PDHonline Course E465 (4 PDH)

Fiber Optic Serial Communication

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Fiber Optic Serial Communication

Roy Timpe, P.E.

1. Introduction

Ever look at fiber in a conduit and wonder about what is going on inside that plastic jacket? Ever wonder about how you can get information sent to you from a computer in another continent, and not pay for the computer time, or the long distance transmission? This has been made possible by the great reduction of the cost of data transmission, largely due to fiber optics. The goal is to familiarize the reader with the typical serial communication schemes used in fiber optic systems. Concepts of evaluating signal quality are introduced, as well as some theory of operation of the systems as well as sampling oscilloscopes. Metrics such as inter-symbol interference, jitter, and signal to noise are introduced. The idea of stressed EYE testing of receivers is explained. The IEEE 802.3aq standard for 10GBASE-LRM is used as an example for several of these concepts. It would be helpful, but not necessary, that the reader have some familiarity with the concepts of semiconductor laser, detectors, and modulators. Laser safety is also introduced as it applies to these fiber optic systems.

2. Serial Communication

There are several modulation schemes for optical communication, but the the most common is Non-Return to Zero (NRZ) serial data.

NRZ data is not only used in optics, but is also used in electrical modes such as Serial Advanced Technology Attachment (SATA), RS232 and I^2C.

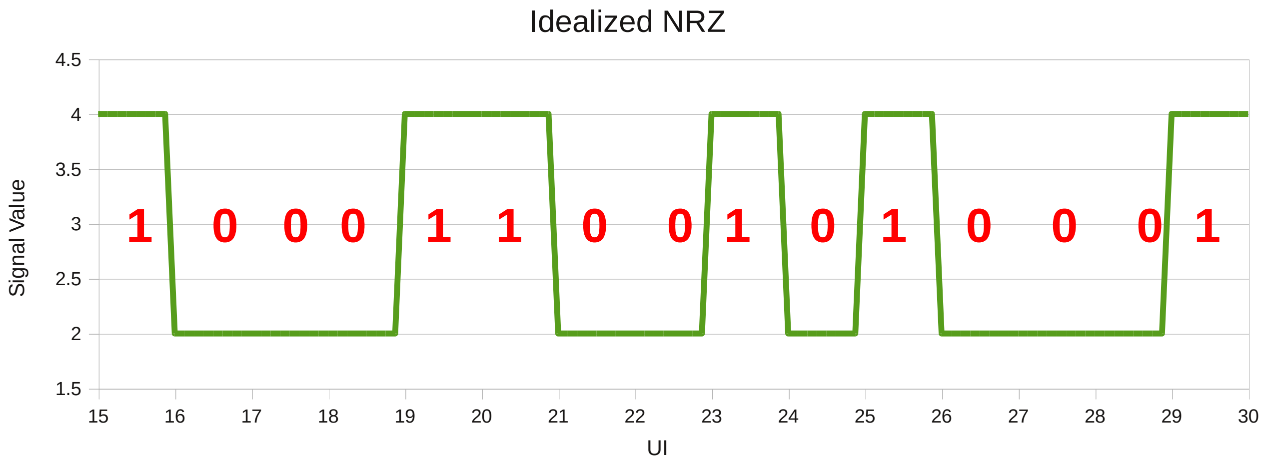


Figure S1

The above figure shows an ideal NRZ serial data stream transmitting 100011001010001. The X axis is time. The “1” on the left was transmitted before the “1” on the right. The time axis is marked off in Unit Intervals (UI) There is one bit per UI. In this example, the Y axis is the signal level. In the case of optics, this would be optical power, measured in mW. This signal has 2 as the optical ZERO level and 4 as the optical ONE level. The Extinction ratio is 3 dB. From the equation:

$$\mathbf{ER = 10 \log (P_1 / P_0)}$$

where P_1 is the power level of the ONE and P_0 is the power level of the ZERO.

The actual time value of the UI depends upon the bit rate. For example, if the bit rate is 10.3124492 Gb/s (giga-bits per second) then the UI would be 96.9702 ps or 1/10.3124492E9.

It should be noted that the bit rate used is the bit rate of the channel. For example, 100 Gb/s systems (100GBASE-LR4) are actually using four different wavelengths of light sending 25 Gb/s NRZ data. In these systems the UI = 1/25.78125E9 or 3.8787 ps.

In an optical system there are several factors working to degrade the signal as it is sent down the fiber. Attenuation is perhaps the most obvious. The fiber is very transparent, but it is not without loss. The signal does become smaller as it propagates down the fiber. At the far end, the receiver will try to detect the signal, however, the detector diode, and amplifier will add noise. Eventually, with enough distance, the signal to noise ratio will be so low the receiver will not reliably tell the ONEs from the ZEROs. In addition to attenuation, there is inter symbol interference (ISI). ISI can be caused by dispersion. In multi-mode fibers the various modes tend to spread the ONEs and ZEROs together. In single mode systems, wavelength dispersion can have the same effect. The low pass filtering effect of components also serves to degrade the signal through increased ISI.

3. The Low Pass Filter

Virtually every component in the data chain has some low pass filtering effect. For example, the detector diode has a finite bandwidth. The detector is followed by a transimpedance amplifier. It too has a finite bandwidth. The next figure shows the idealized signal put through a low pass filter. The ideal signal is how the data looks with infinite bandwidth. The green line is the ideal signal, and the orange line is that same signal after the low pass filter. By low pass filter we mean a filter that lets the low frequencies through (i.e. pass) and reduces the high frequencies in the signal, similar to a voice heard over the telephone as opposed to a voice heard in person. The telephone only lets frequencies up to about 3 KHz through, but the voice is still understandable. In person you hear up to 15 or 20 KHz. Likewise with this signal, you can still tell the ONEs from the ZEROs but the sharp edges of the bits are slowing down, and it is a little more difficult.

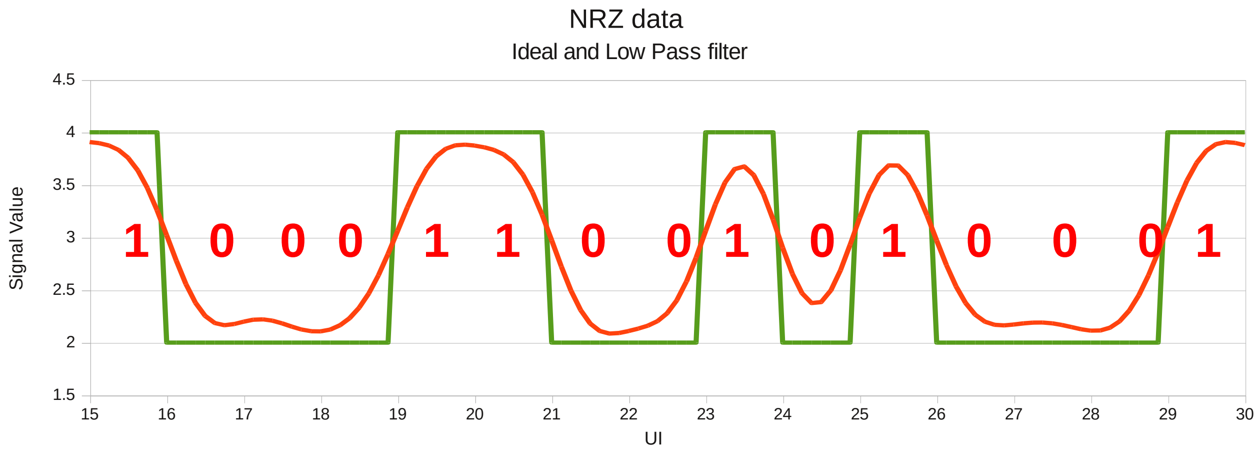


Figure S2

Notice that the transition from the ZERO level of bit 22 to the ONE level of bit 23 takes nearly a full UI. The signal is hardly at the full ONE level for very long before it starts falling to transmit the ZERO level for bit 24. In effect, the ONEs and ZEROs are starting to smear together. This phenomenon is called Inter Symbol Interference. Remember ISI can be caused by wavelength dispersion in the fiber, modal dispersion in the fiber, or (as evidenced here) by low pass filtering effects of devices in the data path.

These systems have a clock that helps determine when the best time is to make the ONE - Zero decision. The next figure shows the system clock added in BLUE. In this case the rising edge of the clock is the best time to make the ONE – ZERO decision.

