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# Lab 2: Attenuation and Pulse Spreading

## Summary

Optical power attenuation and pulse spreading in single mode fiber were investigated by obtaining power spectra, observing eye patterns, and performing bit error rate tests.

## Fiber attenuation

For a laser diode broadband light source Agilent 83437A, optical power spectra were obtained over the ranges 1310-1660 nm and 600-1700 nm. A 30-km length of step-index, single-mode fiber was introduced and the spectra taken again (Figures 1-4).

Viewing of the wideband spectra confirmed that the narrow band (1310-1660) was indeed the range of primary interest; outside this range the laser diode source displayed steep attenuation and noise.

A large dip in the optical power from the light source, centered at 1490 nm, probably results from hydroxyl attenuation introduced by the fiber carrier between the light source unit (across the room) and the experimental area.

The point power values for source and fiber were compared to obtain the attenuation spectra of the 30-km fiber length (Figures 5-6).

In addition to the expected attenuation, the fiber introduced a sinusoidal power variation. The variation period (found by averaging the wavelength differences between peaks) was 24.4 nm over the range 1310-1500 nm, 28.1 nm over the range 1500-1660 nm, and overall 26.5 nm over the range 1310-1660 nm. The cause of the variation was not determined. It was noted that the spooled bare fiber was exposed to ambient fluorescent room lighting. (The variation could represent artifacts of the spectrum of the ambient light being coupled into the fiber cladding.) It was noted also that the fiber ends and couplers had been washed in ethanol (a likely source of hydroxyl ion) a few minutes before introducing the fiber. Also there was an issue with connecting the fiber at the desired points.

The output of a small He-Ne red laser was introduced into a short length of fiber. The fiber was bent at a sharp angle. At the bend region, light could be observed escaping from the fiber cladding into the surrounding environment. This demonstrated attenuation due to macro-bending.

