\omega)$ will cause a vertical shift in the eye diagram which will directly impact extinction ratio. In Figure 2 the two eyes have exactly the same shape and modulation power, but very different extinction ratios ($ER_A = 10$, $ER_B = 4$).
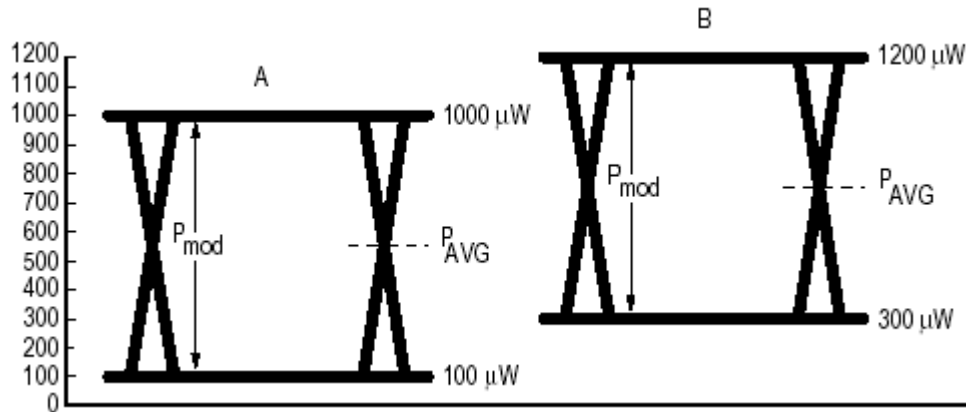
Figure 2. Effect of DC deviation on extinction ratio

The primary physical elements that impose DC deviations in $H(\omega)$ are semi-rigid cabling and microwave switches which introduce monotonically increasing attenuation of the frequency components. The non-DC components of the measured signal are attenuated more significantly than the Fourth-Order Bessel-Thompson response.

The result, with respect to the Fourth-Order Bessel-Thompson response, is
- an effective increase of DC and
- a low frequency AC effect that tends to collapse the mean one and zero levels toward the center of the eye.

Microwave switches and cabling are typically used to provide filter (data rate) flexibility in a reference receiver. Unfortunately, they also provide this other, non-desired effect, which is typically quite repeatable from module to module if the same switches, filters and cables are used.

AC deviation from ideal in $H(\omega)$ will tend to change the shape of the eye which can also impact extinction ratio, especially if overshoot and undershoot are added. In Figure 3 the two eyes have basically the same DC characteristics, but the overshoot on B results in a higher extinction ratio, as the mean of the '1' level histogram will be pulled up by the overshoot, and the mean of the '0' level histogram will be pulled down by the undershoot. In this manner, extinction ratio is especially sensitive to overshoot and ringing.
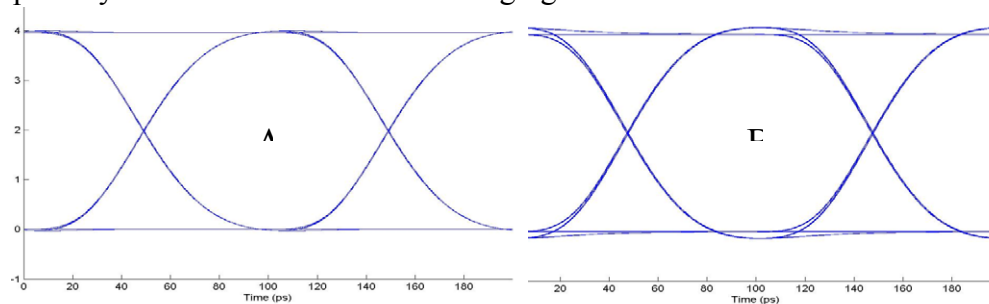

Figure 3. Effect of overshoot on extinction ratio

The typical elements that impose AC deviations are the sampler, the filter shape, and the amplifier that is used in some reference receivers to improve measurement sensitivity. Unfortunately, these elements often introduce additional undesirable artifacts in the frequency and impulse responses. These artifacts tend to be less consistent from module to module than the effects of cabling and microwave switches mentioned above that impact the DC response.

It is the overall shape of the reference receiver frequency response, $H(\omega)$, that dictates if overshoot and ringing will be present in the eye. Note that ripple in the frequency response, usually due to filter mismatch, will typically cause a broadening of the '1' and '0' levels, but will not significantly impact the extinction ratio.

