Interoperability Demonstration of P1V1-2C2 Application Code for 120 km (2400 ps/nm) Reach using Alternate Modulation Schemes

Daniel Mahgerefteh, Azna LLC
Jerry Wood, Essex Corporation
Bob Behringer, Kodeos Communications
Matt Traverso, Opnext
Frank Chang, Vitesse

Test and measurement equipment provided by Agilent Technologies, Anritsu, JDSU, and Tektronix

Executive Summary:

Upgrading 2.5 Gbps networks to 10 Gbps with minimal capital expenditure requires standardization of extended reach technologies that eliminate the need for inline optical dispersion compensation. In consideration of this possibility, the Optical Interoperability Forum (OIF) has proposed a very long reach (VR) application code based on alternate signal modulation schemes to the International Telecommunications Union (ITU). This proposal was accepted and is now part of the ITU-T Recommendation G.959.1 as P1V1-2C2. In February 2006, a number of members of OIF successfully demonstrated transverse interoperability of the new application code with their transmitter-receiver pairs using a common optical link in a private demonstration. According to the requirements of the ITU-T G.959 P1V1-2C2 code, member companies demonstrated performance consistent with a preamplified receiver, NRZ 10G amplified eye mask, and dispersion penalty. The alternate signal modulation transmitters used in the private demonstration reduce the occupied signal bandwidth and increase tolerance to dispersion.

Impact of new application code:

Due to the lower cost of directly modulated lasers, which result in shorter transmission distances, a number of legacy 2.5 Gbps point-to-point fiber optic links are less than 120 km in length. Upgrade of these systems to 10 Gbps using conventional non-return-to-zero (NRZ) transmitters requires the use of inline optical dispersion compensation modules (DCM). The component and engineering cost of DCMs makes this an undesirable solution. Recently a number of dispersion tolerant transmitter technologies have been developed that can address the 120 km (2400 ps/nm) reach using alternative modulation schemes. Examples of extended reach transmitters are optical duobinary modulation and chirp managed directly modulated laser technologies (CML), both of which use standard NRZ receivers without EDC.

A viable solution with multiple vendors and technologies requires adherence to a standard. Responding to this market view, OIF member companies have taken the initiative to work with ITU via liaison to develop a new standard application code for 120 km (2400 ps/nm) at 10 Gbps. In the past two years, OIF companies have provided data to support a proposed code and have developed the parameters in accordance with feedback from ITU through the liaisons. Table 1 shows the new application code, P1V1-2C2. Figure 1 is a schematic of the link and defines the interface points MPI-S, which is the input to the link and MPI-R which is the output of the link. The input and output points of the link are treated as black boxes allowing for inclusion of additional optical components with the transmitter and receiver modules. Note that ITU codes specify the link performance of the MPI-S and MPI-R points. For interoperability purposes, the OIF, on the other hand, specifies the input and output of the transmitter and receiver and treats the link as a black link.

