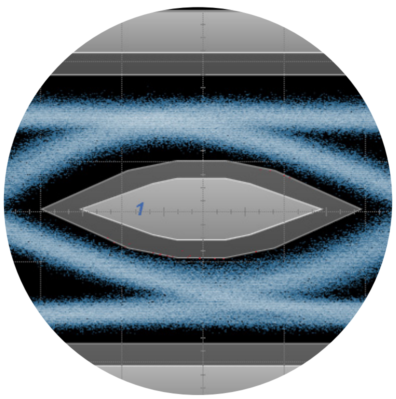
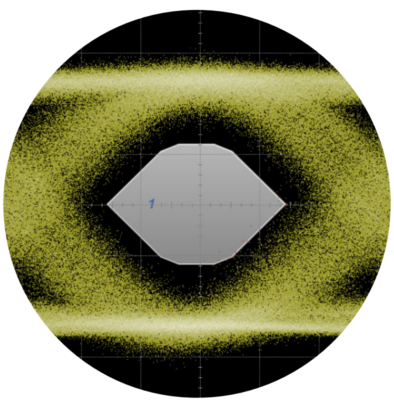
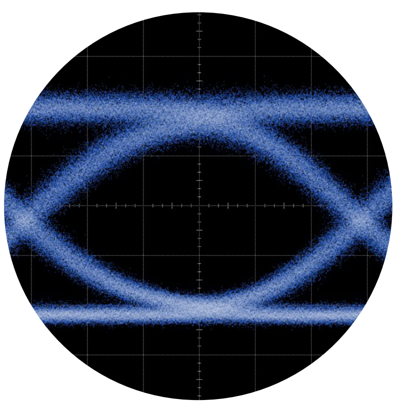
Techniques for Higher Accuracy Optical Measurements

Application Note







Introduction

The worldwide demand for higher digital data throughput continues to rapidly increase, driven by video on demand, more internet services and expanded enterprise-to-enterprise communications. As a result, service providers are challenged to provide greater bandwidth but often within the existing optical infrastructure, thus encouraging development of higher data rates and multiplexing techniques. Where 10Gb/s signals were once viewed as leading-edge and challenging for designers and manufacturers, now R&D engineers are faced with developing technology at 100 Gb/s, which is often being implemented in 4 lanes of 25 Gb/s each in single-mode fiber.

Fibre Channel is one of the leading technologies that push multimode fiber to higher rates. The photo detectors used for multimode are larger and have higher capacitance, which limits the usable upper bandwidths. This drives the continuing need for reference receivers that assure the transceivers provide the cleanest eye possible when operating over longer links with slimmer margins.

As the data rates have increased, the system margins have become more difficult to obtain, thus requiring designers to be more creative and to seek ways to characterize new and novel designs for these emerging technologies. Test equipment must be available in the early phases of development and be enabled with more sophisticated measurement techniques and higher accuracy.

Once products are released for manufacturing, pressure to improve manufacturing costs and yields will increase in today's globally competitive communications markets. Manufacturers seek test solutions that are accurate, are fast and easy-to-use, and provide results that are consistent with those achieved during the design and validation phases. Manufacturing engineers have little time in their busy factories to troubleshoot differences in measurement techniques, particularly when those techniques affect yields.

In order to address both the issues above, Agilent has introduced System Impulse Response Correction (SIRC) which provides the following advantages to design and manufacturing engineers:

- Measure emerging rates early in the development cycle
- Have more accurate results for key compliance standard metrics
- Have more consistent results between design, validation and manufacturing, and between different measurement set-ups
- Quick set-up and intuitive use

Agilent Technologies

Requirements of Communications Standards

Every communications standard has an extensive range of measurements that must be validated and met for a product that is commercially used. Fortunately as rates increase, the types of measurements and requirements remain largely the same while designers and manufacturers find the specific test limits more challenging to achieve. Unfortunately for emerging rates, the standards committees have not yet finalized the standards when designers are in the early development phases, thus leaving designers trying to anticipate data rates and what test limits to achieve. For example, no standards yet exist for Fibre Channel greater than 16X. As a result, test equipment has not been widely available for new standards and rates during early development.

The high volume and lower cost of multimode transceivers has encouraged their use at higher data rates. For example, Fibre Channel has doubled their rate for each successive standard with the recent exception of 14 Gb/s for 16X Fibre Channel. Multimode transceivers require larger photo detectors, which increase the capacitance and make higher bandwidths very challenging.

Key Measurements and Challenges

The communications standards often have more than one hundred pages to describe the tests for just the physical layer, and the corresponding compliance test documents can also be quite extensive. This section describes some of the more challenging tests and potential limitations of test equipment. Solutions for these limitations are offered in the following section.

Eye Diagrams

One of the best indicators of the robustness of an optical transmitter is the quality of the eye. Designers often visually assess the measured eye compared to what was achieved on earlier designs, which quickly becomes challenging as rates double in each generation. Measurements such as rise and fall times and eye opening add quantitative metrics to hone the performance as shown in Figure 1.

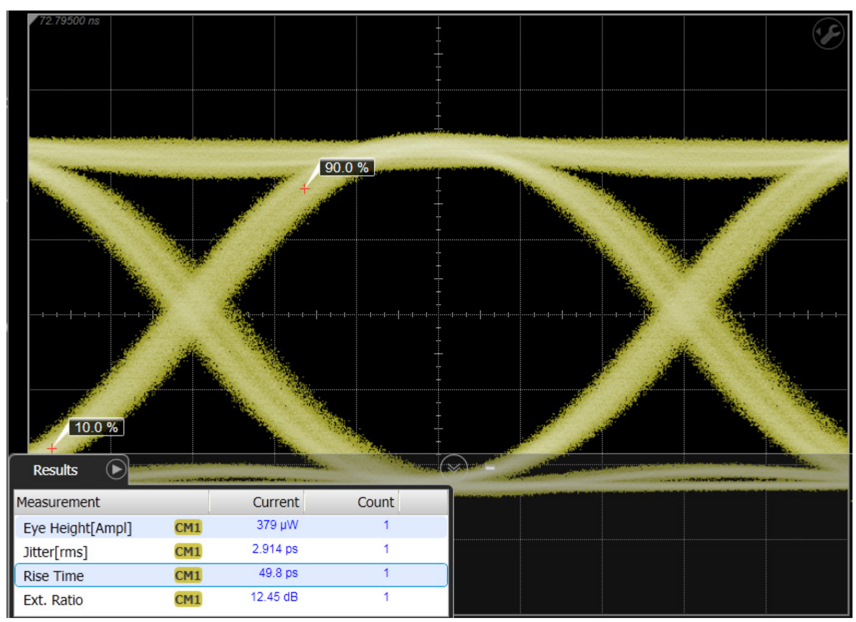


Figure 1. Typical eye diagram and key metrics

Mask Margins

To assure interchangeability of transceivers within a communications system, mask margins are used to quantify the openness of the eye. Masks can be shaped as rectangles, flattened ovals or other shapes with a common example in Figure 2. When the signal has high overshoot, slow rise times, or excessive jitter, the ability of the transceiver to meet the mask is impaired.

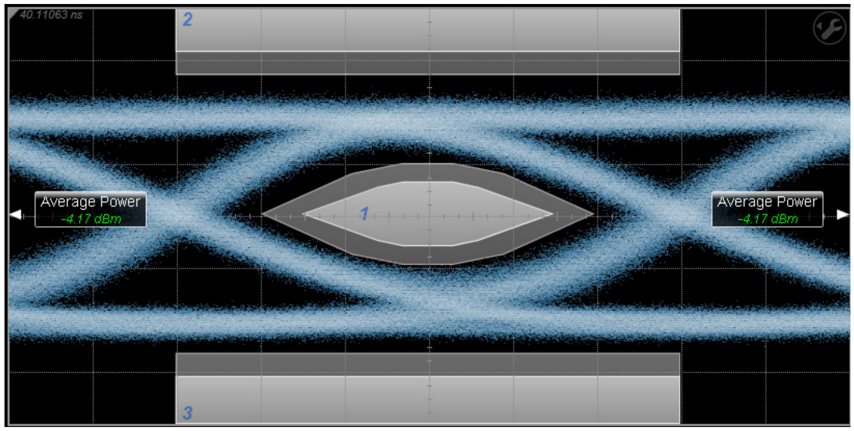


Figure 2. Eye mask from 16X Fibre Channel in light grey, with mask margin in dark grey

Mask margin often provides a competitive advantage to manufacturers of optical transceivers because improved mask margins provide better system margins and more reliable networks. However, the manufacturer must assure the measured margins are accurate and are consistent with what is measured by the end users. Variations in reference receivers can create differences in measured margins therefore driving the need for consistent test system receivers at every rate.