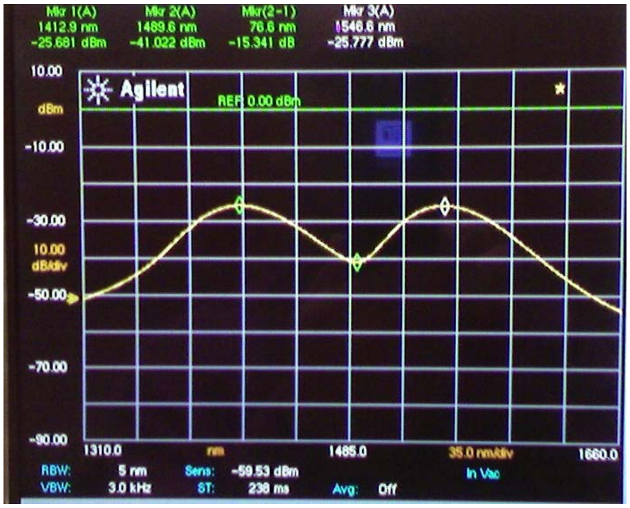


Fig. 1: Source spectrum, 1310-1660 nm

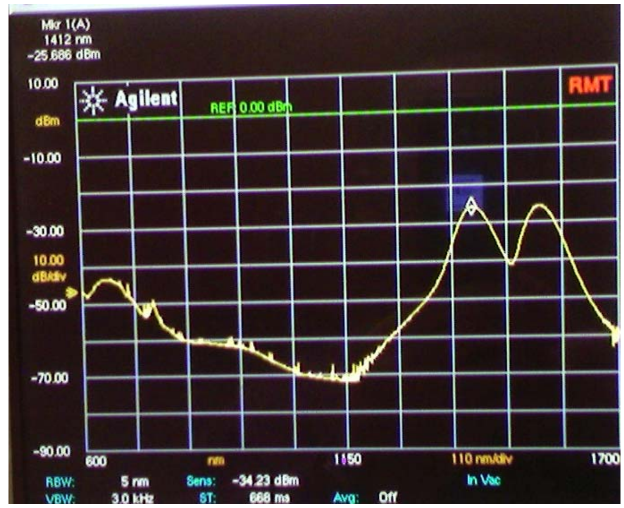


Fig. 2: Source spectrum, 600-1700 nm

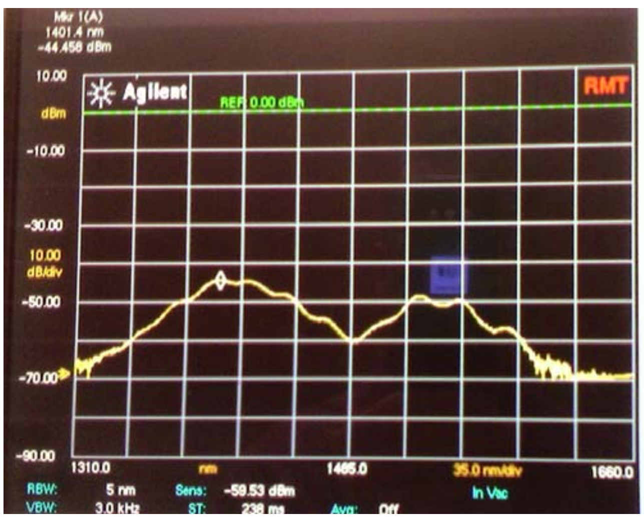


Fig. 3: Fiber spectrum, 1310-1660 nm

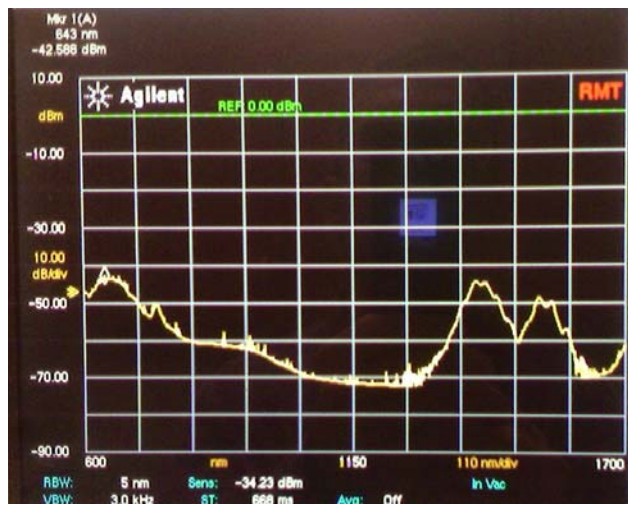


Fig. 4: Fiber spectrum, 600-1700 nm

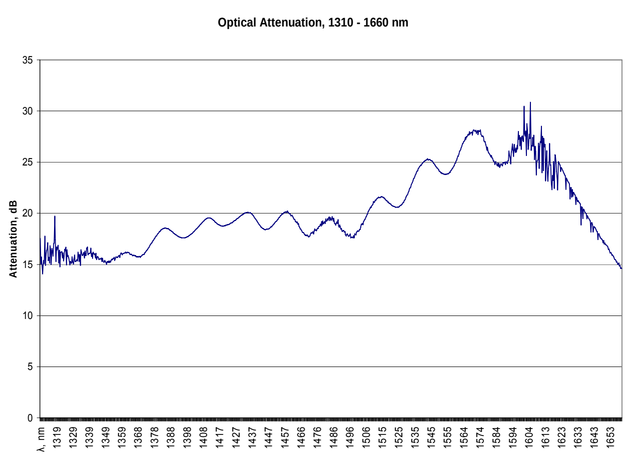