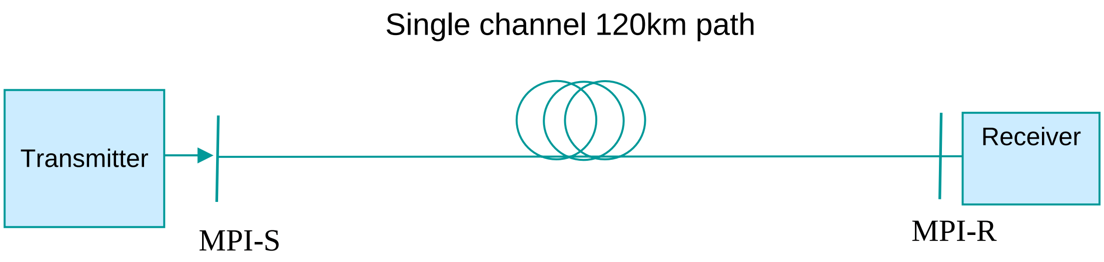


Figure 1. Schematic of link defining the interface points

Parameter	Units	P1V1-2C2
General information	–	
Maximum number of channels	–	1
Bit rate/line coding of optical tributary signals	–	NRZ 10G
Maximum bit error ratio	–	10^{-12}
Fibre type	–	G.652
Interface at point MPI-S		
Operating wavelength range	nm	–
Central Frequency	THz	192.1
Maximum central frequency deviation	GHz	40
Source type	–	SLM
Maximum spectral power density	mW/ 10 MHz	ffs
Minimum side mode suppression ratio	dB	30
Maximum mean output power	dBm	+7
Minimum mean output power	dBm	+4
Minimum extinction ratio	dB	9
Eye Mask	–	NRZ 10G Amplified
Optical path from point MPI-S to MPI-R		
Maximum attenuation	dB	33
Minimum attenuation	dB	21
Maximum chromatic dispersion	ps/nm	2400
Minimum optical return loss at MPI-S	dB	24
Maximum discrete reflectance between MPI-S and MPI-R	dB	-27
Maximum differential group delay	ps	30
Interface at point MPI-R		
Maximum mean input power	dBm	-14
Minimum sensitivity	dBm	-30
Maximum optical path penalty	dB	1
Maximum reflectance of optical network element	dB	-27

Table 1. The P1V1-2C2 application code parameters

Loss Budget and Receiver:

The P1V1-2C2 application code calls for a preamplified receiver in order to achieve required sensitivity. A number of vendors provided data to support a +4 to +7 dBm output power from the alternate modulation scheme transmitters. The link loss budget is 33 dB maximum and the required preamplified receiver sensitivity is -30 dBm minimum.

Definition of Mask:

The P1V1-2C2 standard requires compliance with the ITU's NRZ 10G amplified eye mask. Figure 2 shows eye diagrams for optical duobinary modulation and chirp managed laser (CML) technology with an amplified eye mask superimposed on the image. The receiver is required to have the minimum sensitivity -30 dBm when the stressed transmitter output complies with this mask. The amplified eye mask allows the central region of the mask to move in the eye whereas the more familiar NRZ 10G 1550 eye mask is fixed in both time and amplitude relative to the optical eye.

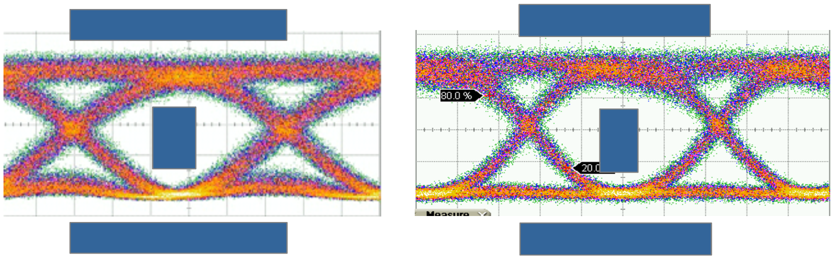
This mask modification is necessary for extended reach applications. For the applications that do not require dispersion tolerance, the transmitter can have fast rise times and fall times, high extinction ratios, and symmetric crossing. This allows the eye to be square like and be compliant with a symmetrically centered mask, often with excess margin relative to that required by ITU. The requirement of dispersion tolerance puts physical limits on the bandwidth and symmetry of the transmitted signal, which affect the transmitter output eye mask. Extended reach transmitters tend to have relatively longer rise times and fall times, which is necessary for bandwidth reduction, and tend to have an optical crossing which is higher than 50%, which leads to an asymmetric eye in the vertical direction. The NRZ 10G amplified eye mask was therefore chosen to accommodate these factors. The amplified eye mask allows the center box to move up and down on the voltage axis relative to the 1s and 0s rails and right and left on the time axis relative to the edges of the eye diagram.