To improve consistency in mask margin results, many standards now include Hit Ratio which is the ratio between mask hits and samples within one unit interval. Mask tests that do not use Hit Ratio consider any hit on the mask to be a failure. That one hit may be statistically insignificant, but will still cause the device under test to fail or at least cause issues with mask margin repeatability or accuracy. Hit Ratio considers the full set of samples taken, then calculates the margin by using the designated Hit Ratio. This technique results in more consistent and accurate results when measuring mask margins.

Inter-symbol Interference

Inter-symbol interference (ISI), consisting of both time jitter or amplitude interference, is often created by lossy electrical transmission lines within the transceiver. ISI can close the eye and impact mask margin as shown in Figure 3.

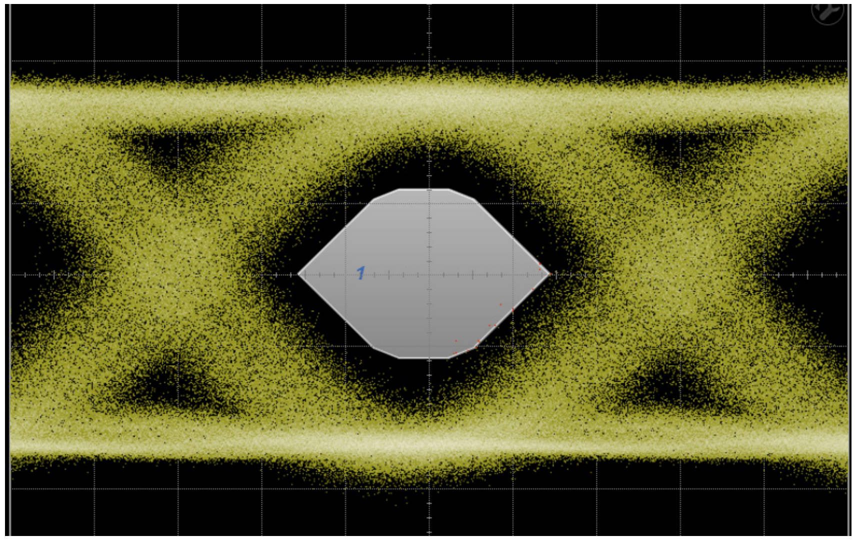


Figure 3. Example of ISI at 25.78 Gb/s

Extinction Ratio

In addition to mask margin, extinction ratio is a key metric of eye quality, which provides the relationship between the one level and zero level in the eye. Extinction ratio is most often specified over the Eye Window between the 40% and 60% interval of the eye as shown in Figure 4. Overshoot or incorrect rise times impact the measured value of extinction ratio, therefore driving the need for a common means of measuring the eye which is accomplished with a reference receiver containing a compliance filter.

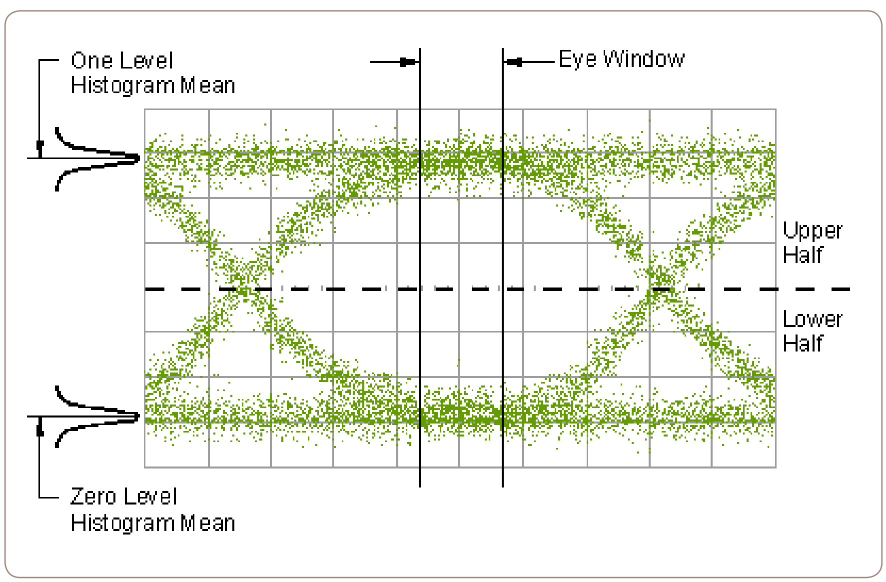


Figure 4. Typical eye showing eye window and histograms for extinction ratio

Compliance Filters

Compliance standards are specific regarding the conditions that govern measurement of each parameter to provide consistency between transceiver manufacturers and between measurement equipment, particularly reference receivers. Reference receivers are available in many different bandwidths and the compliance filters for each rate enable the standardization of eye measurements.

Bandwidth is defined as the half power point for optical signals and the 0.707 point for electrical signals. The optical bandwidth of plug-in modules is based on optical power, which is designated as dBo. The response of the compliance filters are defined using terms for electrical bandwidth since the filtering is done after the optical-electrical converter and is in voltage. This is designated as dBe.

The compliance filter almost always has a fourth-order Bessel-Thomson response while the cut-off frequency is typically at three-quarters of the bit rate. Standards like 8X Fibre Channel have chosen higher reference frequencies while standards utilizing rates around 10 Gb/s have chosen slightly different cut-off frequencies in order to leverage existing test equipment. The reference receiver frequency range is specified from a very low frequency to twice the reference frequency. The two eye diagrams in Figure 5 show the difference between an eye measured without and with the compliance filter. Note that the filtered eye still has some waveform distortions. Further investigation revealed that a compliance filter closer to the ideal Bessel-Thomson response further improved this eye, which is addressed by SIRC as described later in this application note.

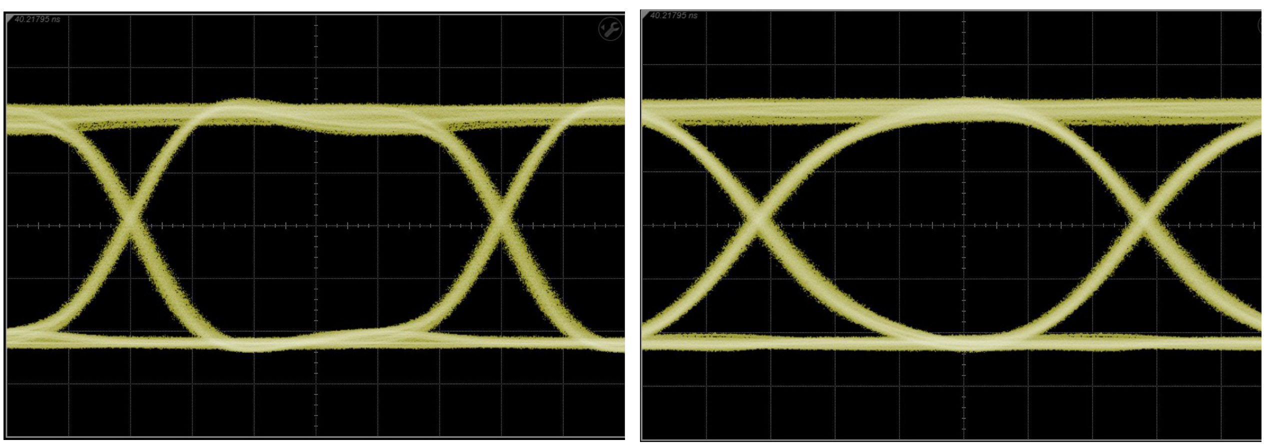


Figure 5. Eye diagram from 6.144 Gb/s signal. The left image is with no compliance filter and shows the raw laser performance, and the right image is with compliance filter

Compliance Filters

Designing and manufacturing a reference receiver with the compliance response very close to the fourth order Bessel-Thomson response is very challenging, primarily driven by the different responses between the optical and electrical sections of the receiver. The standards committees and transceiver designers have worked with reference receiver providers to determine tolerances for the allowable response window on the compliance window, as shown in Figure 6.

