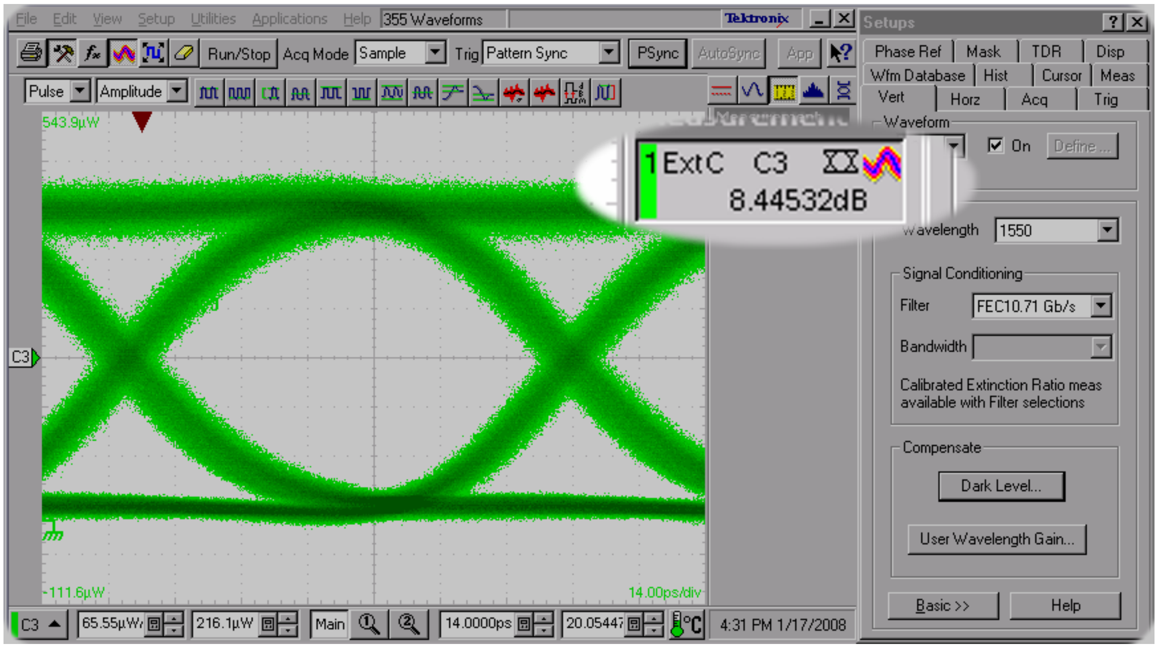
Extinction Ratio (ER) Calibrated

Precise Extinction Ratio measurement for optical 10 Gb/s signaling in Ethernet and SONET/SDH



Introduction

One of the most important measurements in optical NRZ signaling, Extinction Ratio (ER) was often considered an unstable measurement. This has been corrected with the arrival of “ER Calibrated” measurement available on Tektronix DSA8200 Series sampling oscilloscopes. This white paper explains some of the benefits of highly accurate ER measurements in both 10 GbE (Ethernet), with its relatively low ER requirement, and in SONET/SDH, and the methodology that supports consistent, accurate ER result.

Background information on Extinction Ratio

Commonly called out in optical telecommunication standards, ER is a measure of modulation depth, and can be used for example as a figure of merit of an optical modulator. The most common definition is the ratio of power between the logic One and logic Zero. See Figure 1.

Simple Ratio **ER = E_1 / E_0**
or
Percentage **ER = $100 (E_0 / E_1)$**
or
dB **ER = $10 (\log (E_1 / E_0))$**

