TXFP+/MLSE Ecosystem will enable a cost effective 10G DWDM Transmission over Metro Transport and Metro Ethernet Networks

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- **Abstract:** Growth in communication bandwidth is fueling the need for Metro and Regional DWDM networks to provide more transport bandwidth. This will put a burden on network equipment suppliers to produce a bandwidth efficient system with reduced power and cost as well as increased port density per line card. Clariphy's MLSE engine CL1012 and tunable/pluggable XFP module (TXFP+) is the solution that will enable suppliers to meet the bandwidth requirements of tomorrow.

1. Growth in Communication Bandwidth

A major driver for increased growth in Communication Bandwidth is the growing demand for video delivered over the internet, as well as other high-bandwidth services such as internet browsing and data, and video communications. Both the business and residential sectors are showing an increasing demand for higher quality, faster speed at a lower cost. These growing demands are creating greater challenges for service providers as they scramble to meet the needs of their customers. Providers are making significant investments in fiber infrastructures to deliver business, transport and residential services, and carrier ethernet is emerging as an important access and backhaul technology around the globe.

Low speed metro networks consisting of SONET/SDH 2.5Gb/s WAN connections only relocate service problems from one part of the network to another [3]. As access networks are making the transition from TDM to IP over Dense Wavelength Division Multiplexing (DWDM) connectivity in support of new packet based services, and as wireless carriers are moving from 3G to 4G mobile technologies, metro/regional networks are coming under increasing pressure to provide the necessary transport bandwidth. This environment is driving a rapid transition to 10G transport in regional and metro networks in order to keep up with bandwidth demand.

2. Solution - Value of TXFP+ecosystem

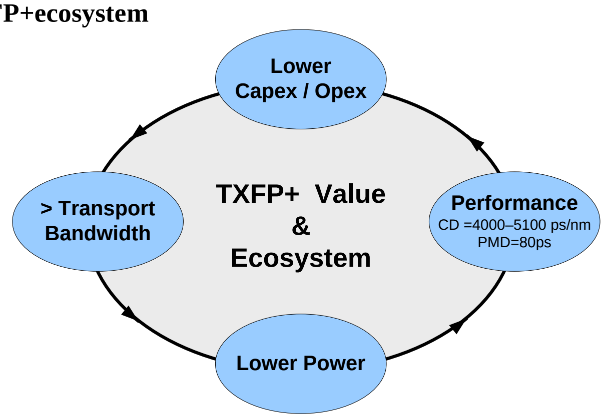

Figure 1.0 TXFP+ / MLSE Value Proposition

There is a demand for increased bandwidth and better performance, but without a significant increase in cost. TXFP+ ecosystem provides the solution using Clariphy's EDC (Electronic Dispersion Compensation) technology known as Maximum Likelihood Sequence Estimation (MLSE) and a pluggable, tunable XFP module known as TXFP+. As shown above in Figure 1.0 this ecosystem will address the expectations of lower CAPEX and OPEX, an increase in performance, increased bandwidth, and an overall lower power solution.

TXFP+ ecosystem with the MLSE engine provides a low cost 10Gb/s upgrade from 2.5Gb/s networks in the metro access and core. It eliminates the need for Dispersion Compensation Modules (DCM) and provides an Optical Signal to Noise Ratio (OSNR) dividend to Network architects. For regional haul or longer metro links it provides Polarization Mode Dispersion (PMD) tolerance. Components of the Ecosystem will be addressed in the next sections.