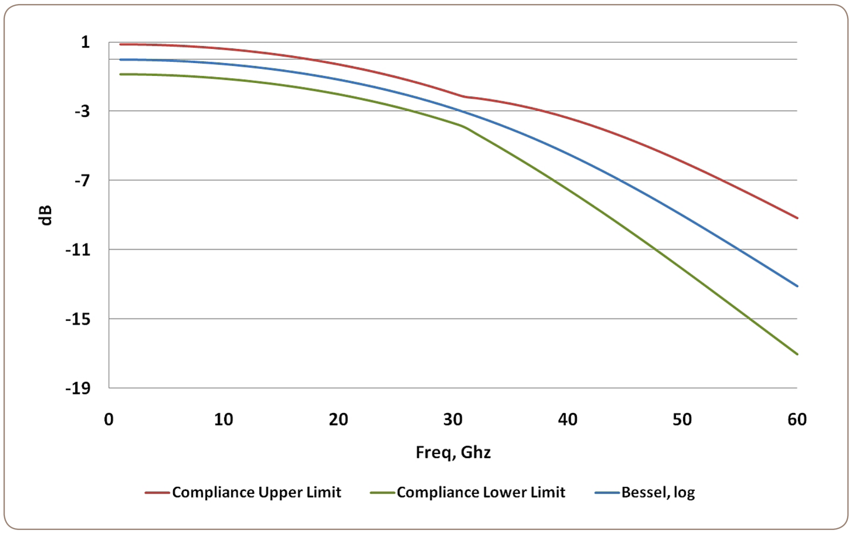
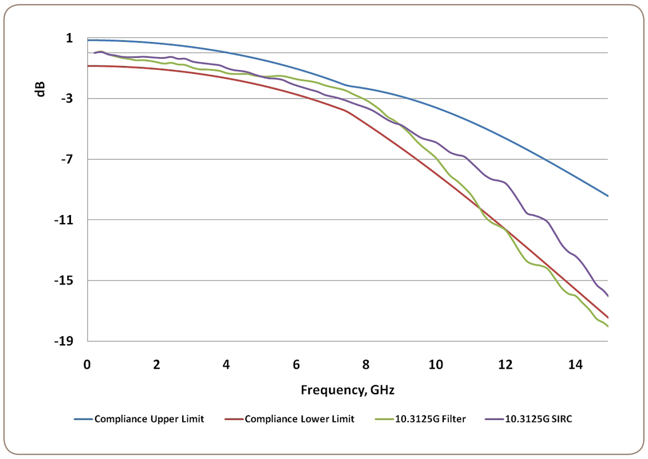


Figure 6. Fourth-order Bessel-Thomson filter response and limits for 39.8 Gb/s

When the compliance filter has a response that exceeds the limits of the compliance window (Figure 7), the measured eye may appear different (Figure 8). The frequency response is still within the specified range of the compliance standard but may result in differences in measured eye parameters and inconsistent values between the designer and manufacturer, or differences when measured on various brands or models of test equipment. Standards committees have considered the impact of frequency responses approaching the limits of the compliance, and allow for adjustment. One example is IEEE Standard 802.3ba-2010 which states: "Compensation may be made for variation of the reference receiver filter response from an ideal fourth-order Bessel-Thomson response."



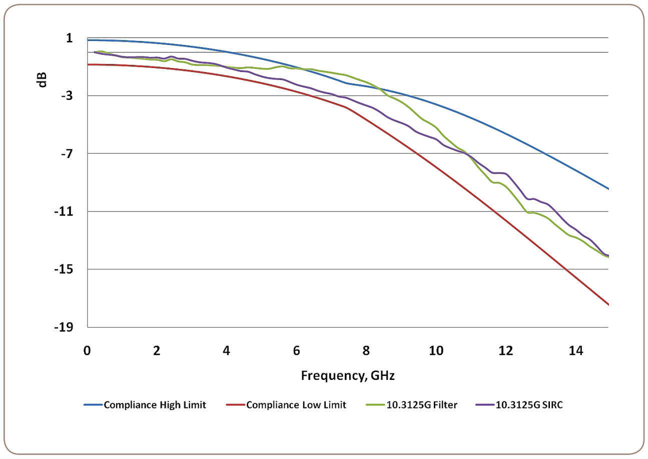


Figure 7. Response of reference receiver filter for 10.3125 Gb/s, intentionally set beyond the low and high limits of the compliance window.

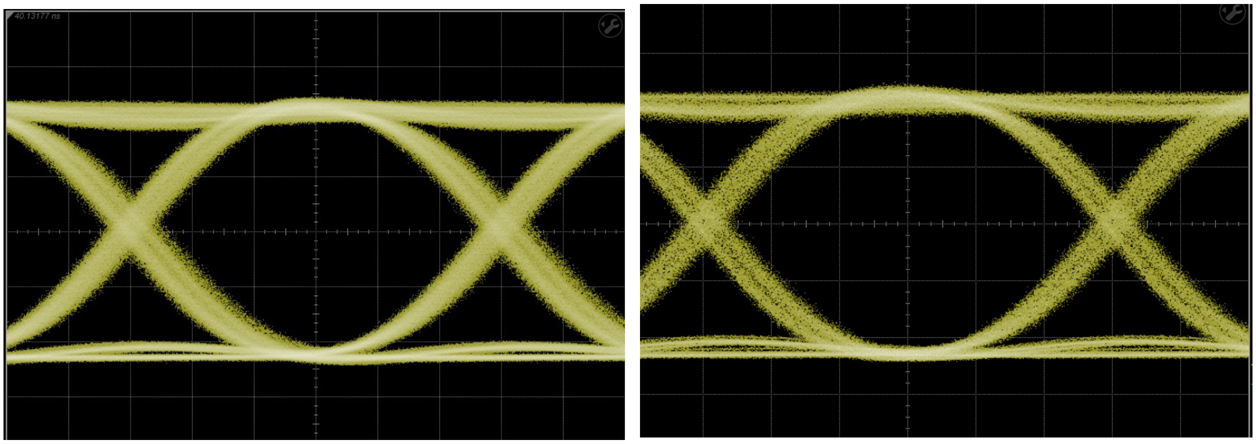


Figure 8. Eye diagrams corresponding to respective low and high limits of the 10.3125 Gb/s filter at the edge of the compliance window.

Reference Receivers

At lower rates, reference receivers typically use passive microwave (L, C, R) filters to create a system frequency response that meets the compliance window. For higher rates (typically 8.5 Gb/s and above) that are still within the optical bandwidth of the optical-to-electrical converter, the bandwidth is adjusted electronically. Designing the filter shape to accommodate the different responses in the optical and electrical paths is very challenging, and results in filter shapes like that shown in Figure 7. Also, engineers may be designing transceivers at rates other than the rates available in standard reference receivers and they still need to characterize their transceiver with the expected compliance filters. One example is Common Public Radio Interface (CPRI) transceivers, which are used on the optical links between the cellular base station and antennas at rates in multiples of 611 Mb/s.

Engineers may also want to characterize rates that are higher than specified for their current test equipment but may not want to pursue capital funding for another reference receiver, including when that rate is not yet specified in available reference receivers. Agilent has created a new test technique entitled System Impulse Response Correction that addresses the challenges of filters with varying responses and the need to measure yet-to-be standardized rates.

System Impulse Response Correction (SIRC)

When measuring higher or non-standard rates, engineers have used a compliance filter at a nearby (often within 10%) rate where measurements don't quite represent the performance of their transceiver. At higher rates, they may use amplification or custom filters that increase the response at the higher frequencies. The downside of this approach is greatly increased noise above the bit rate, which makes more challenging the designer's task of meeting the compliance window. Also, large corrections in the filter may change the phase response thus inadvertently changing the measured eye in undesirable ways.

Agilent has created System Impulse Response Correction (SIRC), an innovative approach that:

- Improves the response of currently specified filters to be much closer to the desired Bessel-Thomson response
- Allows the user to perform measurements at rates other than those already specified within the reference receiver, including those well above and below the typical operating range of the receiver
- Maintains the measurement integrity for the eye quality, mask margin, jitter, amplitude interference, noise and extinction ratio

The SIRC technique makes small adjustments in each region of the compliance window, thus maintaining the measurement integrity and retaining the same overall gain for the filter as when used without SIRC. Figure 9 shows a typical reference receiver impulse response at a standard rate, when using the compliance filter and when using SIRC. The SIRC response is closer to the desired impulse with removal of most of the ripple adjacent to the impulse.

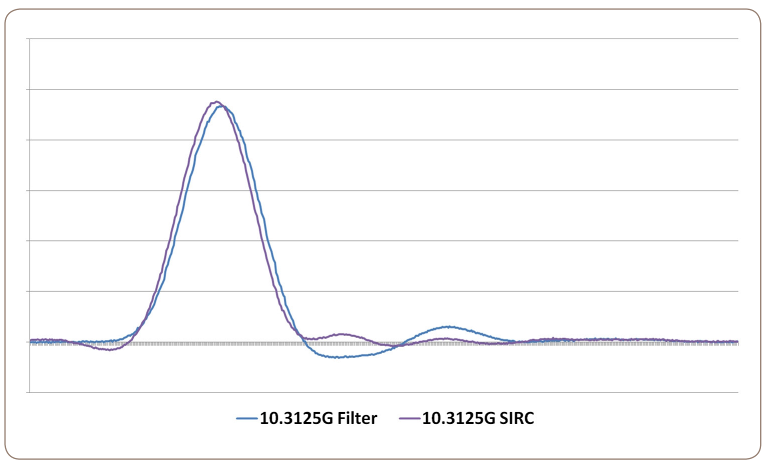


Figure 9. Impulse responses from 86105C without and with SIRC

Figure 10 shows improvement for the compliance filter on the same receiver in the frequency domain as compared to the compliance windows; for this example, the compliance filter was intentionally tuned to the bottom of the compliance window at high frequencies to demonstrate that SIRC adjusts for wide variations. Note the improvement in eye measurements in Figure 11, particularly removal of the small overshoot created by the non-ideal system response. The large ISI was also improved with the use of SIRC.