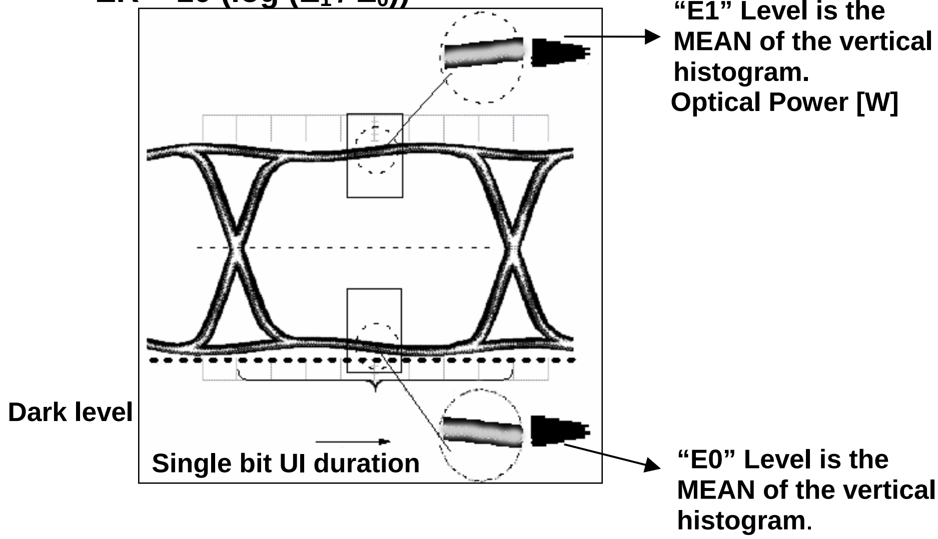


Figure 1. Definition of Extinction Ratio measurement.

There are two reasons why the E0, low-level power of the optical signal, introduces a difficulty in optical measurements. First, the low level power measurement is greatly effected by DC offset of the measurement device (optical oscilloscope). This is effect is corrected by DC Compensation. Second, the AC response of the optical oscilloscope introduces ringing and dribble-up or dribble-down, also impacting the E0 value, and making the result of the fraction E1/E0 unstable. These AC effects were only recently handled by Tektronix DSA8200 Series sampling oscilloscopes.

Importance of accurate Extinction ratio in SONET/SDH

In systems where transmitter is described in terms of Average Optical Power (AOP) and ER, ER expresses how much power is transmitted effectively – that is, how much is used by the modulation. This can then be expressed in terms of loss, or in terms of BER Penalty. See Figure 2. This is the case in SONET/SDH, and in that application the ER is mandated at relatively high level around 10 dB, and it is considered a non-trivial task to comfortably achieve such level – especially before the advent of ER Calibrated feature. The value of having an accurate, oscilloscope-to-oscilloscope guaranteed ER result is obvious in this application.

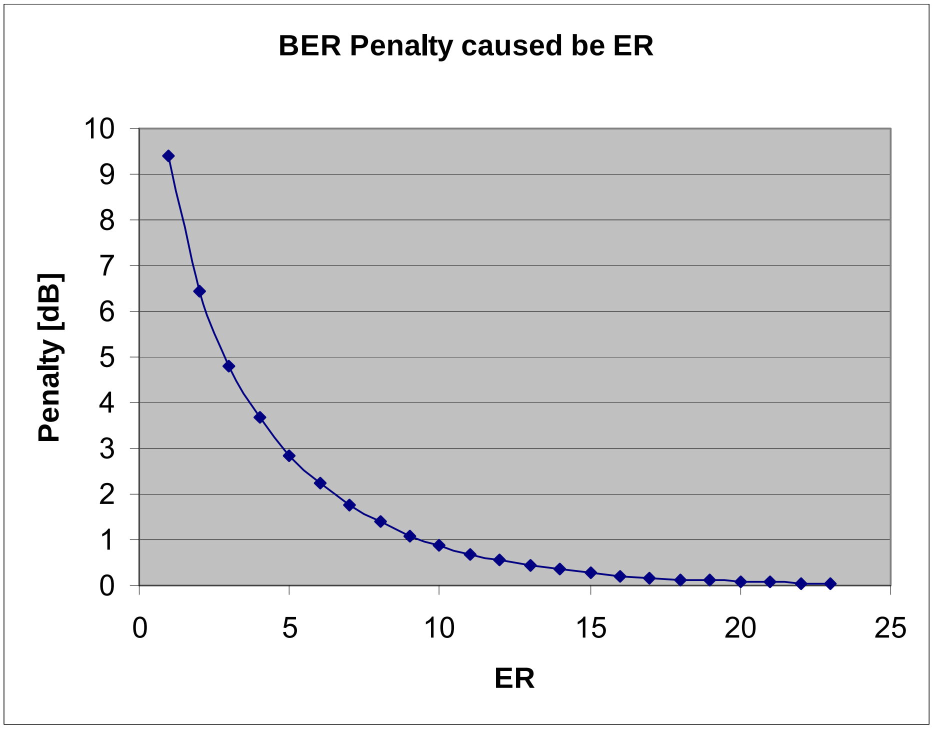


Figure 2. BER Penalty due to ER

Importance of accurate Extinction ratio in 10 Gb/s Ethernet

Unlike in SONET/SDH standards, the 10 Gb/s Ethernet standards (10 GbE), such as the original 802.3ae 10GBASE-SR, 10GBASE-LR, etc.; the 802.3aq 10GBASE-LRM, and others, define power with OMA (Optical Modulation Amplitude) and ER is only set to an easy to reach 3 or 3.5 dB. This leads to common misconception that in Ethernet ER, and ER accuracy, is not of concern.