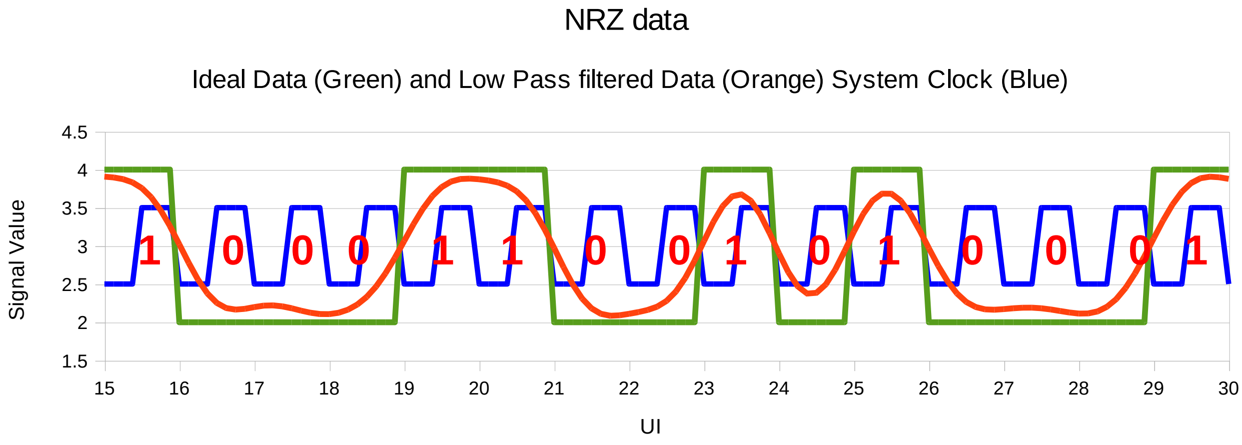


Figure S3.

If additional low pass filter is applied, it can become nearly impossible to determine all the ONES from the ZEROs. (see bits 23, 24, and 25 on Figure S4)

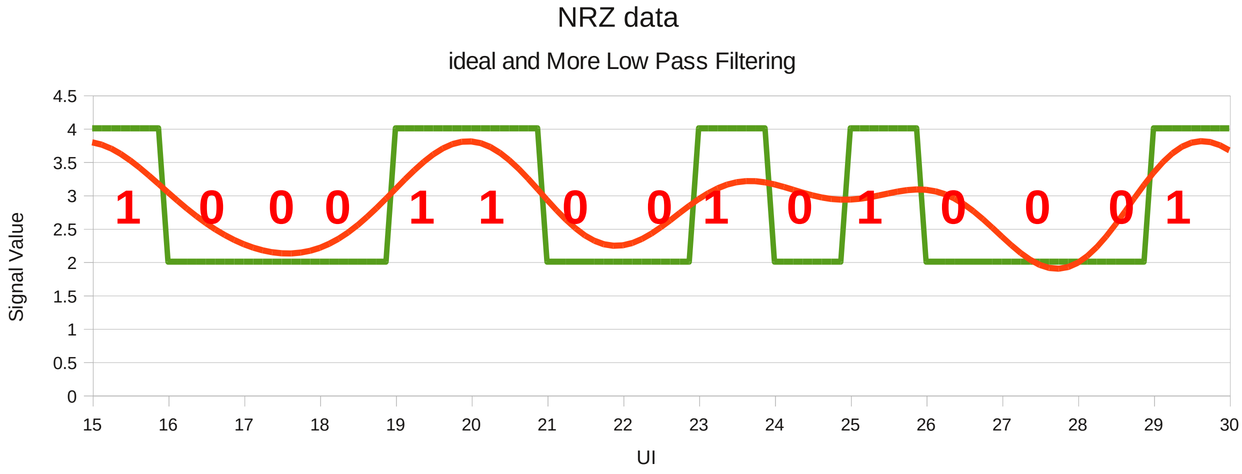


Figure S4

4. EYE diagram

One useful way of looking at these serial data signals is through the use of an EYE diagram, so named because the open portion of the bit resembles a human EYE. An oscilloscope is used and the optical communication system's clock is used to trigger the oscilloscope. In this way, the oscilloscope trace paints all the possible bit transitions on the screen. This displays every possible combination of bits in the space of one UI, in this case between the 1 and 2 on the X axis. See figure S5 below:

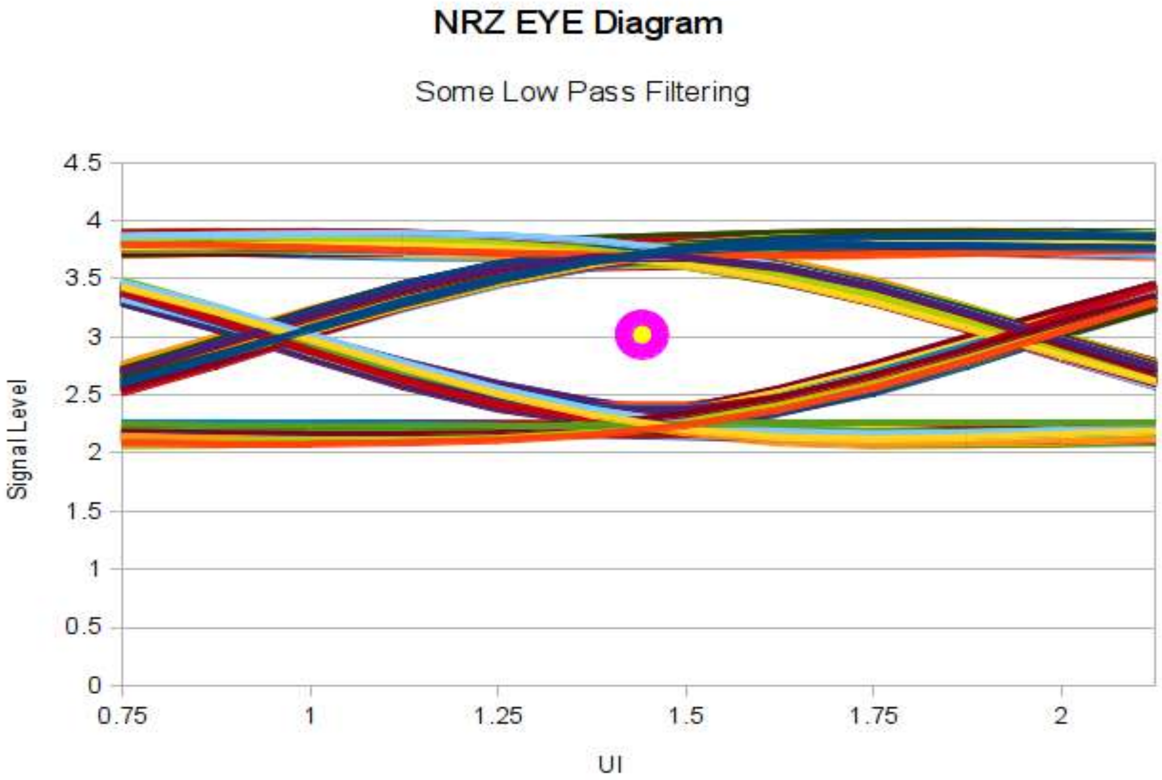
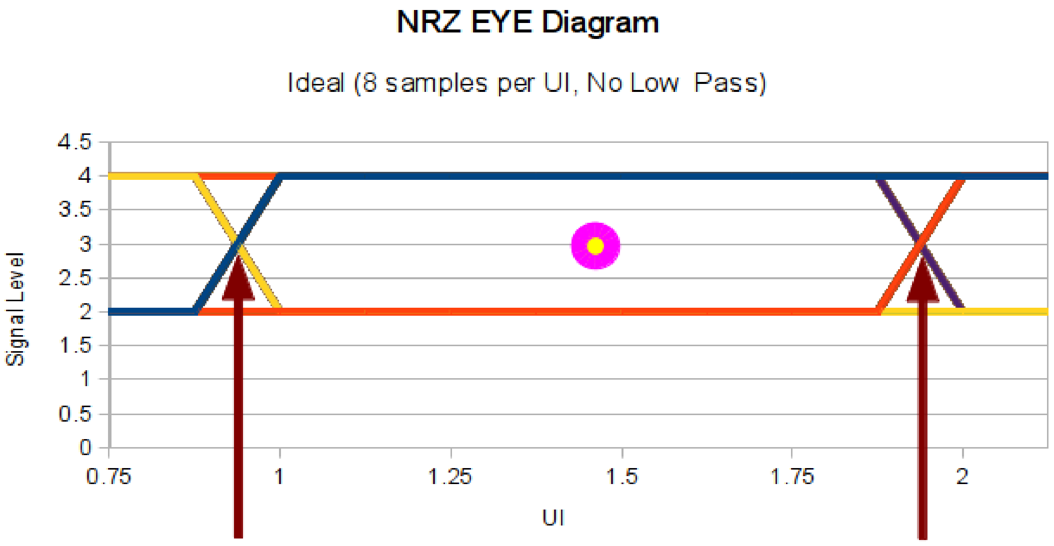


Figure S5

Notice that many bit transitions are superimposed on each other forming the EYE diagram. This EYE diagram is made from 511 bits of the low pass orange line in figure S2. Also notice that if the receiver circuit locates its decision point in time and level at the place shown by the magenta target there will be no difficulty in correctly discerning the ONEs from the ZEROs. The best receiver decision point is in the middle of the EYE opening, in other words, half way between the ONE and Zero Level, and half way from the leading edge to the trailing edge.