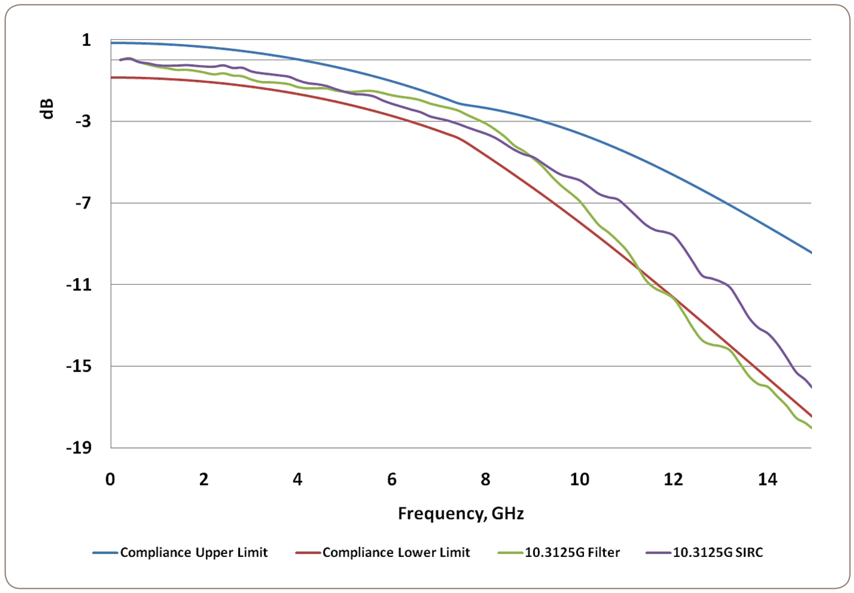


Figure 10. Compliance filter response on 86105C with filter intentionally set at bottom of window and with SIRC

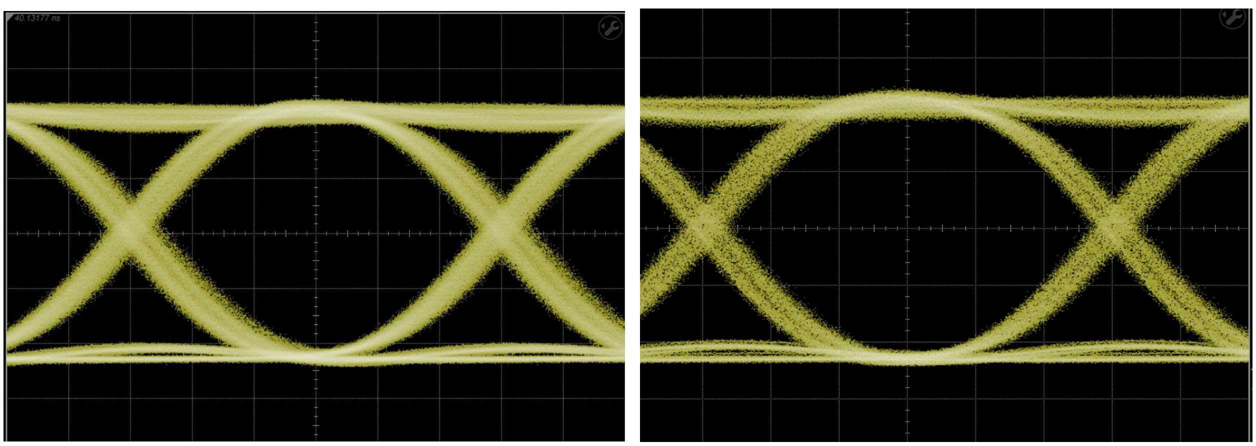


Figure 11. Eye diagram on 86105C at 10.3125 Gb/s, without and with SIRC

The SIRC capability is available in all optical modules presently offered by Agilent and is available as Option IRC on each module. Option IRC enables not only the corrections for standard compliance rates, but for rates above, below and in between the standard rates, and works seamlessly with the filters within the modules. The user can also choose other rates. The range of SIRC rates and typical power range for each optical module is shown in Figure 12. At many rates, SIRC improves the lowest usable power for mask test sensitivity.

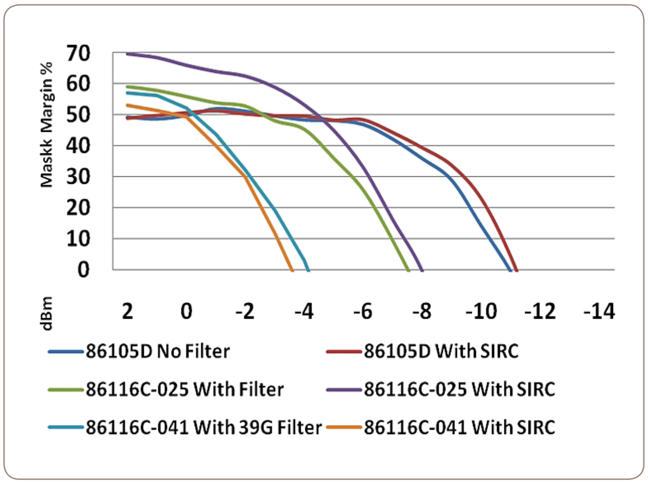
Option IRC works on the below optical modules when plugged into DCA mainframes with these software configurations:

- 86100D DCA-X/ETR using FlexDCA user interface
- 86100D DCA-X/ETR using FlexDCA with PC over LAN
- 86100C DCA-J/001 using FlexDCA with PC over LAN

System Impulse Response Correction (SIRC)

Enhancing Optical Measurements through Choice of Reference Receivers

Photo detectors have a limited range of bandwidths over which they work well; therefore reference receivers are available in frequency ranges that support groups of nearby data rates. Also the usable dynamic range for each receiver design is different where the sensitivity decreases with increased bandwidth or the range is more sensitive with embedded amplifiers. With the availability of SIRC, users can consider using each reference receiver module over more data rates, thus reducing their total capital investment. Figure 12 shows the available data rates and typical power range for each of the modules, tabulated based on an extinction ratio greater than 10dB. The average optical power is the power level at which the standard mask with no margin will experience mask hits with high extinction ratio.



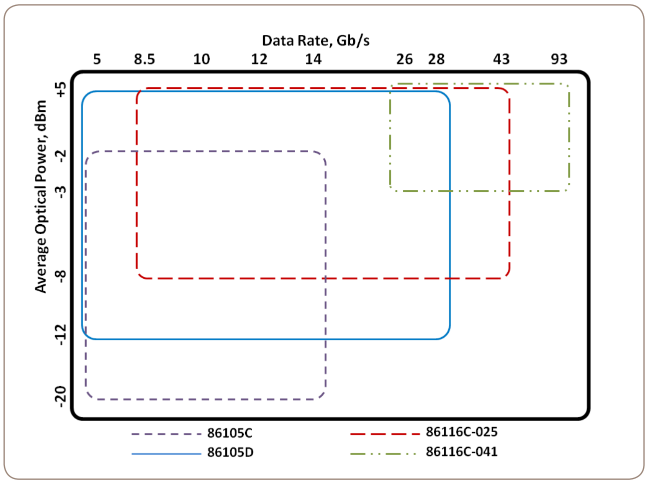
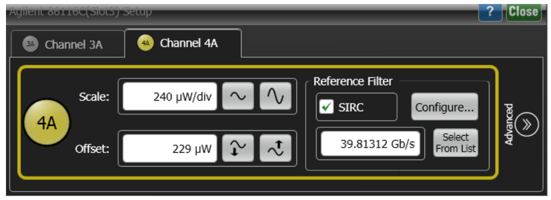


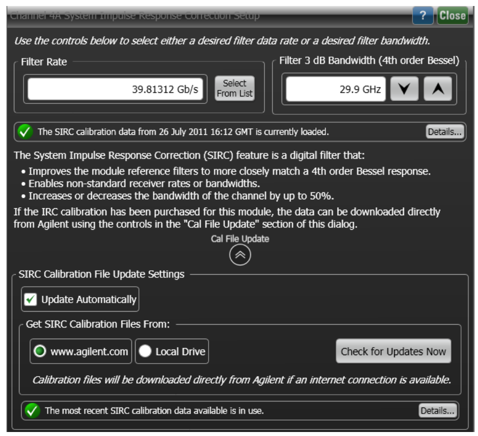
Figure 12a-b. Left diagram shows comparison of mask margin over power at 25.78 Gb/s for three optical modules. Right diagram shows the usable dynamic range and data rates for each module.