Compensating for Non-Ideal Reference Receiver Frequency Response
To compensate for the effects of non-ideal frequency response, an ER correction factor (positive or negative) can be determined that will be added to the ER value measured by the measurement system with non-ideal frequency response. The challenge then is determining the ER Correction Factor, which is complicated by the fact that no calibration standards for ER exist. However, several methods can be used to determine the correction factor.

Simulation-
Simulations can be done to estimate the effects on Extinction Ratio measurements of specific non-ideal response characteristics. One method to accomplish this is to:
1. Measure the impulse response of the measurement system in question.
2. Convolve the impulse response with an "ideal" (infinite extinction ratio) PRBS7 sequence with 15 ps rise and fall times at the appropriate data rate. (The input signal.)
3. Estimate the extinction ratio of the resulting output signal and compare that to the extinction ratio of a measurement system with an ideal Fourth-Order Bessel-Thompson response. The difference is the correction factor. Note that expressing ER as a percentage makes it easy to compare results from system to system.
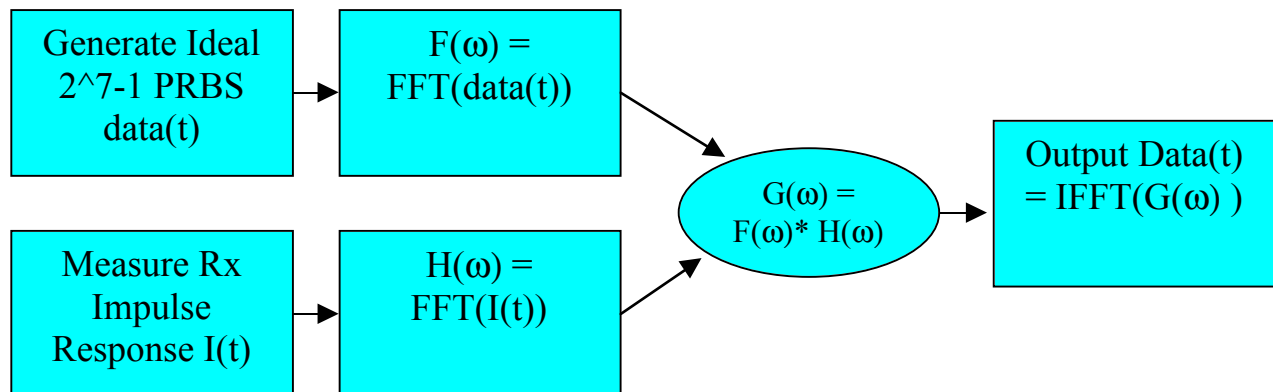

Figure 4. Simulation Process

As an example, the above simulation was performed using the simulated impulse response of an ideal Fourth-Order Bessel-Thompson filter with a 7.5 GHz corner frequency. Looking at the output waveform in figure 5, extinction ratio of the output of the ideal reference receiver stimulated with an ideal PRBS7 waveform is estimated as 0%.
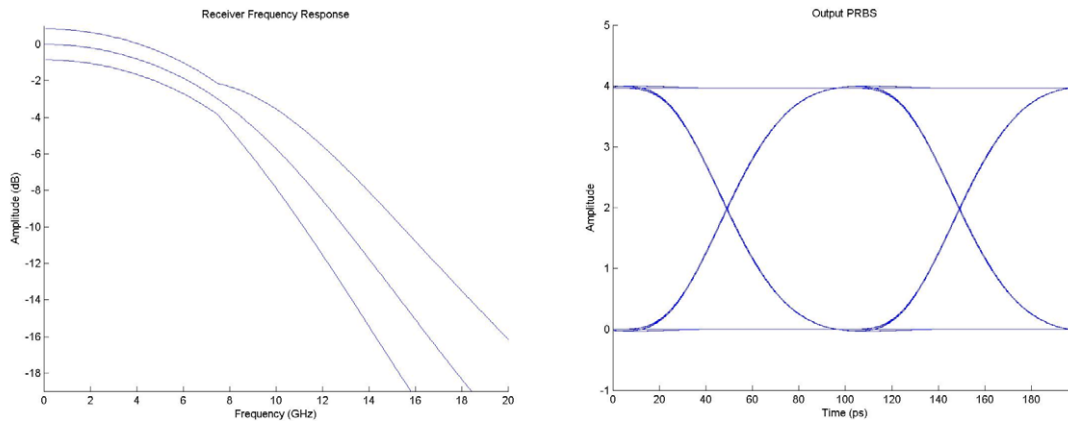
Figure 5. Simulation of ideal Fourth-Order Bessel-Thompson receiver – OC192