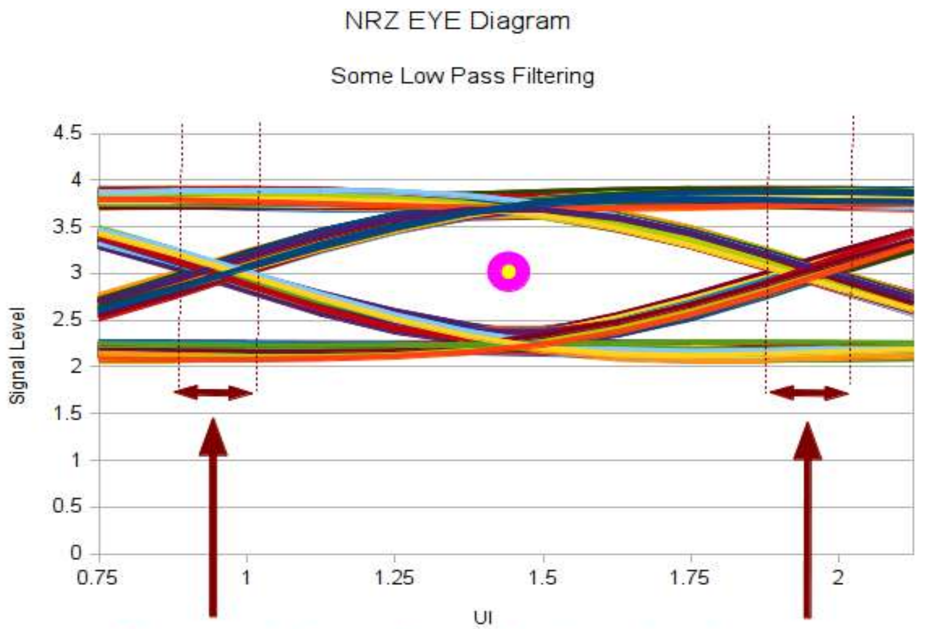
Figure S6 is an EYE digram made from 511 bits of the ideal signal (i.e. the green line in figure S2.) Notice that all the transitions of the ½ signal level happen at exactly the same time. The EYE is wide open for the ideal signal and a receiver making the ONE ZERO decision at the magenta target would have no difficulty. Jitter is defined as the time difference between the real bit transition and the ideal timing for the bit transition. Jitter is sometimes expressed as peak to peak, or RMS (Root Mean Square) about the ideal time of the bit transition. In this EYE diagram there is zero jitter.



All bit transitions of the ½ signal level happen at exactly the same time. There is zero jitter.

Figure S6.

Figure S7 is the same data as figure S6 with the low pass filter's effect of increasing jitter shown:



Bit transitions of the ½ signal value are spread out in time. The low pass filter has caused jitter.

Figure S7.

Notice that the low pass filter signal compared to the ideal signal has width on the X axis (jitter) and width of the signal on the Y axis. As you may expect, additional low pass filtering will increase jitter and the width of the signal on the Y axis.

Figure S8 shows the EYE diagram that results from the additional low pass filtering. This is 511 bits of the orange signal in figure S4.

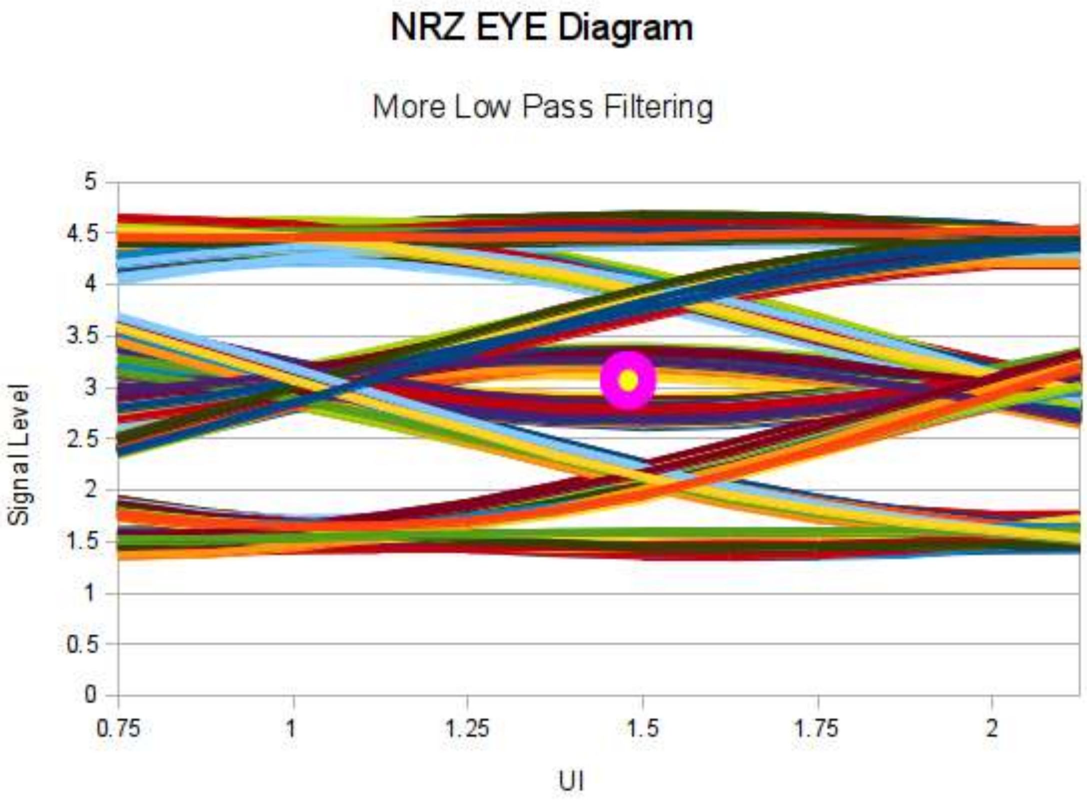


Figure S8

Just as it was very difficult to discern the ONEs from the ZEROs in Figure S4, the additional low pass filtering causes the EYE to close. There really is no place where the receiver circuit can place its decision point and be assured of correctly discerning all the ONEs and ZEROs. The optimum point is shown by the magenta target, but the slightest noise will cause a bit error.

5. Sampling Oscilloscope

The EYE diagrams shown above are computer simulations where the bit transitions are shown as colored lines. Most of the time EYE diagrams are captured on sampling oscilloscopes. A sampling oscilloscope requires a trigger signal that is periodic and has a constant phase relationship to the signal being sampled. It could be a clock at the same bit rate as the signal, or it could be a clock much slower than the signal. In practice it is usually the system clock divided down to a much lower frequency. The trigger signal must not have jitter with respect to the signal being measured. Figure S9 shows a block diagram of a sampling scope measuring an EYE.