3. Increasing Bandwidth by Increasing Port Density (TXFP+ vs. 300PIN MSA Tunable)

Shown below in Figure 2.0 is a comparison between two DWDM 50 GHz C-Band tunable 10G optical modules. The 300pin MSA transponder is twice the size and power as a standard XFP module. There are multiple advantages of the tunable TXFP+ vs. 300pin MSA modules. The first is pluggability, which provides cost flexibility to the network engineer. The network engineer can select a TXFP+ module per reach application (10, 40, &80km), and control cost. The second and most important is the increase in port density. Using TXFP+ modules can provide 20Gb/s of aggregate bandwidth vs. 10Gb/s in the same given space. As shown in the Figure 2.0, TXFP+ modules will enable the development of line cards having up to 160Gb/s (16x10G/) ports to be deployed in a 19” rack vs. the 300pin module only supporting 80Gb/s (8x10G).

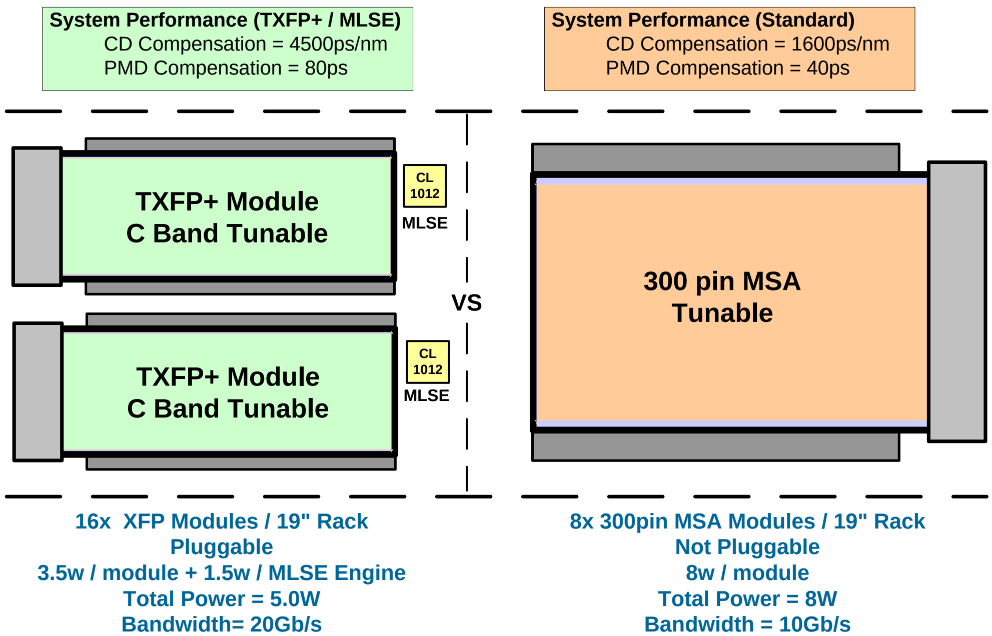

Figure 2.0 Comparison between TXFP+ / MLSE vs 300PIN MSA tunable modules

The third advantage over a standard 300pin MSA module is performance. The solution allows the end customer to use an XFP module with an external EDC/MLSE. Since the XFP module is enclosed there are power constraints of 3.5w max. Since the TXFP+ solution has a linear RX interface shown below in Figure 3.0, it allows use of an external MLSE engine like Clariphy’s CL1012 product. Adding additional power/performance, like MLSE, is not feasible due to the fact that the tunability and performance of the XFP module already adds increased power. The TXFP+ ecosystem provides an ultimate solution of performance, power, DWDM tunability and size.

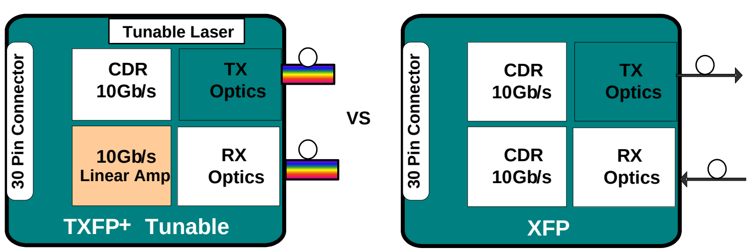

Figure 3.0 Comparison between TXFP+ vs Standard XFP module

Figure 3.0 shows a high level block diagram of TXFP+ vs. a standard XFP module. As one can see, there are two main differences between the modules. First is the tunable laser and the second is a linear RX interface which enables an external MLSE engine. The TXFP+ / MLSE engine support all 10G protocols: 9.953 Gb/s (SONET/SDH), 10.3125 Gb/s (Ethernet), 10.518 Gb/s (Fibre Channel), and corresponding G.709 rates of 10.66, 10.709, 11.04, 11.09, and 11.32 Gb/s.