Fig. 5: Fiber attenuation spectrum, 1310-1660 nm

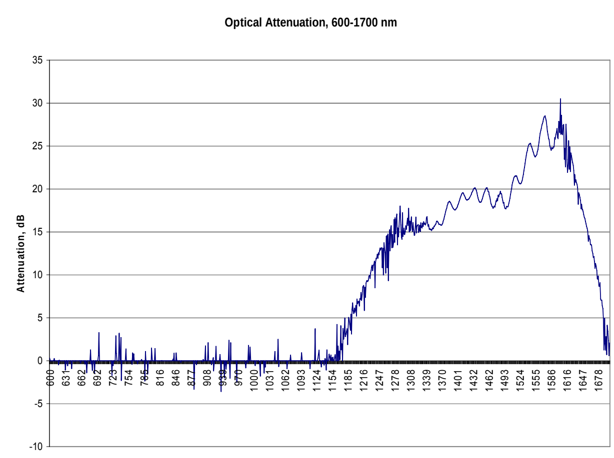


Fig. 6: Fiber attenuation spectrum, 600-1700 nm

## Bit pattern generation and stressed eye pattern

A bit pattern generator was used to modulate an optical transmitter/receiver setup. The reconstructed data were displayed on a digital communication analyzer (DCA) (Figure 7).