Note that mask margin is not indicative of good transmission performance in this application. This is because extended reach is a result of phase correlation between the bits imposed by the alternate signaling schemes, which does not appear in eye diagram measurements. Also large mask margins usually associated with good transmitter performance for short reach and dispersion compensated applications are no longer practical with the extended reach transmitters. As it was determined by OIF and ITU the key transmission performance indicator for the P1V1-2C2 is simply dispersion penalty.

P1V1-2C2 Eye Mask Definition

	NRZ 10G Amplified
x_3–x_2 (Note 2)	0.2
y_1	Δ + 0.25 (Note 1)
y_2	Δ + 0.75 (Note 1)
y_3	0.25
y_4	0.25

NOTE 1 – Δ is a variable $-0.25 < \Delta < +0.25$
NOTE 2 – x2 and x3 of the rectangular eye mask need not be equidistant with respect to the vertical axes at 0 UI and 1 UI.



Optical Duobinary Chirp Managed Laser

Figure 2. Eye mask definition for the P1V1-2C2 application code

Interoperability test setup:

Figure 3 shows the test setup used for the interoperability demonstration between the five participating companies. The outputs of the five transmitters are combined using a 1 x 8 fiber splitter, and the multiplexed channels are optically amplified to compensate for the splitter loss. A Tektronix Communication Signal Analyzer (CSA) is used to monitor the eye diagrams, one of which is selected at a time by an optical filter. The multiplexed signals are transmitted through 150 km of standard single mode fiber having a nominal 16.2 ps/nm/km dispersion, providing ~ 2430 ps/nm at the wavelength of 1540 nm. An optical demultiplexer separates the channels after they pass through an optical amplifier. The five separated WDM signals enter five receivers, each from a different participant company.