Step-by-Step Guide to Using SIRC

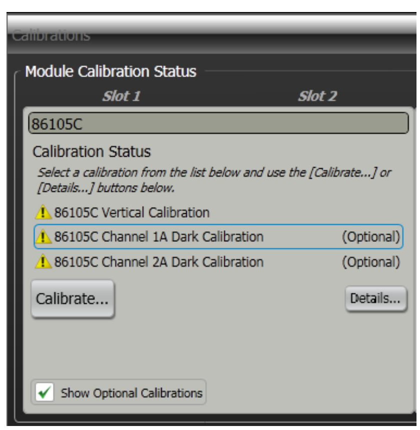
- Choose your mainframe and interface from one of the above configurations
- Plug optical module with Option IRC into your mainframe
- Activate the desired optical channel

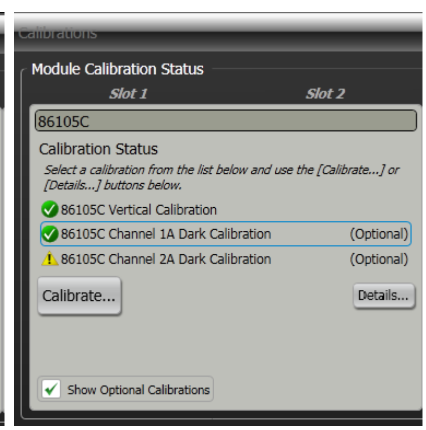


- Be sure your mainframe is attached to an active LAN port with access to the Internet. Load SIRC file by clicking on Check for Updates Now. File will upload from www.agilent.com.



- Allow recommended warm-up period, then calibrate optical module using the Calibrations dialogue



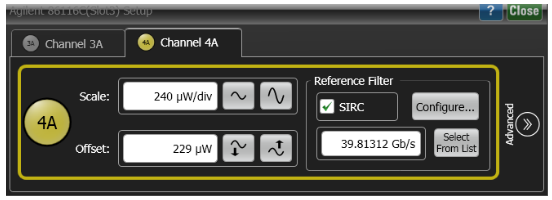


- Connect device to measure.
- Enable Pattern Lock.

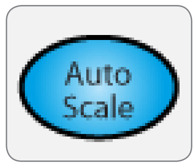
Step-by-Step Guide to Using SIRC

- Turn on desired bit rate using the SIRC interface in the channel setup dialogue.

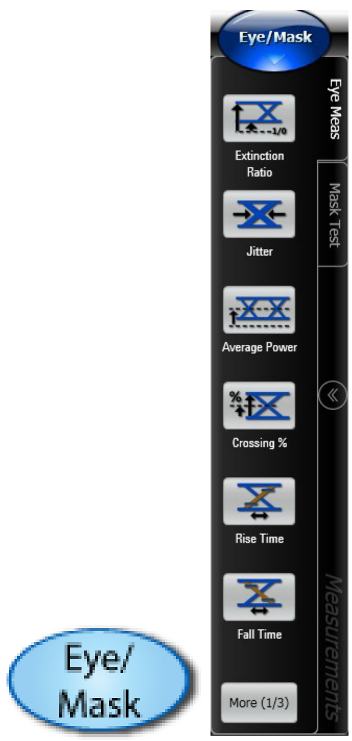
  Click on Select from List to choose standard rates or click Configure to enter your own rate.



- Touch Autoscale.



- Select Eye Mode, then select desired measurements



Comparison of Results With and Without SIRC

The following examples show typical improvements in measurements acquired with SIRC.

Case Study A: Addition of a Lower Rate on the 86105C at 6.25 Gb/s

Previously the 86105C electronically-adjusted filters covered standard rates down to 8.5 Gb/s. The SIRC capability allows the user to select rates down to 5 Gb/s. Figure 13 a-c shows the compliance window and resulting eye diagrams for typical measurements at 6.25 Gb/s. The compliance window without SIRC is shown at 9.953 Gb/s, the filter rate that is used when SIRC is enabled. The eye diagram shows the very clean frequency response of the 86105C with SIRC enabled.

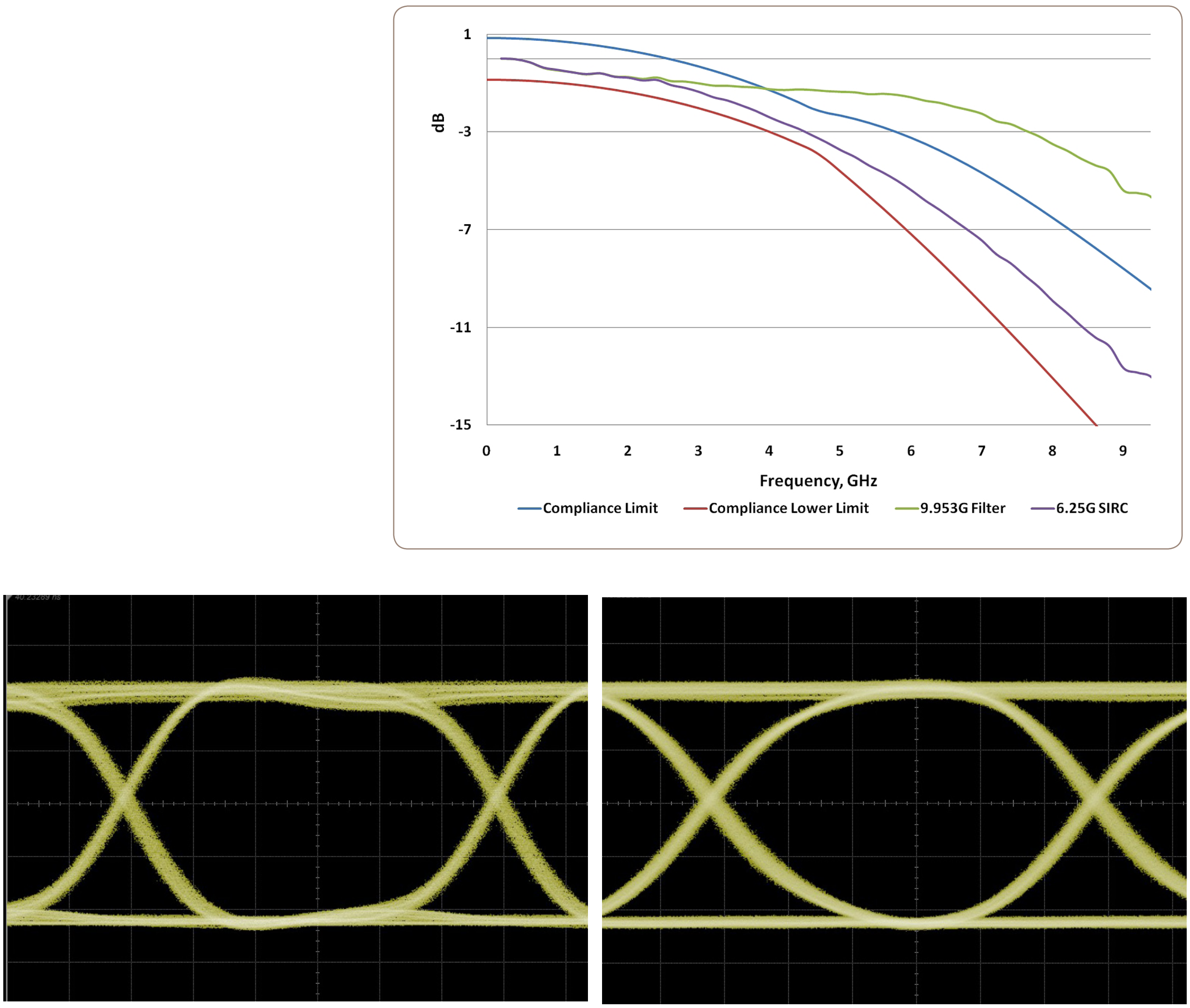


Figure 13 a-c. Frequency response on 86105C extended to 6.25 Gb/s, showing eyes with higher-rate filter and with SIRC

Comparison of Results With and Without SIRC

Case Study B: Extending the 86105C to Higher Data Rate of 14.025 Gb/s

Previously the highest standard rate on the 86105C was 11.317 Gb/s. With the introduction of the SIRC capability, rates to 14.025 Gb/s are now possible as shown with the improvements in Figure 14 a-c. Note the cleaner eye on the one and zero levels, including the removal of overshoot. Even though the adjusted frequency is not compliant at the highest frequencies, the cleaner eye and ability to improve mask margins helps the user.