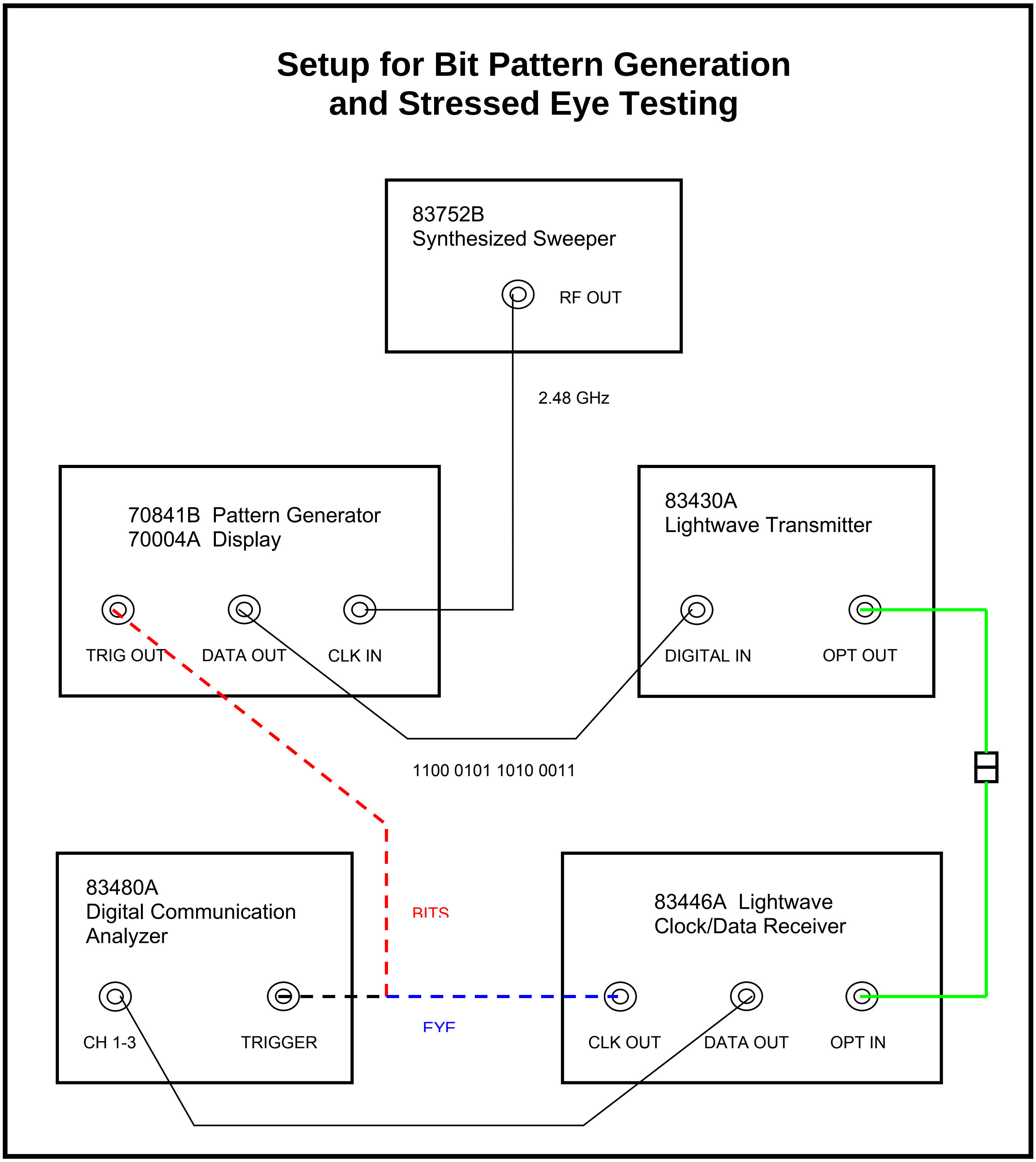


Fig. 7

Multiple cycles of the bit pattern were displayed on the DCA screen and the pattern verified against the setting in the pattern generator (Figure 8).

The setup was adjusted for display of eye pattern on the DCA screen (Figure 9). The bit rate and sync settings were adjusted and the resulting changes to the eye pattern display were noted (Table 1). The primary feature of interest was the appearance or absence of bit errors, indicated by individual points of “snow” outside the framework of the eye pattern (Figures 10-11). A rough quantitative assessment of greater and lesser error rates was easy to make, based on the amount of “snow” on the display.

Generally, bit rates considerably higher than the nominal 2.48 GHz were associated with many errors. Certain lower bit rate ranges yielded fewer errors or no errors; other ranges gave many errors (Table 1).

A 30-km length of step-index, single-mode fiber was introduced between transmitter and receiver. Bit rate and sync settings were adjusted and the resulting changes to the eye pattern display were noted (Figure 12, Table 1).

With bit rate 2.5328125 GHz and no fiber, the eye pattern showed no errors (Figure 9). With the same bit rate and the fiber introduced, a slow rate of errors was seen to accumulate over time (Figure 13). This experiment was repeated with the same results obtained. This is a clear qualitative demonstration of the effect of pulse spread (caused by some combination of material and waveguide dispersion in the fiber) on the occurrence of bit errors for a single data rate.

| f, GHz | no fiber | | with fiber | |
|---|---|---|---|---|
| | errors | observations | errors | observations |
| 4.96 | many | fuzzy eye | | |
| 3.72 | many | fuzzy eye | | |
| 2.56 | many | fuzzy eye | | |
| 2.54 | many | fuzzy eye | | |
| 2.53500000 | many | can sync but can't avoid errors | | |
| 2.53375000 | | | many | can sync but can't avoid errors |
| 2.53312500 | | | many | can sync but can't avoid errors |
| **2.53281250** | **none** | **fuzzy eye** | **few** | |
| 2.53273438 | none | slightly fuzzy eye | none | fuzzy eye |
| 2.53265625 | none | clean eye | none | clean eye |
| 2.53250000 | none | requires sync adjust | | |
| 2.53 | none | requires sync adjust | | |
| 2.52 | none | requires sync adjust | | |
| 2.48 | none | requires sync adjust | | |
| 1.24 | none | requires sync adjust (cleaner eye pattern) | | |
| 0.960 | none | requires sync adjust | | |
| 0.896 | few | requires threshold adjust (can't sync) | | |
| 0.768 | few | requires threshold adjust (can't sync) | | |
| 0.524 | many | can't sync, can't avoid errors | | |
| 0.512 | many | can't sync, can't avoid errors | | |
| 0.500 | none | requires threshold adjust (can't sync) | | |