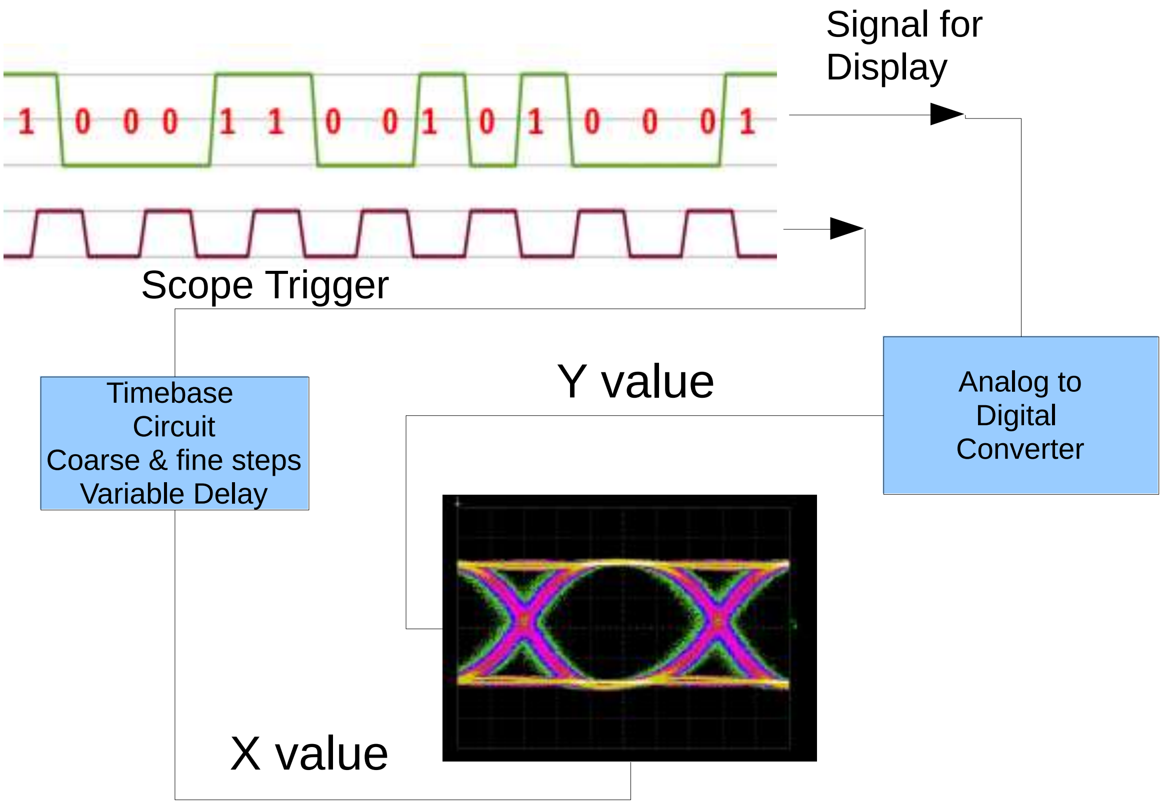


Figure S9

The scope has a calibrated variable delay in the trigger circuit. Depending upon the manufacturer, this delay is usually about 5 to 10 nanoseconds. Let's use 10 ns as an example. When the scope receives the trigger pulse, it waits some amount of time for the calibrated variable delay, and then it converts the analog signal value to a binary number. The signal to be displayed could be electrical or optical. In the case of electrical the Y axes will be in volts. In the case of optical the Y axes will be in power (usually mW.) At this point the scope accurately knows the time value (X axes) and the corresponding voltage or power (Y axes) for that one point on the signal. The above process is repeated many times using different portions of the calibrated variable delay to “paint” the picture of the EYE on the scope display. In this example notice that there are different colors on the display. This is referred to as color grade mode. The colors correspond to the number of times the particular X,Y point has been hit by the signal. White is the most hits, followed by orange, red magenta, and finally green indicates the fewest hits.

If the signal we are looking at is longer than 10 ns, the scope will measure several portions with the variable delay and stitch the portions together.

The sampling oscilloscope is by far the most common way to investigate the EYE digram.

A common test for transmitters is what is called an “EYE Mask.” A carefully defined polygon is placed inside the EYE. The sampling oscilloscope is allowed to run for a specified number of samples. If any points are found inside the polygon, the transmitter failed the EYE mask.

6. Sampling Oscilloscope Used to Test a Laser Transmitter

Figure S10 shows an EYE mask. In this case, points significantly above the Logic 1 level and below the Logic 0 level are also considered failures. Depending upon the specification, the polygon may be a rectangle, and/or points above the Logic 1 level and below the Logic 0 level would not be considered failures.

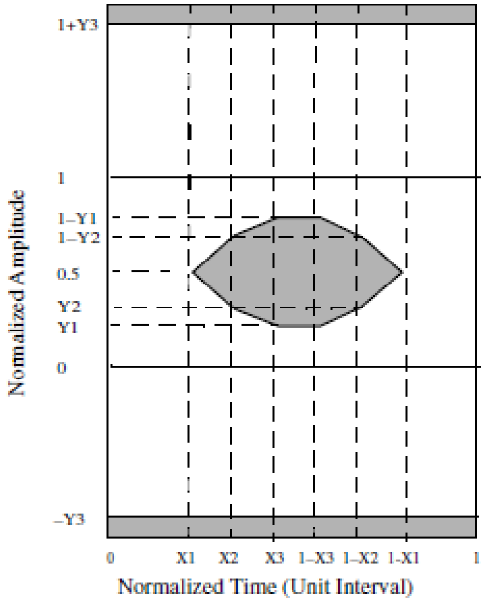


Figure S10

Any sampling scope points inside the gray area would cause the transmitter being measured to fail the test. This figure is from IEEE P802.3aq, numerous standards have similar masks. It should be noted that sampling scopes (because they are just sampling the waveform) will not see every possible problem with the EYE. To show up as a point on the sampling scope, the event needs to be happening at least about once every 3,000 bits.

7. Bit Error Rate Testing

The Bit Error Rate (BER) is defined as the number of bit errors divided by the number of bits transmitted. So a bit error rate of 10^{-3} would mean that one out of 1000 bit was an error. A sampling scope with the proper setup will see a 10^{-3} event. Most specifications require the receiver to achieve 10^{-12} BER, or only one bit error every trillion bits. A sampling scope will not see a 10^{-12} event. A different test method is required. In figure S7 we saw that if the receiver makes its decision (between a ONE and ZERO) at the magenta target (i.e. in the middle of the EYE), the receiver will always be correct. There is plenty of margin about the magenta target both on the X axis (time) and the Y axis (optical power level.) To get an idea of how bit error rate varies with optical power, consider the following thought experiment. You are standing upon a dock on a moonless night. Your friend is on a kayak with a very bright flashlight. You are required to say if the flashlight is ON or OFF. As he is very close, the flashlight appears like a camera flash. You see purple spots, and cannot tell if the light is OFF or ON at any one moment. As he paddles further away, you have no difficulty telling if the light is ON or OFF. Finally, the kayak is very far away, and you begin to have difficulty seeing the flashlight. Eventually you can not see the light at all.

Since there are only two states for the flashlight, you have a one out of two chance of just guessing the right answer. Therefore, when the flashlight is very close (you see purple spots, and can't see anything) and when it is very far away (you just can't see it at all) your error rate will be ½. In between these two points your bit error rate will decrease as the light is no longer too bright, and finally increase again as the light gets too dim. The BER curve for a receiver is exactly the same. The figure below depicts a receiver run over a wide range of optical power. Note: “OMA” on the X axis is “Optical Modulation Amplitude” it is measured in dBm and is only the power in the optical signal. Note: dBm is decibels with respect to 1 mW. It is calculated by:

$$\textbf{Power in dBm} = 10 \log_{10} [P_1 / (1.0 \text{ mW})]$$

where P_1 is the linear power level in mW.

This signal may well be “riding” on a constant light level. OMA does not include this constant level. This constant level and OMA are related through the extinction ratio.

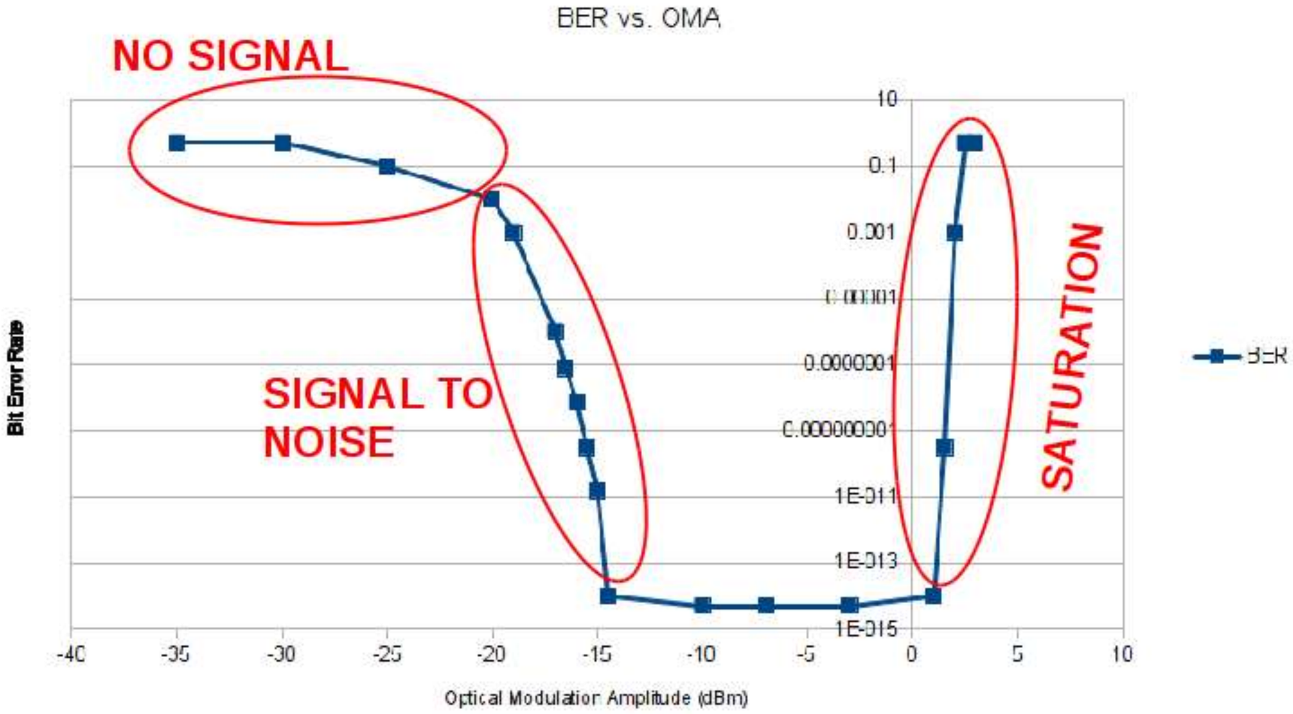
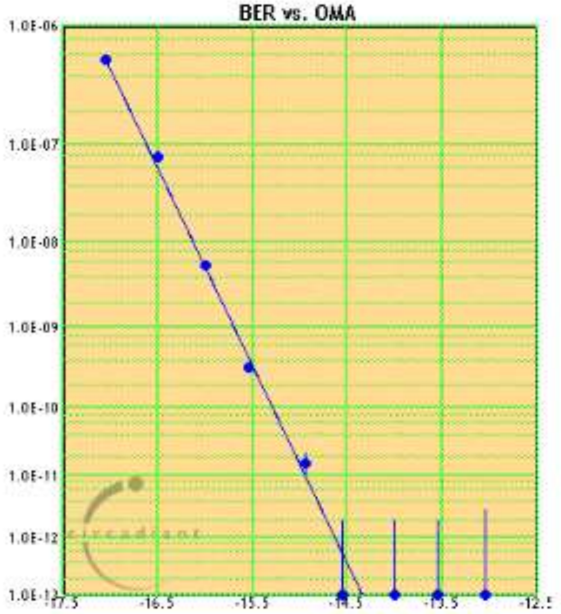


Figure S11.