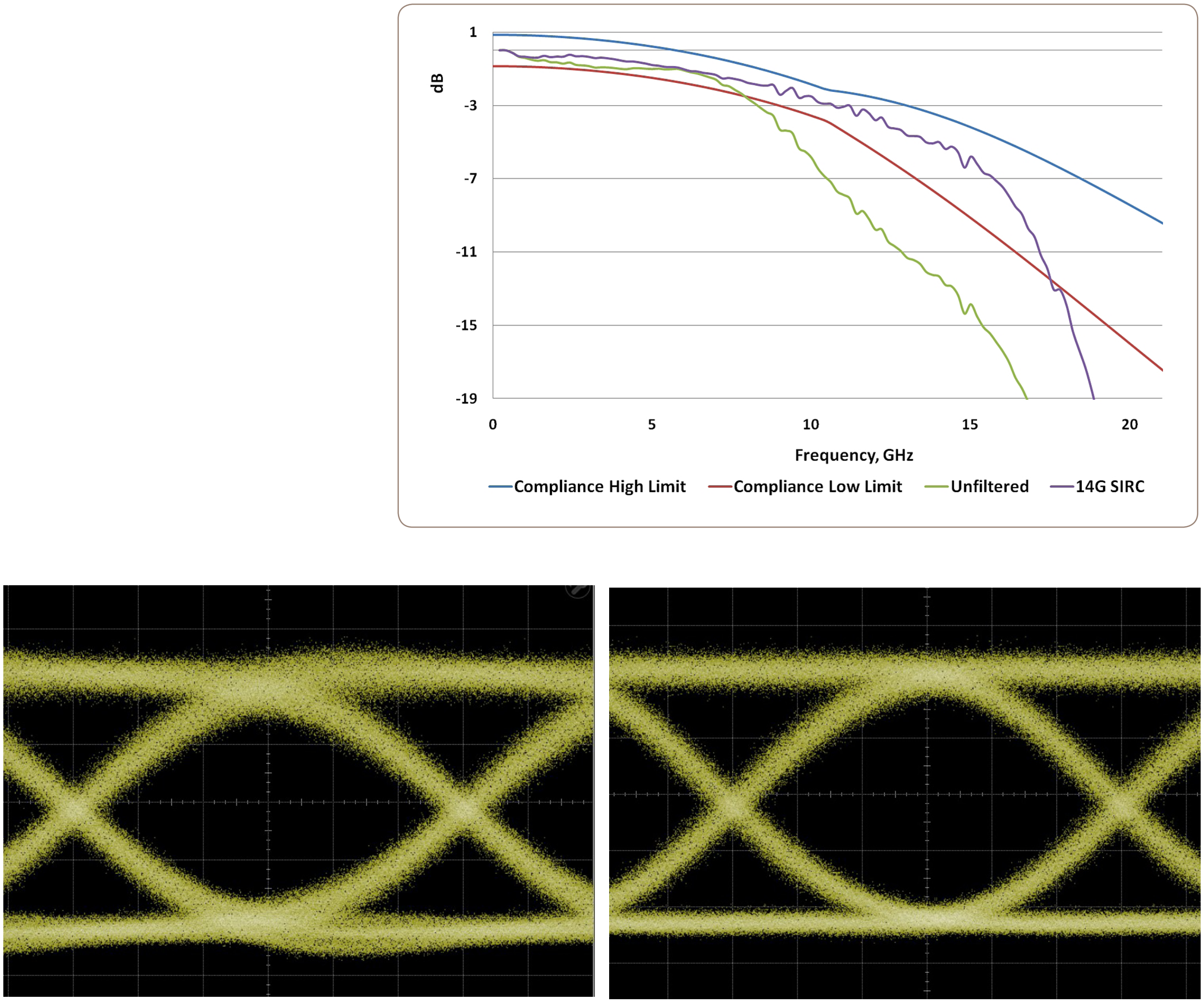
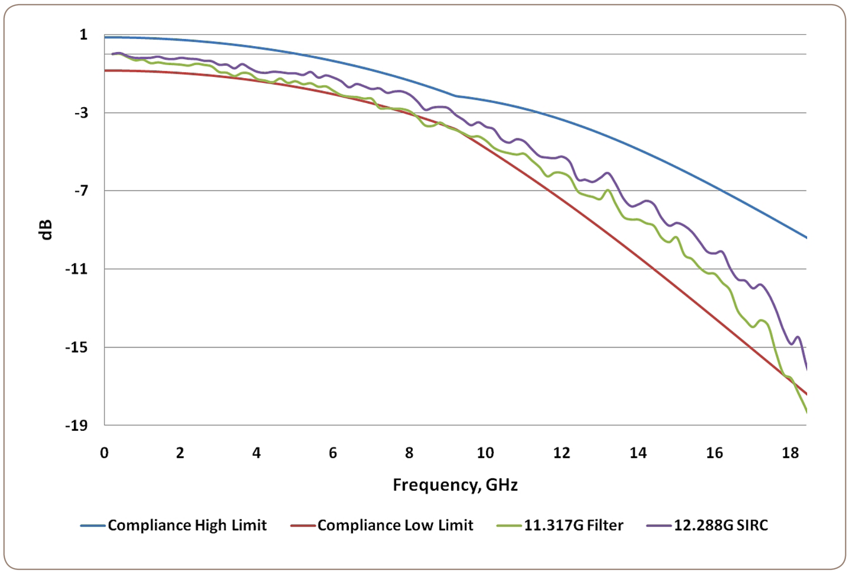


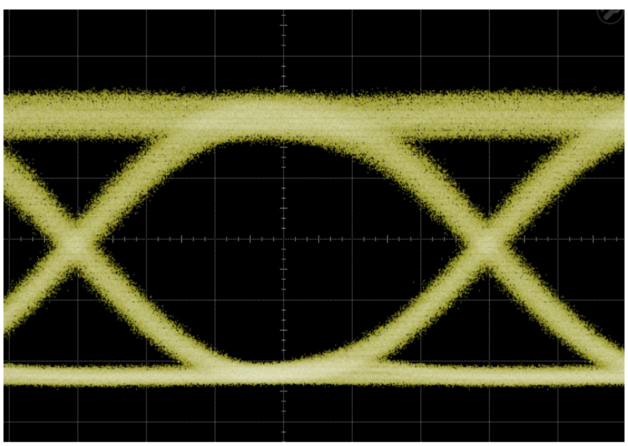
Figure 14 a-c. Frequency response and eye measurement on 86105C extended to 14.025 Gb/s, without and with SIRC

Comparison of Results With and Without SIRC

Case Study C: Addition of an Intermediate Rate on the 86105D at 12.288 Gb/s

Previously the 86105D covered standard rates from 8.5 Gb/s to 11.317 Gb/s and 14.025 Gb/s. The SIRC capability allows the user to enter a rate in between at 12.288 Gb/s. Figure 15 a-c shows the compliance window and resulting eye diagrams.





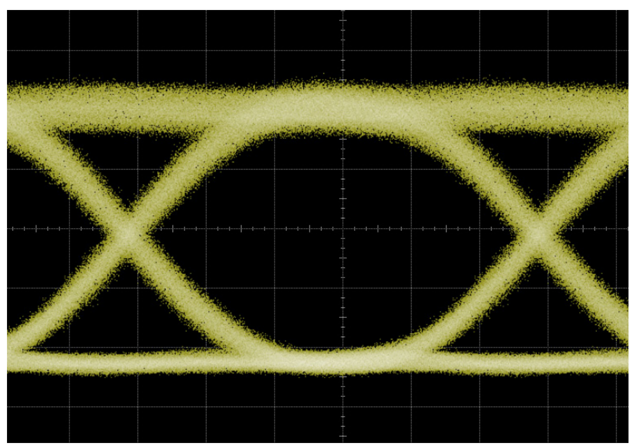


Figure 15 a-c. Frequency response and eye measurement on 86105D extended to 12.288 Gb/s, without and with SIRC

Case Study D: Showing Improvements with SIRC on Two Modules at 14.025 Gb/s

One important criteria to evaluate the performance of SIRC is to measure the same optical signal on a module that is being used at a rate higher than standard filters (86105C at 14 Gb/s) and compare that to the eye acquired on a module that has that rate as a standard (86105D at 14 Gb/s). Figure 16 shows the nearly identical agreement between two eyes when measured with SIRC enabled.