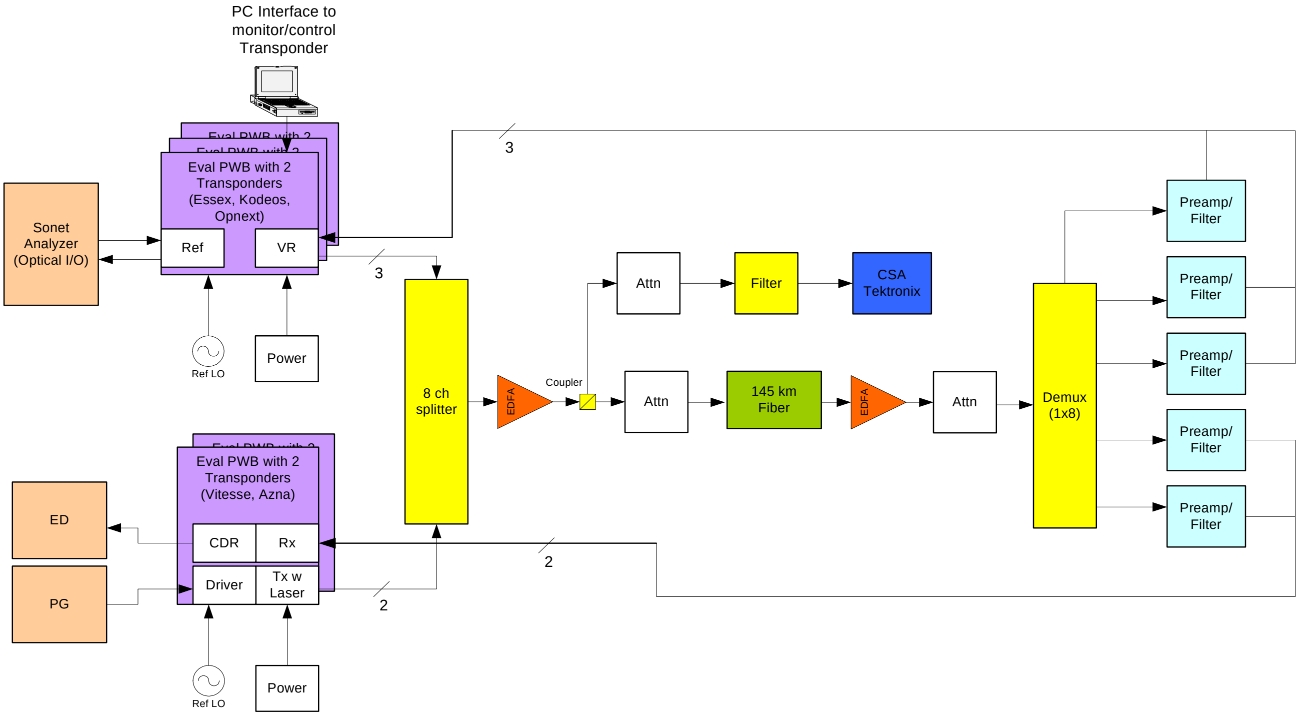


Figure 3. Schematic of interoperability test setup supporting P1V1-2C2 application code

A complete array of tests was performed between the various Tx/Rx pairs, two pairs at a time, in a separate, private test site, using an equivalent transmission system. In each case, 10^{-12} BER sensitivity was demonstrated back-to-back and after ~2400 ps/nm by using transmitter from vendor X with receiver provided by all other vendors.

Figure 4 shows bit error rate performance of two example transmitter-receiver pairs for back-to-back (0 ps/nm) and after ~ 2300 ps/nm as a function of optical signal to noise ratio (OSNR) in 0.1 nm bandwidth. In one case, transmitter from company X is paired with receiver from company Y, while in the other, transmitter from company Y is paired with receiver from company X. The decision threshold on the CDR was optimized for best BER at each OSNR. The required OSNR for 10^{-12} BER was ~22.0 dB for back to back in both Tx/Rx configurations. The dispersion penalty was -1 dB in one case and -0.5 dB in the other. The last data point in each case indicates error free operation (no errors for 5 minutes), and demonstrates the interoperability of the various Tx/Rx pairs provided by the participating companies. The performance is expected to be similar for 2400 ps/nm called out by the application code. This was verified for a particular Tx/Rx pair for 2600 ps/nm, where no additional dispersion penalty was observed at the longer reach.