As another example, the simulation was performed using the actual measured impulse response of an Agilent reference receiver. Looking at the output waveform in figure 6, the ER is approximately 1.43%. Since the simulation of the ideal Fourth-Order Bessel-Thompson filter resulted in a 0% ER with the same stimulus, the correction factor for this reference receiver is negative 1.43% (1.43% should be SUBTRACTED from the measured ER, expressed in %), indicating the DUT actually has a slightly better extinction ration than reported by the measurement system.
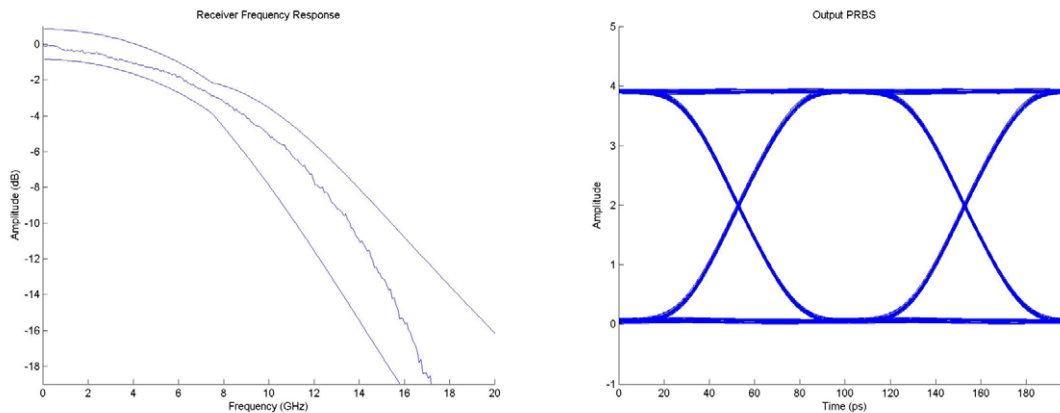

Figure 6. Simulation of an actual Agilent reference receiver – OC192

Direct Measurement-
Measuring a transmitter with a very high (ideally infinite) extinction ratio enables a direct measurement of the extinction ratio correction factor for a particular measurement system. Although a transmitter with infinite ER doesn't exist, building a test transmitter using back-to-back Mach-Zhender modulators can closely approximate one.

Such a transmitter was built at Agilent with the actual ER value verified using an Agilent 86119A Optical Sampling Oscilloscope with 800GHz of bandwidth that is immune to the effects discussed in this paper.

Measuring the same transmitter with the measurement system of interest produces an extinction ratio measurement somewhat different than that measured with the 86119A. This difference is the correction factor.

ER correction factors determined using this method very closely correlated to those determined using the simulation method.

A paper titled 'Accurate Optical Extinction Ratio Measurements' by Per Andersson, published in 'IEEE Photonics Technology Letters Vol 6. No 11. November 1994' also deals with this topic.

Summary and Conclusions
Extinction ratio, especially at large values (if expressed in dB, small if expressed as %), continues to be a challenging measurement to make, and measurement repeatability from system to system remains an industry concern.

Physical limitations, such as the performance of cables, switches, amplifiers, filters, and samplers used in the measurement system, contribute to the measurement uncertainty.

By using the methods described in this paper to determine extinction ratio correction factors, the user can both decrease the uncertainty in the measurement and improve repeatability from system to system. Based on the causes of the ER inaccuracies the correction factor is compensating for (DC effects, AC effects or both), a correction factor may be applicable to a specific measurement system or a family of measurement systems.

Our experience in determining correction factors has shown they are dependent on both bit rate and pattern type/frequency content, with the most significant variable being bit rate (OC-48 vs. OC-192, etc.). For the most accurate extinction ratio measurement results, the correction factor for any particular measurement system should be determined for the specific bit rate and pattern of interest.

Agilent has determined extinction ratio correction factors for their most popular reference receivers and these are available from your local Agilent Field Engineer.

Agilent Technologies