Notice 4 regions of this curve. At low light (OMA < 25 dBm) the receiver can not tell anything, and the BER = 0.5. There is no significant signal for the receiver to detect. In the region labeled "SIGNAL to NOISE" the BER is dominated by the signal to noise ratio. The receiver adds a constant amount of noise, so when the optical power is small OMA ~ -17 the BER is somewhat high. As OMA increases, BER decreases. Finally in the region of - 15 < OMA < +1.0 the receiver has no difficulty. The BER is about $5x10^{-15}$ or so. This would be the region of the BER curve the receiver would normally operate. For optical power above +1.0 (in this example) the BER starts to climb rapidly back to 0.5. This is the region of the BER curve where the receiver saturates. Actual measurements of receivers concentrate on the region labeled "SIGNAL TO NOISE." The figure below shows an actual measurement on a receiver.



BER plot from Circadiant Tester

Source:
"Sensitivity and Random Jitter" by Mike Dudek August 10 2008
http://wwwieee802.org/3/ba/public/AdHoc/MMF-Reach/dudek_xr_01_0808.pdf

Figure S12.

It is customary to extrapolate or interpolate the power required for for a specified BER (in this case BER = $1x10^{-12}$.) This power is known as the sensitivity. In this case the power required for BER = $1x10^{-12}$ was -14.62 dBm.

Notice on the Circadiant BER plot there are error bars about the 5 points to the right side of the graph. BER is a Poisson process. That is to say the errors occur at a constant average rate, and the errors are statistically independent of each other. BER = $1x10^{-9}$ measured with 1 error for a billion bits is less certain than the same BER measured with 10 errors for ten billion bits. These uncertainty bars are saying there is a 90% chance the real BER is somewhere on the blue bar. The Poisson distribution says a measurement of 0 errors in a given time interval, has about a 0.3679 chance of yielding 1 error if the measurement is repeated. Therefore, the error bars on points that measure zero errors are quite large. The 100 year flood plane calculated on a land survey is also a Poisson process. If the flood plane is calculated correctly you expect that nominally the water will reach or exceed the 100 year level once every century. However, there is about a 37% chance of not seeing that level in any given 100 year period. There is also a significant chance of seeing 2 or more floods of that magnitude. If you actually observe more events (be they bit errors or floods) than you expect, you need to assure the underlying assumptions have not been violated. For example towns on the Missouri river in the 1990s suffered more floods than their 100 year flood plain surveys and Poisson distribution would have predicted due the building of levies upstream. Likewise, actual BER performance that is outside of the expectations based on Poisson's distribution are an indicator of trouble. For example, impedance mismatches or coupling capacitor trouble anywhere in the transmitter or receiver RF chain can cause pattern dependent bit errors. The errors are no longer statistically independent of each other. Laser chirp (the laser not offering a pure “tone” of light) combined with wavelength dispersion will make a ZERO appear as a ONE, but never make a ONE appear as a ZERO. This means the probability of a ZERO having an error is more than the probability of a ONE having an error. Comparing the BER of the ONEs to the BER of the ZEROs is a useful diagnostic tool, also looking for pattern dependence in the BER can yield insights into problems with the physical layer.

8. Modal Dispersion

Multi-mode fiber has been installed since the early 1980's in building, corporate campuses, etc. Modal dispersion limited the data rates and lengths. Fiber of 220 meters would be limited to 1 Gb/s or so. In multi-mode fiber at 220 meters, the energy of a 1350 nm pulse can spread over nearly 300 picoseconds (ps). At 1 Gb/s, the Unit Interval (UI) is 1 ns or 1000 ps. Having the middle half of the eye clear, and the edges ambiguous from model dispersion is acceptable. The receiver can still do its job. Figure S10 shows how modal dispersion can work. Four modes travel down the fiber, and after 220 meters they arrive at the opposite end spaced 75 ps apart in time, since each mode travels at a different rate.

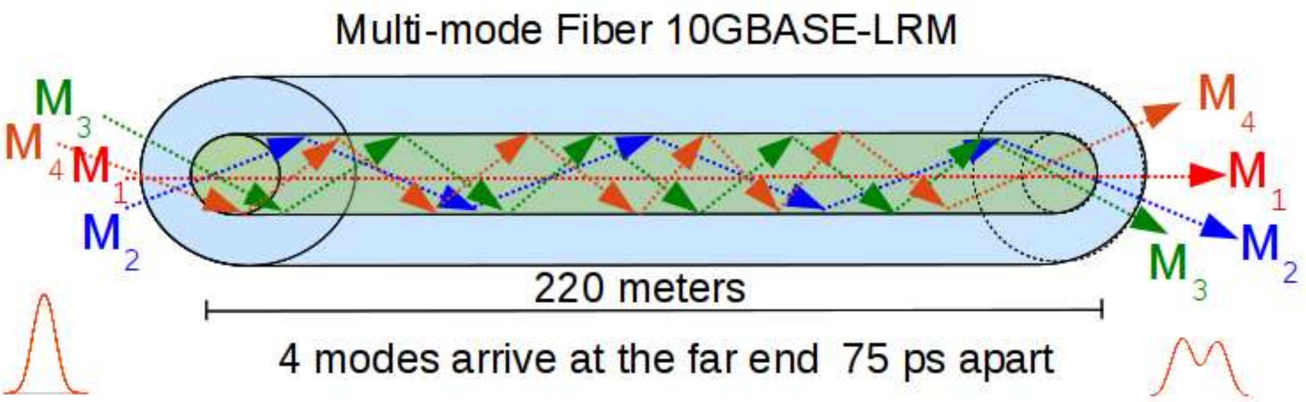


Figure S13

The trouble is, that there is a bunch of this fiber installed in buildings and corporate campuses and today 1 Gb/s is simply too slow. There was a real need to re-use this installed fiber at the newer standard data rate of 10.3 Gb/s. However, at this data rate, the fiber modes completely close the EYE after 220 meters of fiber. Thankfully, modes in the multi-mode fiber create ISI in a deterministic way. In theory, an optical receiver could receive the signal with all of the ISI and then electronically process the signal to remove the effects of the modal dispersion. Since the modal dispersion is deterministic, and slowly changes with time, such a receiver could use the existing multi-mode fiber at 10 Gb/s. The IEEE 802.3aq standard for 10GBASE-LRM envisions these receivers. Four modes in the fiber that are spaced ¾ of a UI apart (about 75 ps) for a fiber length of 220 meters are considered. These 4 modes are used to create 3 different pulses. The energy in the pulses always adds up to 1.0 or 100%, however, the energy is distributed differently between the 4 modes. As you can see from the table, the sum of the power distributions over these 4 modes is always unity. Table S1 shows the stress names with the power in the various modes.

	Energy in Mode			
Stress	**Mode 1**	**Mode 2**	**Mode 3**	**Mode 4**
Symmetric	0.000	0.513	0.000	0.487
Pre-cursor	0.158	0.176	0.499	0.167
Post-cursor	0.254	0.453	0.155	0.138

Table S1

The shapes of these pulses along with the resulting EYE are shown in the following figures. Remember each mode is about 75 ps (or ¾ of a UI) apart. Figure S14 (the Symmetric Pulse) is what an isolated ONE would look like after propagating down 220 meters of fiber with the energy in the modes as described in Table S1.