Table 1. Eye pattern observations


Fig. 8: Source bit pattern

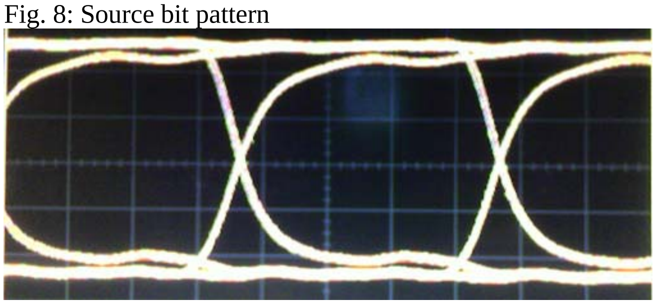
Fig. 9: Source eye pattern, no errors

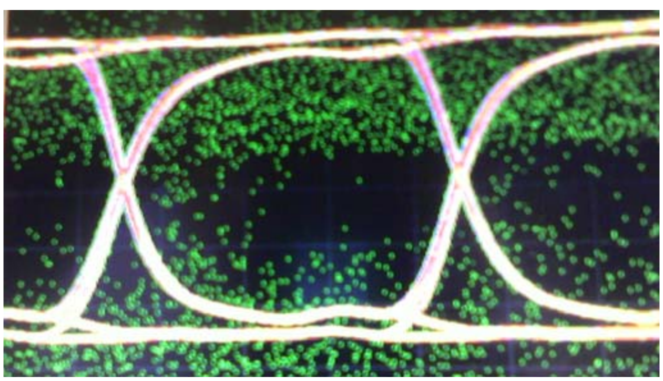
Fig.10: Source eye pattern with many errors

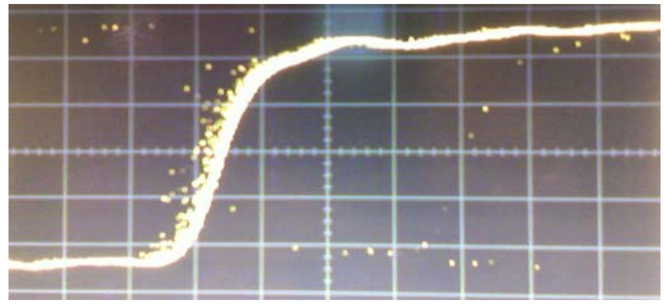
Fig.11: Source rise time with errors

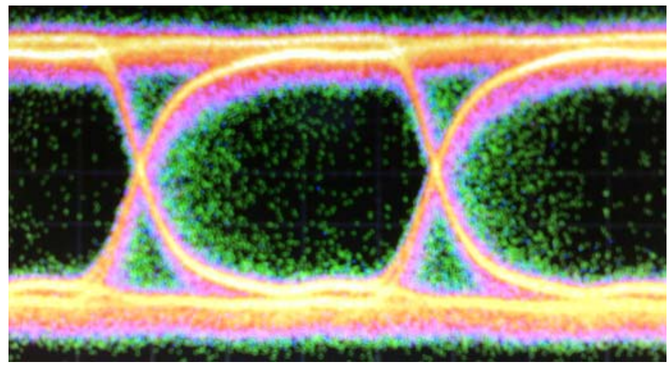
Fig.12: Fiber eye pattern, fuzzy with errors

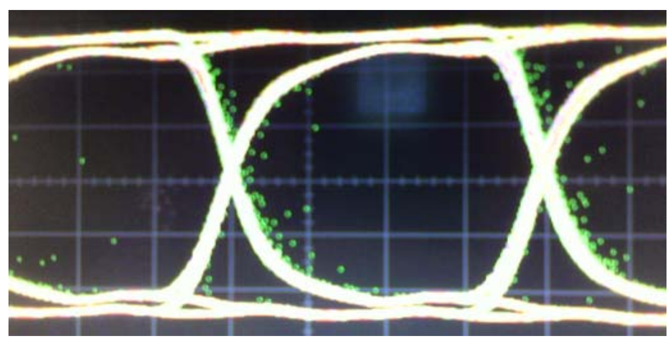
Fig.13: Fiber eye pattern, clean with few errors

## Bit Error Rate measurement

A bit error rate tester (BERT) was used to modulate an optical transmitter. The received and demodulated signal was catered back to the BERT for error analysis (Figure 14).