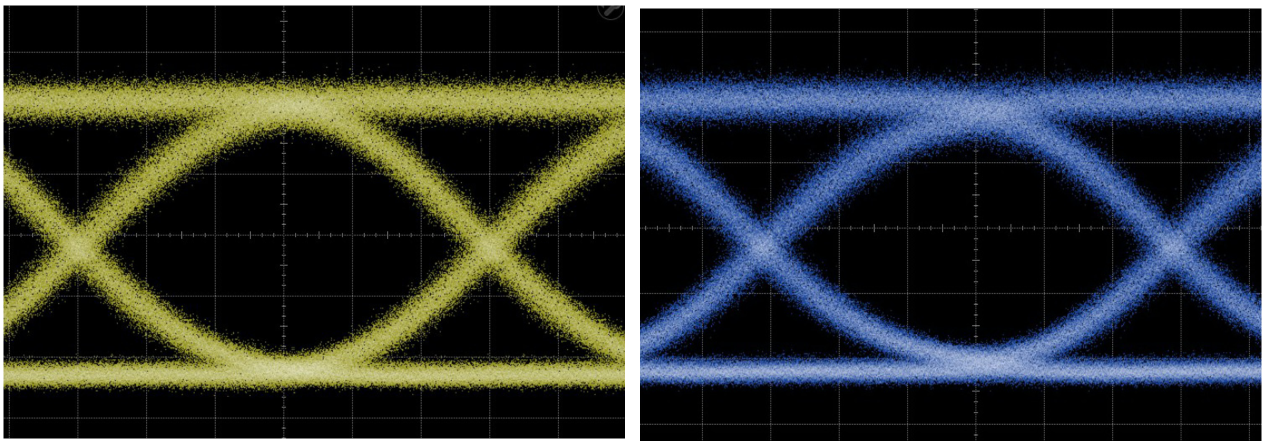
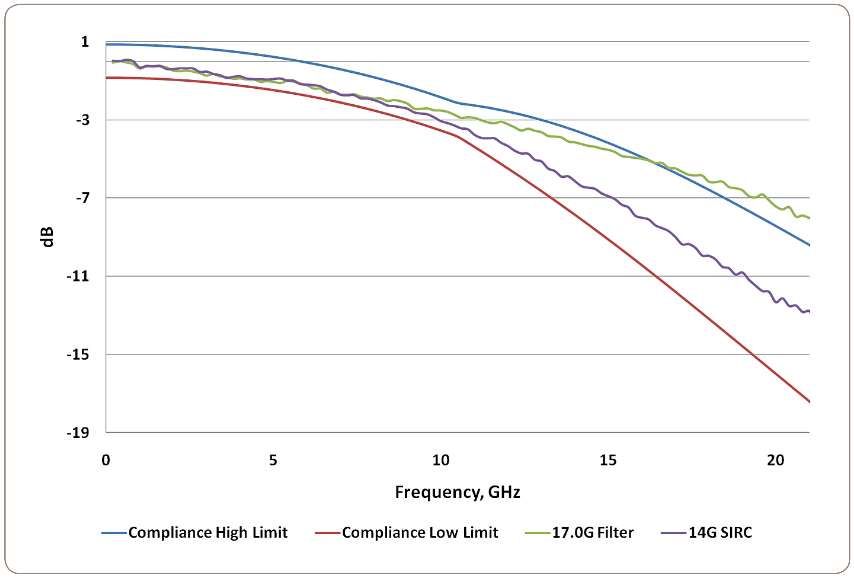


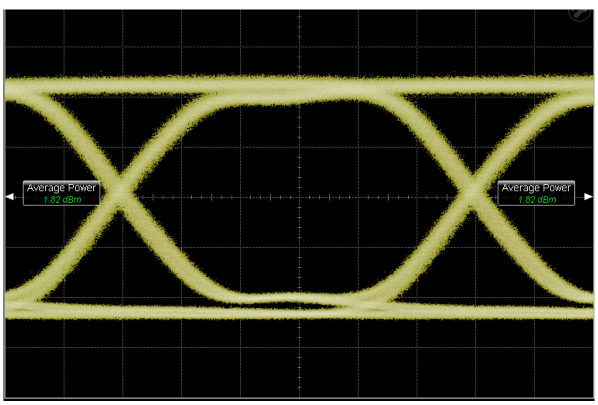
Figure 16. Eye diagrams at 14.025 Gb/s with SIRC enabled for 86105C and 86105D

Comparison of Results With and Without SIRC

Case Study E: Addition of a Lower Rate on the 86116C-025 at 14.025 Gb/s

Previously the 86116C-025 had standard rates starting at 17 Gb/s. The SIRC capability extends the usable range to 8.5 Gb/s with a very clean frequency response and eye in Figure 17.





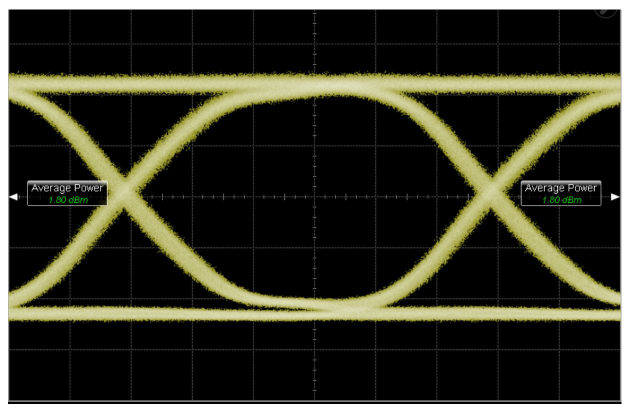
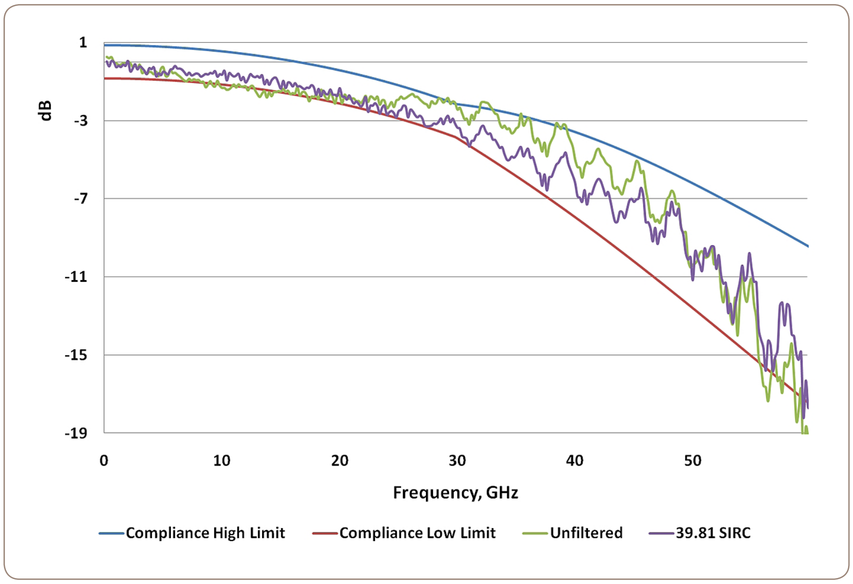


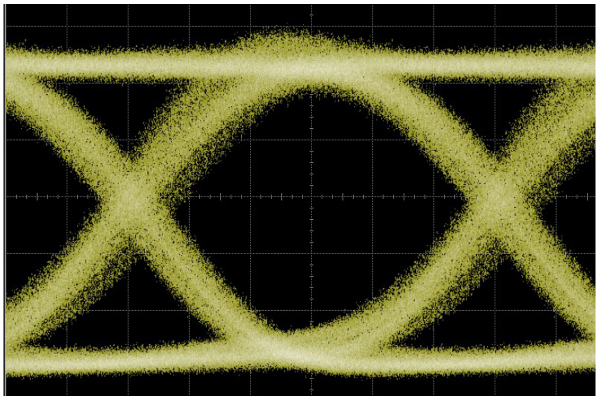
Figure 17 a-c. Frequency response and eye measurement on 86116C-025 extended to 14.025 Gb/s, without and with SIRC

Comparison of Results With and Without SIRC

Case Study F:
Addition of a Higher Rate on the 86116C-025 at 39.81 Gb/s

Previously the 86116C-025 included standard rates up to 27.78 Gb/s. The SIRC capability extends the usable range to ~40 Gb/s, a compliant response as shown in Figure 18a and a clean eye as shown in Figure 18b. Figure 18c shows the same signal when measured on the 39.81 Gb/s filter in the 86116C-041 module. Note the very close agreement between the eye diagrams..





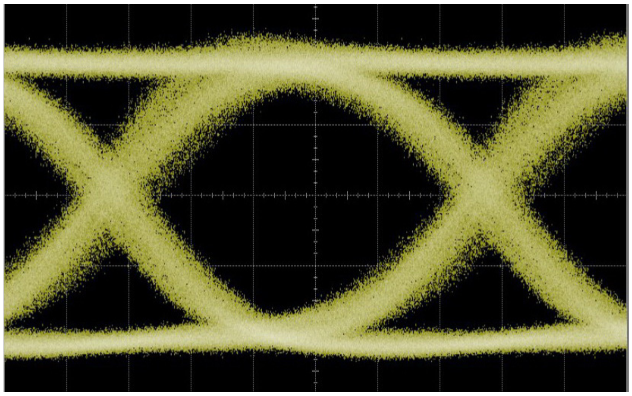


Figure 18 a-c. Frequency response and eye measurement on 86116C-025 extended to 39.81 Gb/s, with SIRC shown in the left image. Right image shows eye as captured using 86116C-041.