While an ER of 3 dB is indeed much easier to achieve than the values used in SONET/SDH, the 10 GbE technology is different than that of SONET/SDH, and the directly modulated vertical cavity surface emission laser (VCSEL) used for 10 GbE exhibits growing amount of relaxation oscillation (ringing) as ER is adjusted upwards.

For this reason it is desirable to keep ER low. Due to accuracy of measurement and end-of-life performance, the optimum value is a dB or two above the 3.0 or 3.5 dB prescribed by the standard. Most exacting system vendors require tight specification for the ER value in Ethernet, which is one of the reasons why this is an issue for the module manufacturer. See Figure 3.

This ER result taken for *one* optical module, a module which should be adjusted to the specification of <5.5 dB .. 6 dB> ER. This module, measured with nine different optical oscilloscope modules with the traditional, uncalibrated ER measurement (shown in purple bar graph), evaluates as between 5.4 to 6.2 dB ER.

In other words, due to the variability of the measurement equipment alone, one single module's ER varies more than the tolerance field for the whole product.

The real result, guaranteed by Tektronix to a tight tolerance, is shown by the blue bar graphs on the right; here the same nine optical oscilloscope sampling modules are used, but instead of the raw ER result their “ER Calibrated” result is plotted. So not only were the results in purple widely spread; even their mean is wrong.