4. Reducing CAPEX and OPEX for Metro Access, Metro Core and Regional DWDM Networks

Currently, the majority of metro access and core networks still operate at 2.5Gb/s transmission, however due to the demand for increased bandwidth, more and more service providers are moving to 10Gb/s. Clariphy's TXFP+/MLSE ecosystem addresses the demand for high density tunable pluggable optics and eliminates the need for optical dispersion compensation in 2.5Gb/s to 10Gb/s upgrades. Tunable modules have gained significant traction in metro, regional and long haul networks for using 300pinMSA transponders. With the pressure to upgrade networks from 2.5Gb/s to 10Gb/s, the network equipment manufacturers are actively seeking electronic dispersion compensation technologies in order to reduce the costs associated with optical dispersion compensation elements.

For many service providers, it is simply not cost effective to install/upgrade to 10Gb/s network equipment, since they have not fully utilized their existing 2.5Gb/s networks. Thus the increase in baud rate would cause additional Chromatic Dispersion (CD) in the link, which would create the need to add optical dispersion compensation and additional EDFAs, thereby increasing the cost. Adding optical components would cause the interruption of service in order to add the compensators, and EDFAs, increasing OPEX. The alternative is to use electronic dispersion compensation like MLSE, which can compensate CD and PMD, so that 10Gb/s traffic can be added to a metro network previously designed for 2.5G traffic.

5. Past and Future Metro access and Metro Transport Architecture (Ring, Mesh, and Point to Point)

Sonet/SDH was the transmission protocol of choice in the late 90's and early 2000's. It has been at the core of provider/carrier networks for many years, providing reliable services at 2.5Gb/s and 10Gb/s over links of 10km, 40km, 80km, and for 2.5G metro rings, mesh, point to point networks and access points of 120km, 160km, and 240km. DWDM networks provided wavelength services for OC-48/STM-16. 2.5Gb/s links were multiplexed down a single mode fiber using DWDM. This provided a low cost solution for increased throughput/bandwidth over a longer distance for both Metro and Regional networks. Today 75% of the DWDM long haul is 10Gb/s whereas only 20% is 2.5Gb/s. In the metro this is a different story as the current 10G ports make up only approximately 25% of the market, with the remaining 75% less than or equal to 2.5G.

With the introduction of Optical Transport Network (OTN) ITU-T G.709, a digital wrapper was added to the SONET/SDH frame / payload to produce a robust transmission with the introduction of Forward Error Correction (FEC). OTN/G.709 provided a cost effective 10Gb/s transmission for long haul networks. It provided a transparent transport of client signals (Ethernet, SONET/SDH, Fibre Channel, HDTV, ESCON etc), 6 levels of Tandem Connection Monitoring (TCM), performance monitoring/automatic provisioning similar SONET/SDH protocol. With GFEC operation the channel can be run at 8e-5 and decoded to 10-15. With EFEC operation the channel could be run at 2.0e-3 and decoded to 10e-15 [3]. FEC plus EDC/MLSE is a powerful combination that can attenuate the optical impairments sufficiently to enable the upgrade of the current metro network to 10Gb/s service. With this combination (FEC/MLSE) 10G Ethernet and IP over DWDM can be transported over metro and regional haul links. The next sections will discuss optical impairments and electronic compensation.