Comparison of Results With and Without SIRC

Case Study G: Addition of a Lower Rate on the 86116C-041 at 25.78 Gb/s

While the 86116C-041 has been the reference receiver of choice for rates near 40 Gb/s, SIRC extends the capability very cleanly down to 25.78 Gb/s as shown in Figure 19.

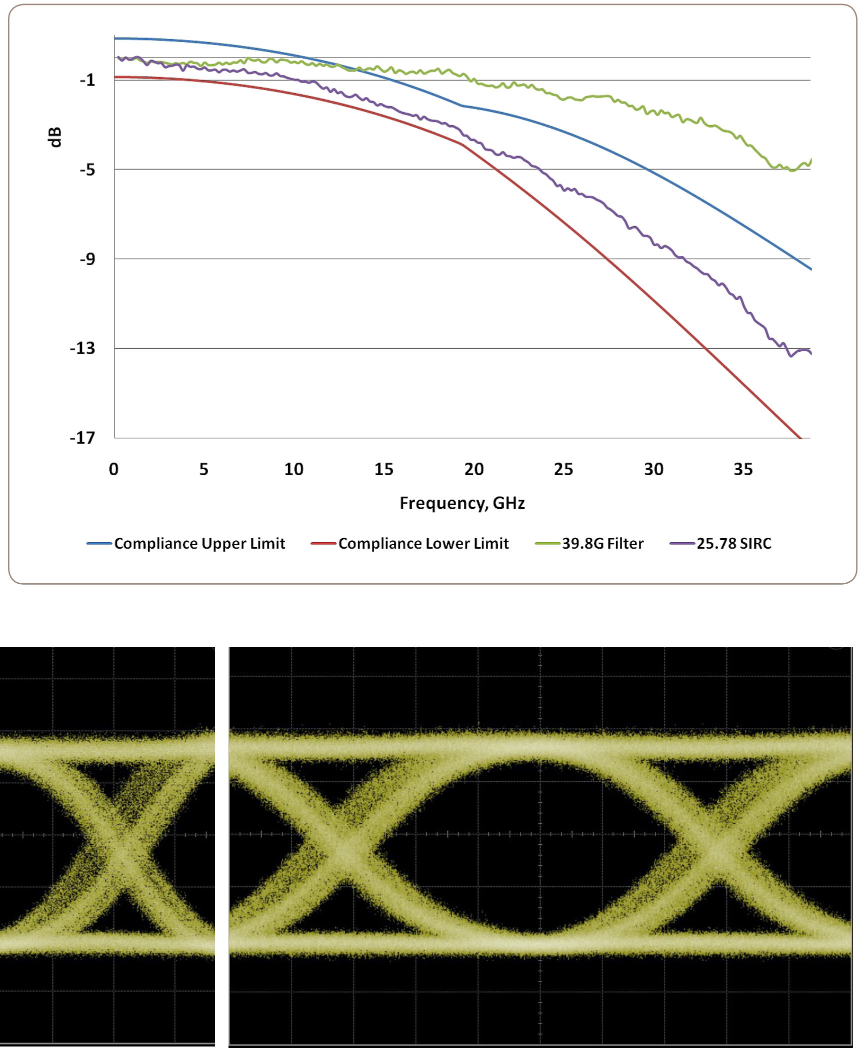


Figure 19 a-c. Frequency response and eye measurement on 86116C-041 extended to 25.78 Gb/s, without and with SIRC

Comparison of Results With and Without SIRC

Case Study H: Assessment of jitter, amplitude interference and noise performance when using SIRC

One of the downsides of earlier compliance filter adjustment techniques is the change in measured values of key parameters. The SIRC option provides a sound technique to improve the compliance filter and eye measurements with virtually no impact on required measurements. Table A shows jitter and amplitude interference results at 10.3125 Gb/s with increasing amounts of jitter, with the filter and with SIRC. Table B shows the optical noise of the module, without and with SIRC. Note the close agreement showing SIRC does not impact these measurements.

Table A. Jitter and amplitude interference results in presence of increasing amounts of injected jitter, with filter and with SIRC.

	No Injected Jitter		Injected RJ, 0.03 UI		Injected PJ, 0.2 UI		Injected RJ and PJ	
Parameter	Filter On	SIRC On	Filter On	SIRC On	Filter On	SIRC On	Filter On	SIRC On
PJ, ps	0.7	0.1	0.5	0.0	7.0	7.0	6.9	6.9
DJ, ps	7.0	7.9	5.8	5.4	25.0	27.4	20.5	21.4
RJ, ps	1.5	1.5	3.5	3.4	1.5	1.5	3.6	3.5
RN, uW	28.2	28.2	28.9	28.2	28.4	28.2	29.6	28.2
DI, uW	161	168	163	166	178	172	192	176

Table B. Noise on module optical channel, without and with SIRC

Noise in uW	86105C at 10.3 Gb/s	86105D at 14.025 Gb/s	86116C-025 at 25.78 Gb/s	86116C-041 at 39.81 Gb/s
SIRC Off	1.0	8.7	16.1	40.6
SIRC On	0.9	7.3	16.2	40.5

Key Considerations While Using SIRC

Use a repeating pattern. SIRC uses the statistics from the repeating pattern to perform the measurement.

Enable Pattern Lock. The frequency domain transforms used in SIRC require a repeating pattern.

Calibrate the module. For the most accurate measurements, vertical calibration and dark calibration must be performed after the appropriate module warm-up period.

Observe the pattern lengths. The SIRC capability works for patterns up to 2^16-1 on 32 bit operating systems and up to 2^23-1 on 64 bit operating systems (external PC with Flex operating software over LAN).

Recognize that extinction ratio, noise and jitter measurements are not impacted. The SIRC technique does not impact these measurements and Agilent has extensively tested these measurements to look for changes.

Use external computer with the 86100C. The Flex software contains the SIRC capability and works either directly on the 86100D mainframe or on an external computer with the 86100C or 86100D.

Recognize the low and high bit rate limits for each module. To assure the best eye quality, the SIRC algorithm limits how far the bit rate is extended which is typically +/-50 percent.

Adjust settings as needed for large jitter. The measurement software flips into Large Jitter Mode in the presence of large jitter values. The user may also need to increase the points per bit beyond 32 for the largest values of jitter.

Consider changes in throughput speed. The SIRC feature can be enabled for the eye, mask and other key measurements. With external computers having low processing power and under some operating conditions, the measurement results while using SIRC may take slightly longer to acquire. While this is an important consideration in manufacturing test times, the additional yield from improved accuracy will likely offset any time changes.

Choose the appropriate reference receiver for your transceiver. Consider the signal power levels being measured and which other nearby rates are being characterized.

Conclusions

Higher data rates require more creative transceiver designs and enhanced measurement technology to verify performance to the compliance standards. Agilent has expanded the suite of measurement capabilities on the 86100 DCA product family, enabling designers to characterize a wider range of transceivers with each optical module.

Transceivers at emerging and non-standard rates can now be quickly, accurately and easily measured. Standard rates can be measured even more accurately on the 86100 DCA product family through the use of System Impulse Response Correction. Designers and manufacturing engineers will focus keenly on the challenges of the increasingly competitive markets and spend less time on obtaining just the data that are required to meet the difficult measurement requirements.

Related Literature

Agilent Data Sheet, 86100D Wide-Bandwidth Oscilloscope Mainframe and Modules

Agilent Application Note 1550-9, Improving the Accuracy of Optical Transceiver Extinction Ratio Measurements

Agilent Product Note 86100C-1, Precision Jitter Analysis Using the Agilent 86100C DCA-J

Frequently Asked Questions

Q: With is the impact of SIRC on critical measurements like jitter?

A: The SIRC capability minimizes the amount of adjustment in each segment of the compliance window. This enables the jitter statistics to be preserved and offers the user the same accurate measurements offered from Agilent starting with the DCA-j. The user does not need to manually enter any values.

Q: How often does the SIRC calibration need to be repeated?

A: The recommended calibration for SIRC is one year, which is the same interval recommended for the plug-in modules.

Q: Are there any pattern length limitations when using SIRC?

A: The SIRC capability works up to 2^16-1 when using 32 bit operating systems and up to 2^23-1 when using 64 bit operating systems.

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Revised: June 8, 2011

Product specifications and descriptions in this document subject to change without notice.

Published in USA, September 21, 2011
5990-8812EN

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