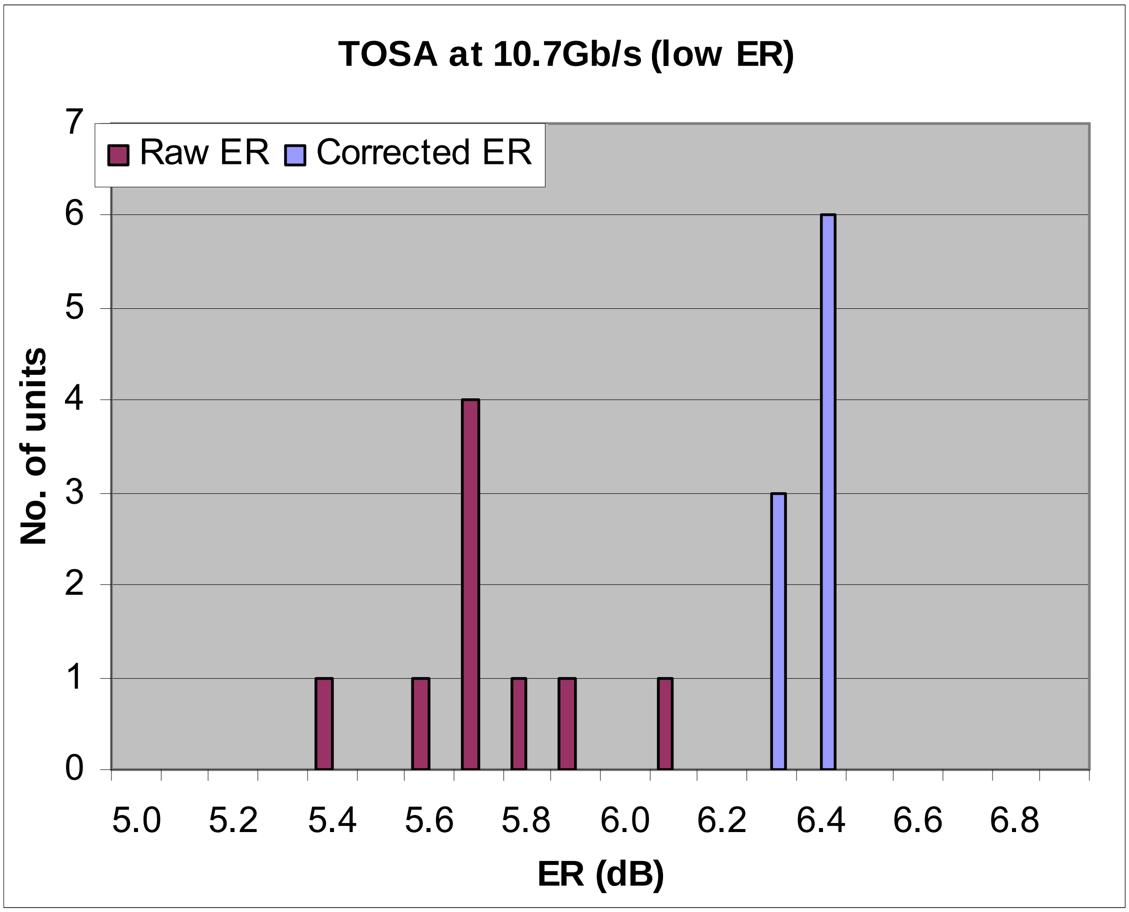


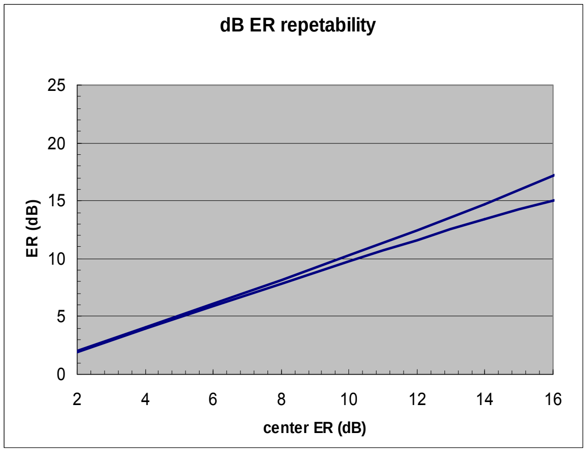
Figure 3. Single optical source measured with multiple measurement devices

Even in case when the targeted ER range is easier, e.g. 5 to 6 dB, it is clear that the manufacturing process will be better controlled if the result is known with the accuracy shown by the blue bars on the right.

Beyond manufacturing, stable and accurate ER result removes problems between the optical module manufacturer and their customer, since whatever results are shipped from manufacturing are then also confirmed by the incoming inspection at the customer.

Achievable Accuracy

Optical oscilloscope module datasheets contain the specifications for guaranteed accuracy. See Figure 4. These plots show typical performance of ER Calibrated.



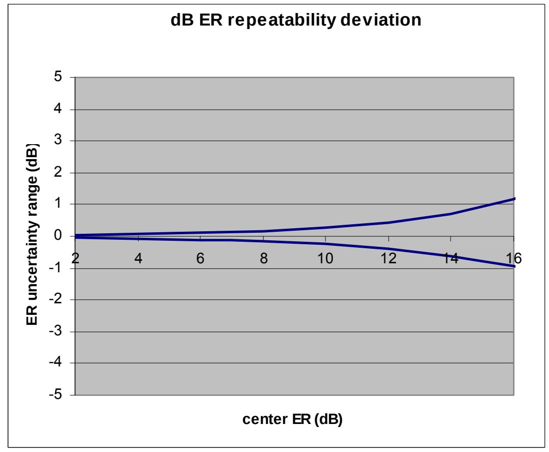


Figure 4. ER Calibrated typical performance

Conditions: Conditions: 50% ± 5 % mark density, PRBS-like distribution of run-lengths, 50 % ± 10 % eye crossing level

Low ER Lasers (ER ≤ 6 dB): signal passes 802.3ae-like mask (scaled horizontally for bit-rate) with 0 margin; 10^5 samples in mask.

High ER Lasers (ER > 6 dB): signal passes OC-192-like mask (scaled horizontally for bit-rate) with 10% margin; 10^5 samples in mask.

Recommended Procedure

The following sequence is recommended as best-practice to obtain the highest level in ER accuracy and repeatability:

Prior to any measurement the module and mainframe has to be fully warmed up (>25 minutes) and full module Compensation has to be performed (see under **Utilities->Compensation**).

Step 1. Under **Setup->Horizontal** set the bit rate to match the input data rate.
Under **Setup->Vertical->Optical** select the applicable filter that matches the signal bit rate.
Under **Utilities->Autoset Properties** select **NRZ Eye**.

Step 2. Under **Setup->Measurements->NRZ->Amplitude** turn on "**Extinction Ratio (dB) - Calibrated**". This measurement appears on the measurement sidebar as "**ExtC**".

Step 3. Apply the optical signal to the module input.

Step 4. Perform **AUTOSET**. The eye diagram should now be centered on screen and cover about 80% of the vertical scale.

Step 5. Disconnect or disable the optical input signal, perform a **DARK LEVEL COMPENSATION** (under **Setup->Vertical->Optical**) to zero out any finite offset in the sampling module.