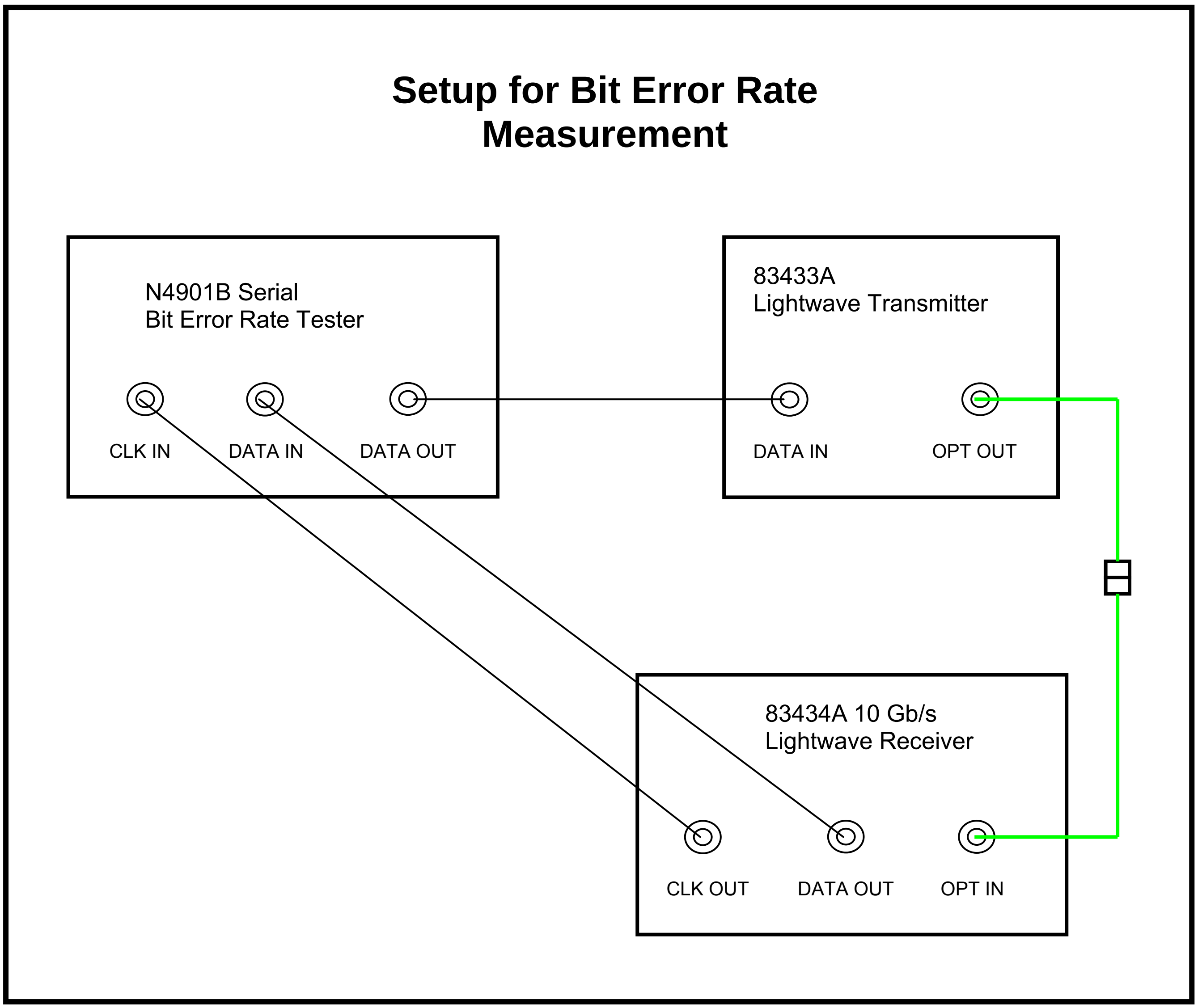


Fig. 14

With a default suite of BERT settings applied and a bit rate setting of just under 10 Gbps, an Auto Align was performed (Fig. 15). The Decision Threshold and Data Delay controls were adjusted, and the resulting effects on bit error rate were recorded. The observed results of modifying Decision Threshold (DT) are shown (Table 2).