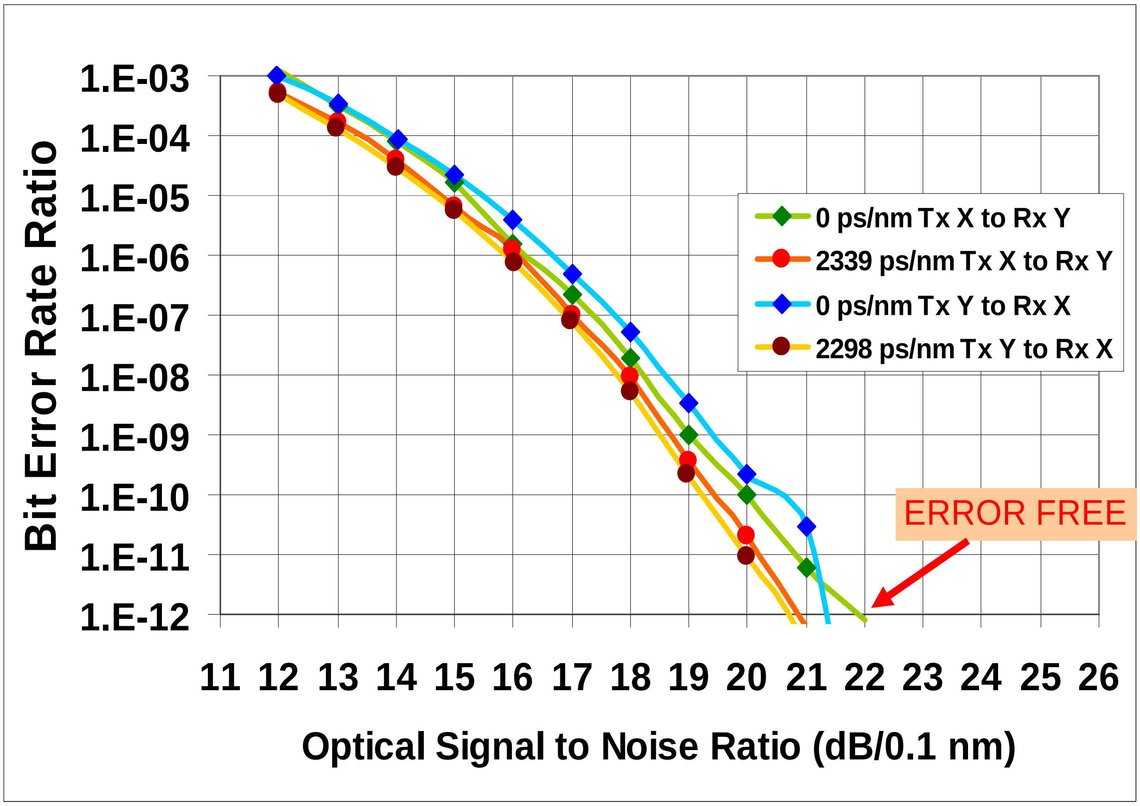
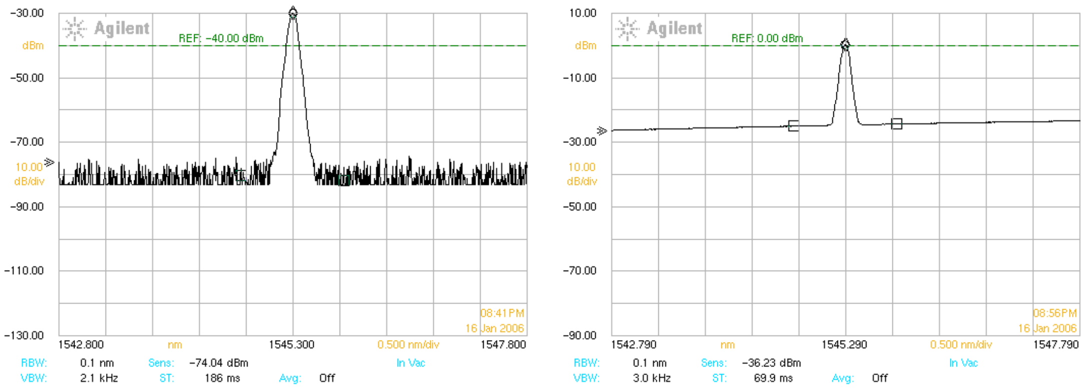


Figure 4. OSNR performance of two Tx/Rx pairs showing interoperability

Note that interoperability was established by measuring BER versus OSNR because an appropriate low noise preamplifier was not available at the private testing. However, these two tests are equivalent. A preamplifier that has a 3.5 dB NF with a -30 dBm input provides a signal out with an OSNR of ~24.5 dB. Figure 5 illustrates the input signal and output signal for the condition described. In this figure, the output OSNR is ~24.9 dB indicating a noise figure of less than 3.5 dB. For interoperability testing, we verified each of the modules had OSNR performance back-to-back and through fiber of better than 24 dB for a 10^{-12} BER allowing for end of life performance margin.



Input to Preamp   Output from Preamp

Figure 5. OSN from a representative preamp for the P1V1-2C2 application code

Conclusion:

In conclusion, the participating member companies have successfully demonstrated the interoperability of their transmitter-receiver pairs towards the new P1V1-2C2 application code addressing the 2400 ps/nm reach. This new standard, supported by optical duobinary and chirp managed laser technologies demonstrated by participating companies, will enable the low cost upgrade of 2.5 Gbps metro systems to 10 Gbps without the need for additional dispersion compensation.