6. Optical Impairments

Random Noise – FEC will compensate
EDFA's add noise to the signal
Electrical noise in electronics
Inter-Symbol-Interference (ISI) – Dispersion – MLSE will compensate
Chromatic Dispersion (CD)
Polarization Mode Dispersion (PMD)
Electrical Bandwidth limitations
Non-Linearities
XPM, FWM, and SPM.

Dispersion is classified into two broad categories, Chromatic Dispersion (CD) and Polarization Mode Dispersion (PMD). All fibers show some degree of dispersion due to the non-ideal nature of the fiber medium. The two types of dispersion arise from different effects within the fiber, but both types of dispersion have the effect of spreading out the energy of each transmitted pulse and potentially causing ISI/bit errors.

Chromatic Dispersion (CD)

Different wavelengths travel at different speeds in fiber. As the data speed increases, so does the data bandwidth which in turn increases the speed difference among the different wavelengths. This impairment causes data pulses to smear into their neighboring bits. This smearing effect due to speed difference produces ISI, is known as CD. As the data rate increases, ISI increases. Therefore, CD is more pronounced at data rates of 10Gbps. A system today running at 2.5Gb/s will see 16x increase in CD at 10Gb/s. The CD is measured by a parameter D in ps/nm*km by fiber manufacturers, where bandwidth is given in nm, the fiber link length is given in km, and the pulse expansion is given in ps. A fiber with D=17 ps/nm*km will generate 1360 ps/nm CD at 80km distance.

Polarization Mode Dispersion (PMD)

At a given time, the light travelling in fiber can be represented by two orthogonal or polarized signals. These orthogonal signals will travel at different speeds when the fiber core is asymmetric. When these two orthogonal signals are detected by the optical receiver, they are combined. Since one is delayed with respect to another, it would smear into the neighboring bits, causing ISI. The ISI caused by this asymmetry is called polarization mode dispersion (PMD). Differing from CD, the PMD effect is a random process since the effects that cause asymmetry in fiber are random: external facts like stress on fiber, temperature, or manufacturing defects all contribute. It is approximated by a maxwell distribution and its mean value is given by fiber manufacturers with a parameter P in ps/km1/2. For already laid fibers, P value can be as high as 10 ps/km1/2 where as for new fibers, this value is as low as 0.1 ps/km1/2. Therefore PMD impairments caused by old fibers in metro links can be as dominant as CD. For regional, long and ultra-long hauls, PMD is an impairment that needs to be addressed. The random nature of PMD requires adaptive compensation techniques (CL1012).

7. Maximum Likelihood Sequence Estimation (MLSE) – Clariphy's 1012

MLSE is a form of Digital Signaling Processing (DSP) to compensate signal dispersion and aims to compensate optical impairments that affect the signal during the propagation in fiber. It is considered as a key solution for future networks able to provide better economics and ease the network design burdens.

To deal with ISI, an MLSE receiver compares a long section (several symbols long) of the noisy received signal with all the possible waveforms of the same length that could be received in the absence of noise. See Figure 4.0 below