| Decision Threshold, mV | occurrence of errors |
|---|---|
| < 506 | constant |
| 506 <= DT < 521 | few |
| 521 <= DT <= 985 | none |
| 990 | few |
| 995 | many |
| 1005 | constant |

Table 2. Results of adjusting Decision Threshold setting

For Data Delay settings between -3.3 ps and +65.7 ps, no errors were recorded by the analyzer. Outside this range, errors were recorded.

With both Decision Threshold and Data Delay in intermediate (error-free) position, bending the lightwave pigtail caused errors to be recorded.

A 30-km length of single-mode fiber was connected between transmitter and receiver. Auto-align was performed. With this setup, frequent errors were recorded by the analyzer, regardless of the settings for Decision Threshold and Data Delay (Figure 16). Using a 10 second single-pass window, the accumulated results over two trials for BER averaged **$0.702 \times 10^{-9}$ errors per second**.

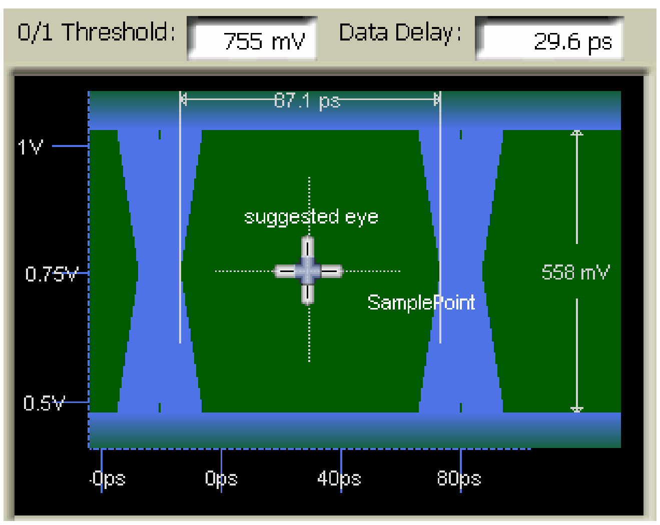

Fig. 15: Eye and sampling point, source only

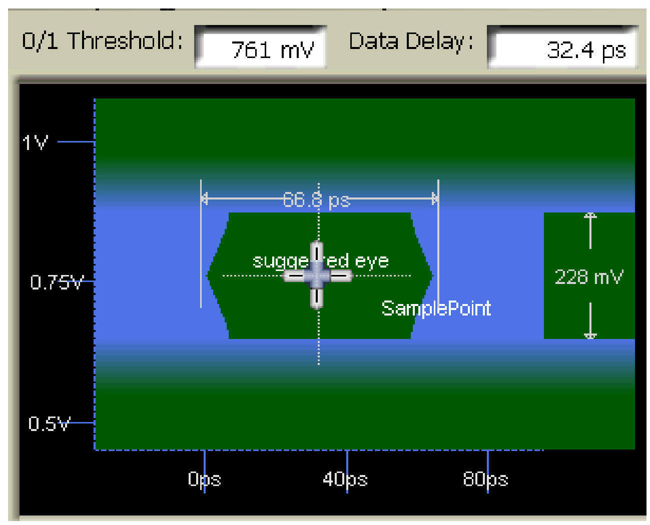

Fig. 16: Eye and sampling point, fiber

## Conclusion

Optical power attenuation in a length of fiber was demonstrated and evaluated quantitatively. Effects of source data rate variation on the occurrence of bit errors were shown qualitatively. Effects of pulse spreading on bit error rate at a single data rate in a length of fiber were evaluated.