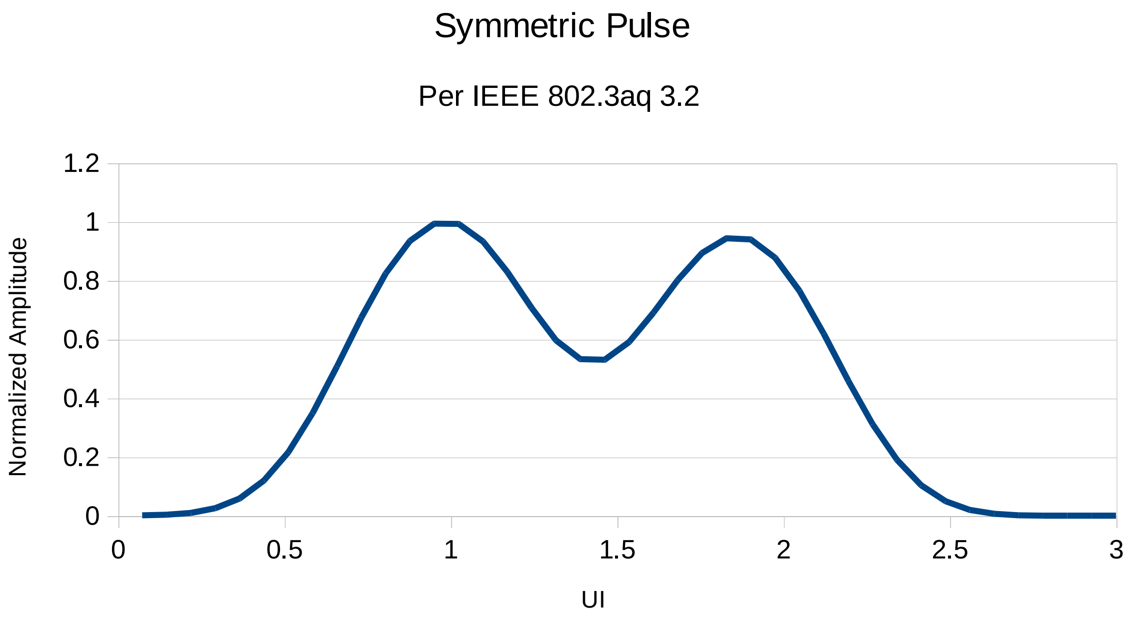


Figure S14.

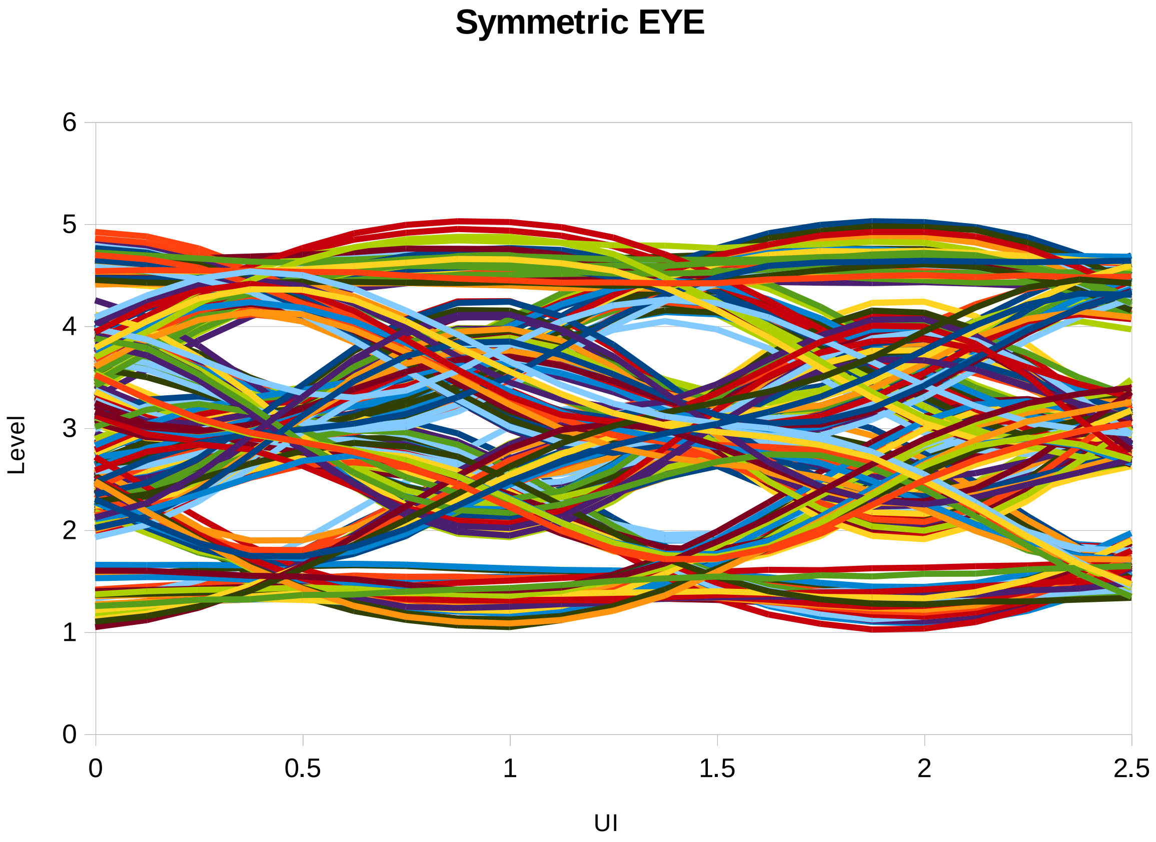


Figure S 15.

Figure S16 is what an isolated ONE would look like after propagating down 220 meters of fiber with the energy in the modes as described in Table S1.

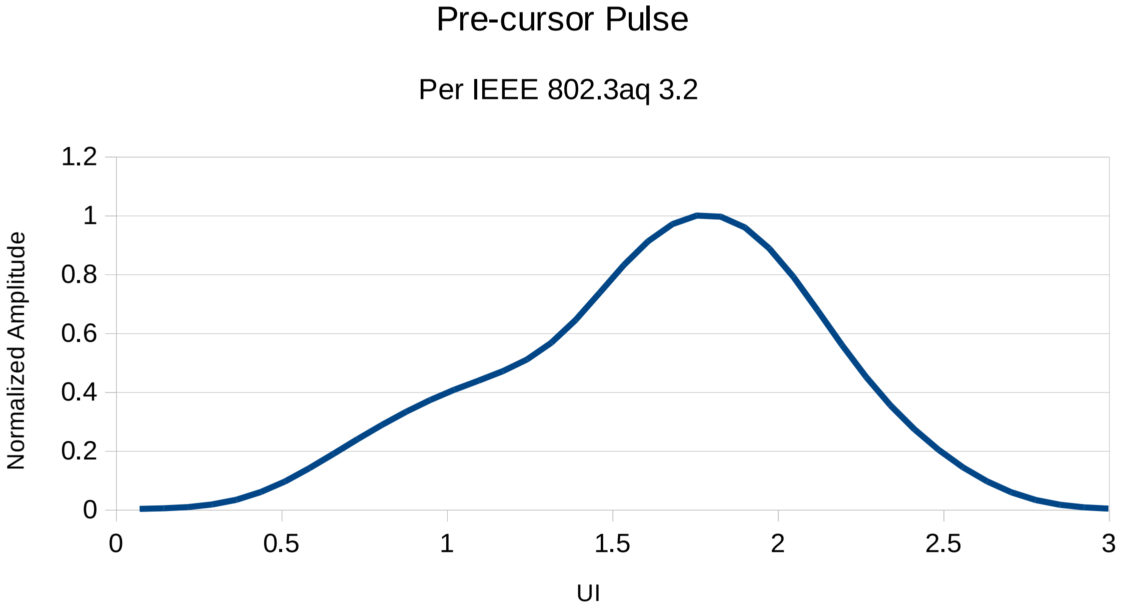


Figure S16.

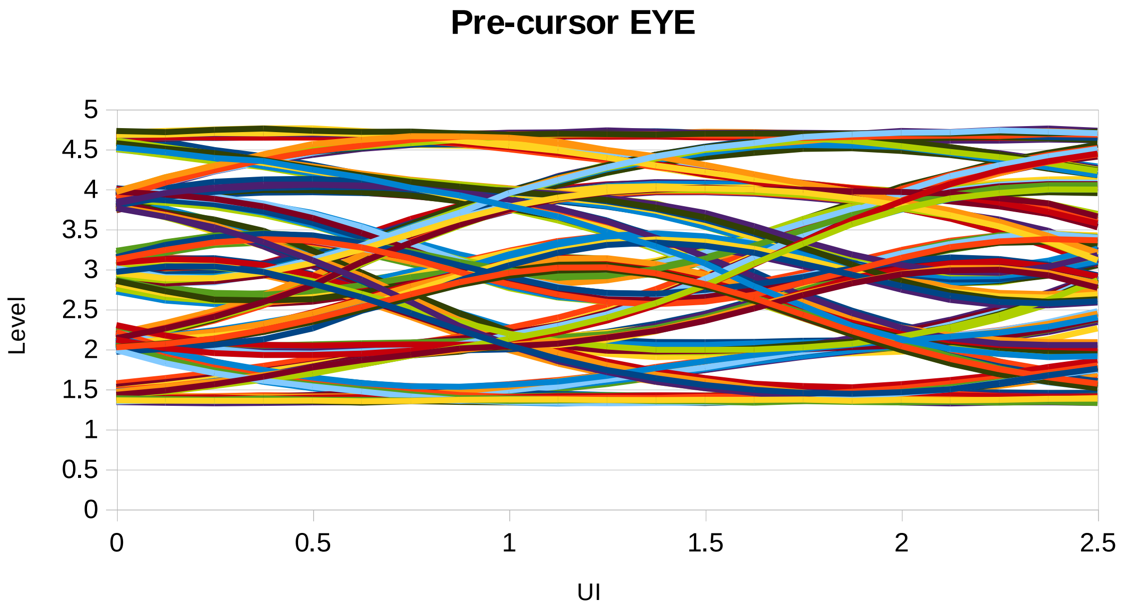


Figure S17.