Step 6. Re-connect or enable the optical signal. Start acquisitions; after several waveforms have been acquired (at least 1) perform **CLEAR DATA**; do not stop the acquisitions.

Step 7. Continue acquiring at least 1M samples into the waveform database before recording the ER Calibrated result.

Technical Notes

Triggering

It is critical that the triggering path and the trigger signal used during the Dark Level calibration remains the same as during the measurement.

So for example if Clock Recovery is used then the triggering should remain in Clock Recovery (without input signal the circuit will free-run, which is appropriate). If 80A06 Pattern sync is used then the 80A06 should remain programmed as is, and the clock signal to the 80A06 should be the same during the Dark Level compensation as it is during the normal operation.

Speed of Execution

If speed of execution is very important and the repetitive execution of Dark Level Compensation presents a measurement throughput problem then step 5. can be modified as follows: once an **Autoset** and **DARK LEVEL COMPENSATION** are done, save the value of Vertical Offset (**Setup->Vertical->Offset**) of the measuring channel. The ER Calibrated measurement for next DUT can avoid Dark Level Compensation if the following is fulfilled:

The oscilloscope is running with the same triggering, horizontal, etc.;
Also: the exactly same Vertical Offset is used; and the signal is close in size to a signal that went through Autoset (signal fully fits onto the screen, has the proper time/div, and is larger than 3 divisions). In other words, the next DUT doesn't need to be Autoset if its amplitude is similar to the 1st DUT. (Autoset would change the Vertical Offset).

Dark error, as measured by Mean (Pulse) measurement while no signal is connected, remains very small. Precise definition of 'very small' depends on ER Calibrated measurement accuracy required but e.g. for 80C11 (as well as for the 80C09, 80C04, 80C02) this is below 1 μW while the signal is 500 μW or more; or a half of these amplitudes if 80C08 or 80C12[1] are used.

Should any of the conditions above become impractical, the full procedure needs to be run. For example, if the new DUT generates a signal so large that it will not fit onto the screen without a change to Vertical Offset, then an Autoset followed by a new Dark Level Compensation needs to be done, as per the recommended procedure above.

When measuring the residual offset Dark Level position do throw away the first waveform after Acquisition was turned ON after the **DARK LEVEL COMPENSATION**. Leaving the acquisitions running and simply initiating a **CLEAR DATA** when the **DARK LEVEL COMPENSATION** is done is a good way to do that.

[1] Some limitations and restrictions apply when using ER Calibrated on 80C12. Contact your Tektronix representative for more information.

Troubleshooting

If the ER reports only “???”, several causes are possible. Troubleshoot in the order listed below.

Step 1. Is the correct oscilloscope firmware installed?

The oscilloscope FW version should be 5.0.0.5 or higher.
(Pull down **Utilities->System Properties** for FW version).

Step 2. Is the optical module optioned for ER Calibrated (option 01)?

Pull down **Setup->Vertical**. Make sure the top-left readout “Waveform” shows your selected channel. See Figure 5. Compare the area circled in red.