Figure S18 is what an isolated ONE would look like after propagating down 220 meters of fiber with the energy in the modes as described in Table S1.

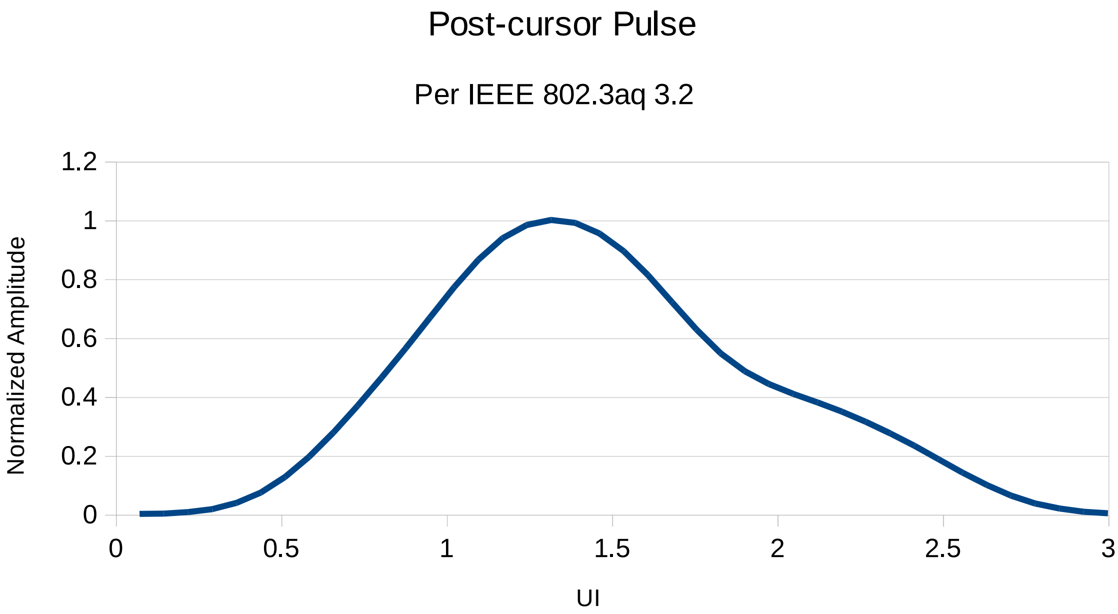


Figure S18

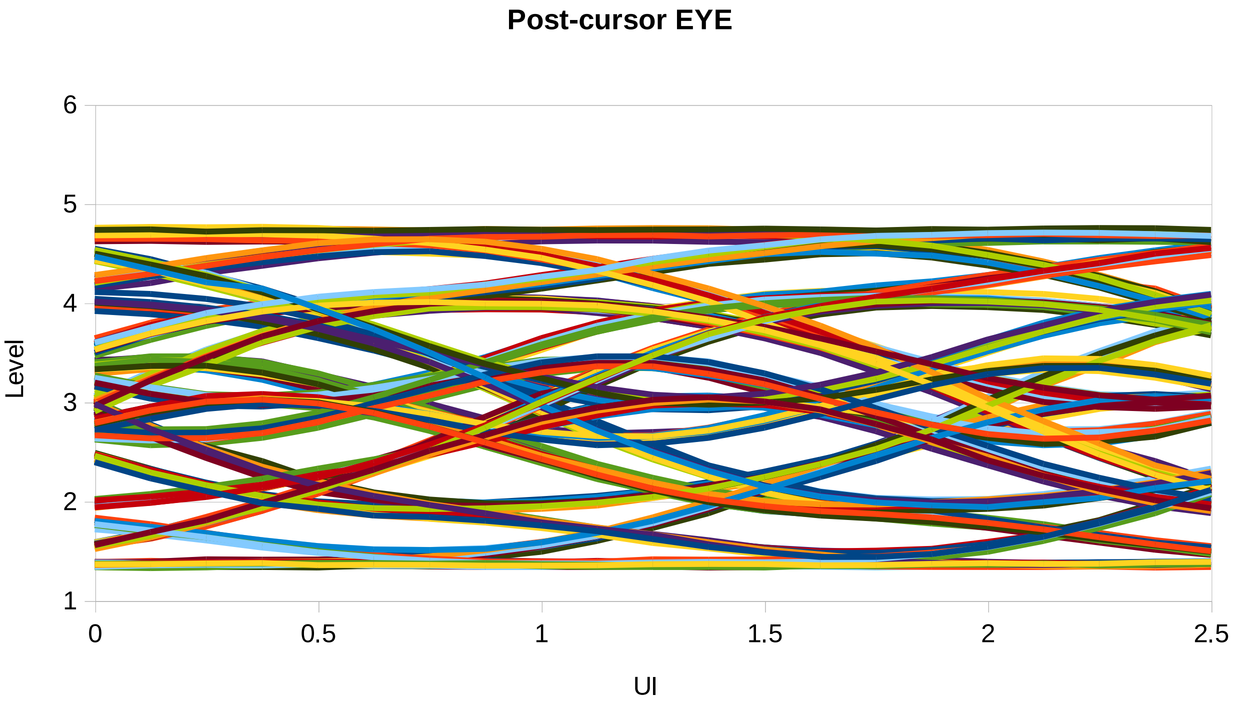


Figure S19.

The IEEE 802.3aq standard specifies these shapes (ISI) and specific signal to noise ratios as well. For a receiver manufacturer to comply with the standard he needs to assure his receiver can accurately decode a data stream with these levels of ISI. This decoding of the ISI to reveal a usable EYE is done using Electrical Dispersion Compensation or EDC chips. These devices are enabling the re-use of multi-mode infrastructure at data rates never considered when these fibers were installed.

9. Stressed EYE testing of Receivers.

Before year 2000 optical receivers were tested for Bit Error Rate (BER) using ideal signals. The EYE would be generated by a “golden” transmitter and the amplitude would most often simply be attenuated rather than sent through a length of fiber. As a result the signal at the receiver under test would be a low level (similar to real use in the field) but signal to noise inter-symbol interference, and jitter would all be better than what the receiver would experience in the field. Often each link in long haul systems was “engineered.” In other words not every receiver would work with every transmitter over every length of fiber. Finally, the idea of doing Bit Error Rate testing with stressed EYE signals was broached. The IEEE 802.3aq standard for 10GBASE-LRM is just one example. The imperfections in the EYE are specified to yield a worst case EYE. If the receiver can yield an acceptable sensitivity with that EYE, then it should work well in the field no matter which transmitter and fiber it is paired with. These standards specify amounts of low pass filtering, jitter, signal to noise, and inter symbol interference.

10. Signal to Noise

Signal to noise can be measured several ways. It can be expressed as a linear dimensionless ratio, or also in dB. The IEEE 802.3aq standard for 10GBASE-LRM uses a linear measurement for signal to noise called QSQ. Given by the equation:

$$QSQ = OMA/(Noise_{ONElevel} + Noise_{ZEROlevel})$$

Remember OMA is the optical modulation level. The noise on the ONE level and ZERO levels are measured on a sampling scope with the signal transmitting eight ONES followed by eight Zeros. This looks like a square wave. The sampling scope can report the standard deviation of the distribution in a defined X-Y box on the screen. Remember the scope does have this type of statistical information to give us the color-grade display. The OMA is merely the average value of the ONE level minus the average value of the ZERO level. However, the detector and amplifiers in the sampling scope also have noise. To get an accurate signal to noise measurement, we need to subtract out the scope noise for each of these levels. The scope noise is also likely to be a function of the vertical scale used for the measurement. To measure signal to noise first you get the scope on the desired vertical scale for the measurement of the eight ONES followed by eight Zeros. You then remove the signal from the scope. This yields a flat line on the screen. You then get the standard deviation of this flat line. The average will be zero, but the scope noise will be the standard deviation. The noise for the two optical levels is then calculated as follows:

$$\text{Noise}_{\text{ONElevel}} = \sqrt{\{[\sigma\ (\text{one level})]^2 - [\sigma\ (\text{scope background})]^2\}}$$

$$\text{Noise}_{\text{ZEROevel}} = \sqrt{\{[\sigma\ (\text{zero level})]^2 - [\sigma\ (\text{scope background})]^2\}}$$

where σ (scope background) is the standard deviation of the scope with no signal.
Where σ (one level) is the standard deviation of the optical ONE level and
σ (zero level) is the standard deviation of the optical ZERO level.