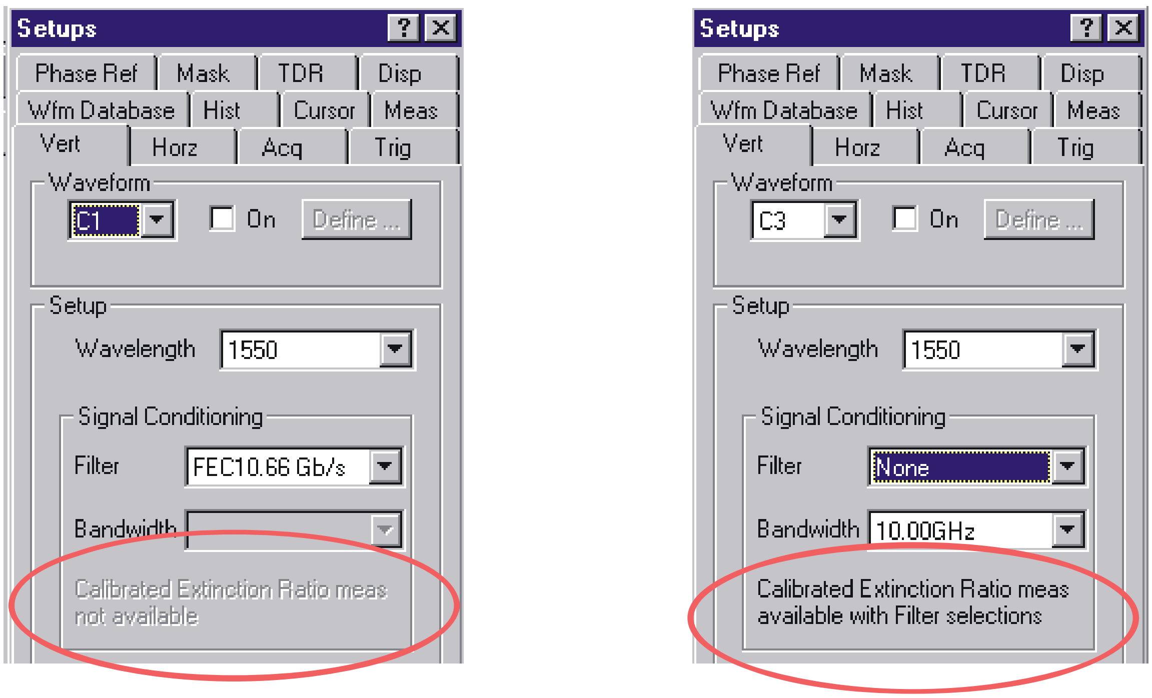


Figure 5. ER Calibrated *Not installed* (left) and *Installed* (right)

The same operation can be achieved programmatically by executing command
ERCAL ; example:
ch3:ercal?
will return
CH3:ERCAL 1
if the option is enabled.

Step 3. Is the ORR (Optical Reference Receiver) filter enabled?

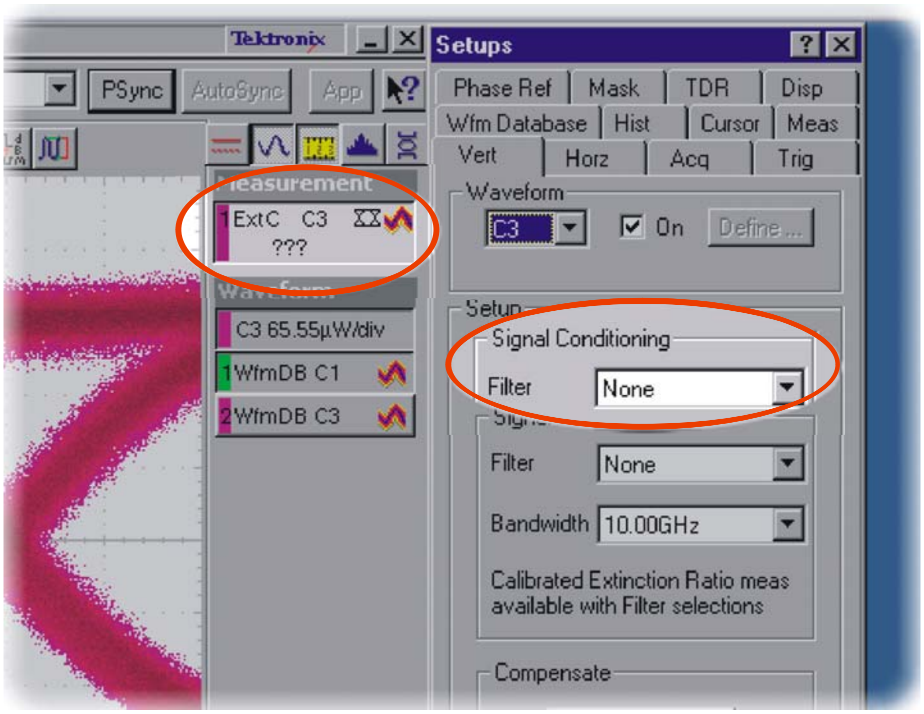


Figure 6. ER Calibrated will report “???” if an ORR filter is not selected

Step 4. Was Compensation run? Was Dark Level run? Is the temperature stable?

System compensation and Dark Level calibration must be performed; without them, the dark offset might make the result so wrong that the measurement finds a physically impossible (“dark light”) result – oscilloscope firmware then reports “???”. Following the steps above, you can trust the ER Calibrated result ***even*** if it’s higher than what you expect based on past results.

<u>Bibliography</u>

Jeffrey A. Jargon[1], Xiaoxia Wu[2], Paul D. Hale[1], Klaus M. Engenhardt[3], and Alan E. Willner[2], "Transmitter for Calibrating Extinction Ratio Measurements of Optical Receivers," in *Optical Fiber Communication Conference*, OSA Technical Digest (CD) (Optical Society of America, 2009), paper JWA24.

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03/2010 Internal/WWW 85W-25115-1