This subtraction in quadrature is possible because there is no correlation between the optical system noise and the sampling scope noise. The Signal to noise set points for the stresses are given in the following table.

Stress	**QSQ**	**Noise BW (GHz)**
Symmetric	37.2	7.5
Pre-cursor	45.6	7.5
Post-cursor	47.0	7.5

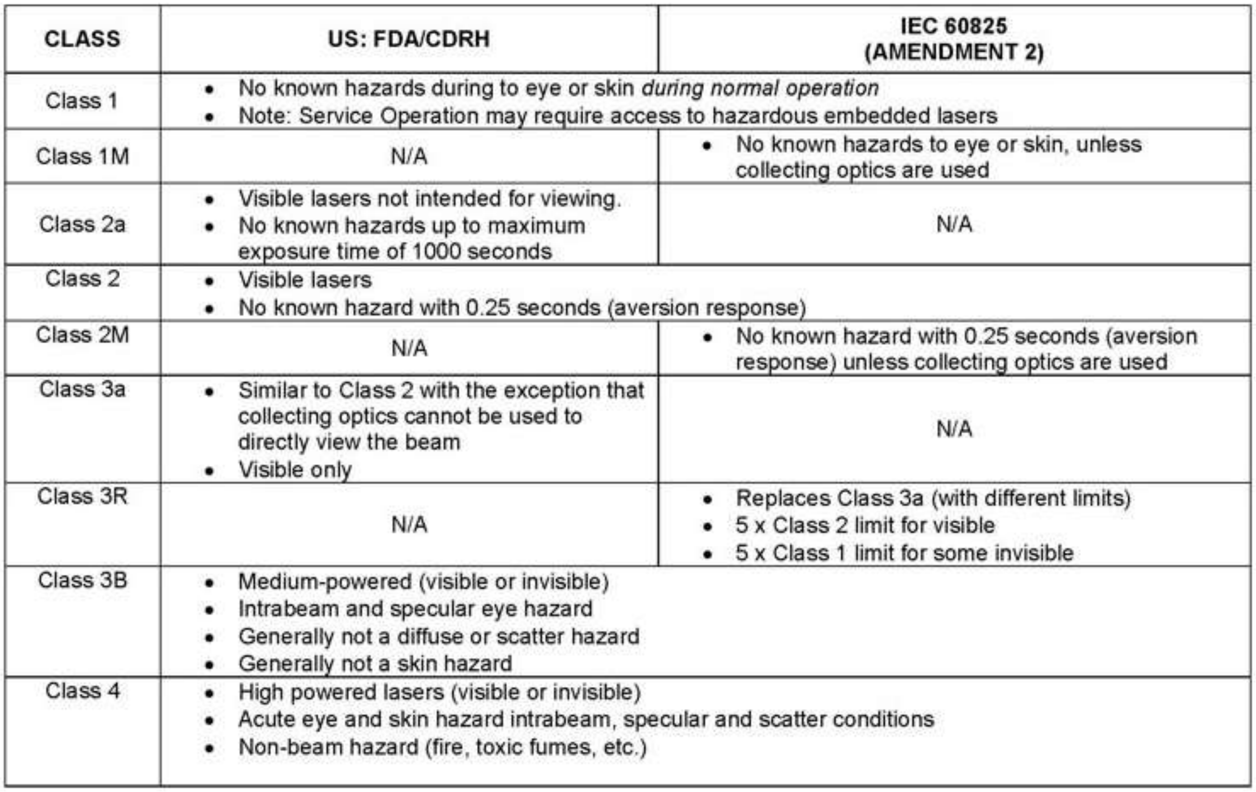
Table S2

The Noise BW refers to the bandwidth of the noise. It is white noise (i.e. constant noise containing all frequencies) put through a 7.5 GHz filter. By manipulating the signal to achieve the shapes of the Pre-cursor, Post-cursor and Symmetric pulses, and adding the required noise, a person can then use this stressed signal to test their receiver followed by an EDC chip.

11. Laser Safety

Nothing written in this section should be viewed as superseding any warning labels on equipment or any safety warnings in the technical manuals for the equipment. This section is a discussion of laser safety principles as they apply to fiber optic systems.

In the USA the FDA (Food and Drug Administration) is charged with regulating laser safety. The CDRH (Center for Devices and Radiological Health) is a division within the Food and Drug Administration. They have placed lasers into various classes according to power and wavelength. Internationally the IEC (International Electrotechnical Commission) has produced a similar scheme in their document 60825. The older Food and Drug Administration system used Roman numerals for the laser classes. The Food and Drug Administration and International Electrotechnical Commission have harmonized their systems, and Arabic numerals are used in the new system. This is briefly summarized in the figure below:



CLASS	US: FDA/CDRH	IEC 60825 (AMENDMENT 2)
Class 1	• No known hazards during to eye or skin *during normal operation* • Note: Service Operation may require access to hazardous embedded lasers	
Class 1M	N/A	• No known hazards to eye or skin, unless collecting optics are used
Class 2a	• Visible lasers not intended for viewing. • No known hazards up to maximum exposure time of 1000 seconds	N/A
Class 2	• Visible lasers • No known hazard with 0.25 seconds (aversion response)	
Class 2M	N/A	• No known hazard with 0.25 seconds (aversion response) unless collecting optics are used
Class 3a	• Similar to Class 2 with the exception that collecting optics cannot be used to directly view the beam • Visible only	N/A
Class 3R	N/A	• Replaces Class 3a (with different limits) • 5 x Class 2 limit for visible • 5 x Class 1 limit for some invisible
Class 3B	• Medium-powered (visible or invisible) • Intrabeam and specular eye hazard • Generally not a diffuse or scatter hazard • Generally not a skin hazard	
Class 4	• High powered lasers (visible or invisible) • Acute eye and skin hazard intrabeam, specular and scatter conditions • Non-beam hazard (fire, toxic fumes, etc.)	

Source: http://www.erchonia.com/references/laser-classifications

Figure S20.

In fiber communication systems the light is infrared and far below the power of lasers used to weld or cut metal. Therefore, the chief concern is damage to the eye. The designers usually assure that all the power is contained in the chassis and the fiber, making the systems class 1 for the end users. Installers and users of these systems are not likely to be exposed to harmful laser radiation. The usual signal wavelengths used are 850 nm, 1300 nm and 1550 nm. Now 600 nm is near the edge of your ability to see red. Laser pointers are about 630 nm. Somewhere above 1100 nm the light will not focus well on your retina. If you can see the light, your body will automatically protect itself. You will flinch, squint, blink, etc. The region of light between 600 nm and 1100 nm is of most concern. The energy can reach your retina, and **your flinch response will not protect you.** Your first knowledge of damage will be loss of vision due to retina damage. This has given rise to the cynic's first rule of laser safety, “Do not look into the laser with your remaining good eye.” Thankfully, most systems are 1300 and 1500 nm and the 850 nm systems are usually low power. The other thing that tends to protect the user is that the light out of the fiber diverges quickly. You can think of the light coming out of the fiber in about a 30º cone. So even if there is power in the fiber, the energy density will rapidly disperse with distance. This angular dispersion is enough to protect the worker, unless the power is very high or it is refocused. **Never look at the end of the fiber with any optics** (i.e. eye loupe, microscope, etc.) If you have to inspect the end of a fiber for damage, assure that the laser(s) are **OFF**. Many inspection scopes in the field use small video screens, or a filter such as KG3 glass, to preclude possibility of injury. Made by Schott, KG3 attenuates infrared while allowing visible light through. Perhaps the most dangerous laser in fiber systems is the pump laser for fiber amplifiers. They create a population inversion in erbium doped fiber. The population inversion without feedback causes the fiber to amplify 1550 nm light. These pump lasers are high power, and are usually around 980 nm. Remember, between 600 nm and 1100 nm is the most dangerous to the retina. Thankfully, the designers of the amplifiers assure all the 980 nm light is contained in the fiber amplifier. I have personally measured several of these while doing a survey for laser safety, and the 980 nm light was negligible outside the fiber amplifier. It should be noted that the 1550 nm light in systems with amplifiers can achieve very high powers +30 dBm (1000 mW) is common. Any dirt on the fiber connectors in these systems can be vaporized and immediately damage the fiber ends. Remember, the single mode fiber ends are only 9 µm. Another opportunity for injury comes from red fiber inspection lasers. These are often fairly high power approximately 1 to 5 mW (class 2 or 3R). They are usually HeNe (Helium Neon) with a wavelength of 633 nm. The red light is launched into the fiber, and any crack or bad fusion splice, etc. will scatter the red light, making the location of the fault obvious. The rule of never using magnification to look at the fiber end is especially important when using these red fiber diagnostic lasers. A fiber inspection scope with a video screen is the best choice since a filter such as KG3 will not protect well at 633 nm. However, these systems are safe. If you never defeat an interlock, and if you never look at an active fiber end especially with optics, you can safely work with these systems.