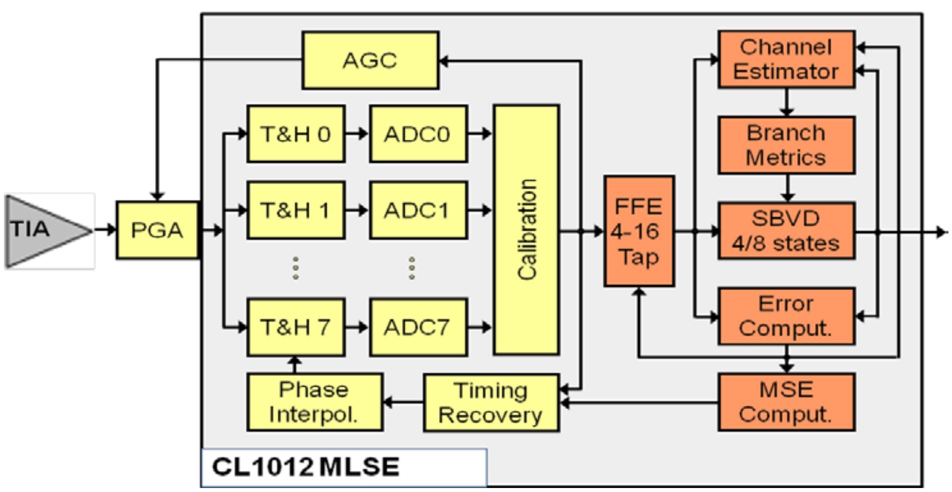

Figure 4.0 High Level Block Diagram of the CL1012 MLSE Product

8. DWDM Transport - ROADM / OADM

There are three major DWDM architectures a 1.) Point-to-Point Link (Dark Fiber), 2.) Mux/Demux OADM, and Reconfigurable-OADM (ROADM) architectures. This paper will address PT-PT and ROADm.

A ROADM is a form of optical add-drop multiplexer that adds the ability to remotely switch traffic from a WDM system at the wavelength layer. This allows individual wavelengths carrying data channels to be added and dropped from a transport fiber without the need to convert the signals on all of the WDM channels to electronic signals and back again to optical signals. The main advantages of the ROADM are: 1.) allows for remote configuration and reconfiguration. 2.) allows for automatic power balancing of signals. 3.) Multi-degree ROADMs are the key to metro and regional networks. They offer all the benefits of dynamic bandwidth allocation and protection schemes. In the long haul space today, ROADM's are equipped with DCM elements to compensate chromatic dispersion. DCM compensation adds cost to the overall system. Plus DCMs adds insertion loss and needs to be followed up with an EDFA which are also expensive. By managing the dispersion through the link one can eliminate DCM and EDFA blocks from the network. Below in Figure 5.0 is a 10G transport line card showing the TXFP+ ecosystem using Clariphy's MLSE engine. On the client side of the network it can receive all types of 10G traffic, add the G.709 overhead plus FEC and transport the signal on the line side.

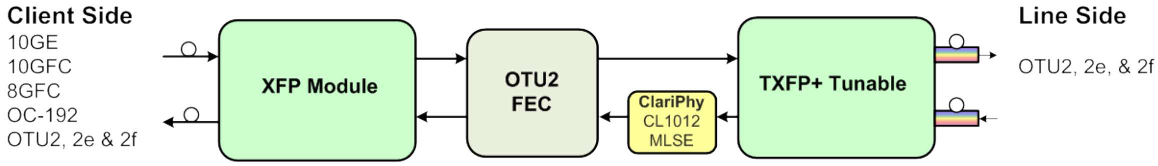

Figure 5.0 DWDM 10G Transport Solution with TXFP+ Ecosystem

Shown below in Figure 6.0 is an example of a Metro Access and Metro Core DWDM Transport network. The architecture consists of access links of 80-120km and within the DWDM ring links consists of 40-280km. The protocol is OTN, OTU2 transmission (10.709/11.095Gb/s). For this application only EDFA's are needed for signal attenuation. DCM elements are not needed when using the TXFP+ ecosystem. The CL 1012 (MLSE) mitigates chromatic dispersion. This will save on both CAPEX and OPEX. For this type of application the network is OSNR and dispersion limited. The combination of FEC and MLSE can compensate for optical noise and CD. So the network engineer responsible for this link would need to understand OSNR penalty vs span performance. Usually in this case OSNR would range from 10-20dB. Figure 8.0 shows a graph of OSNR penalty vs span (chromatic dispersion) for a BER =1e-3 with a fixed RX optical power at baud rate of 10.709Gb/s. The data shows a 5.0dB OSNR penalty for a 294km link. Without MLSE technology the link budget with an OSNR penalty of 5dB would be a100km link vs 294km. .

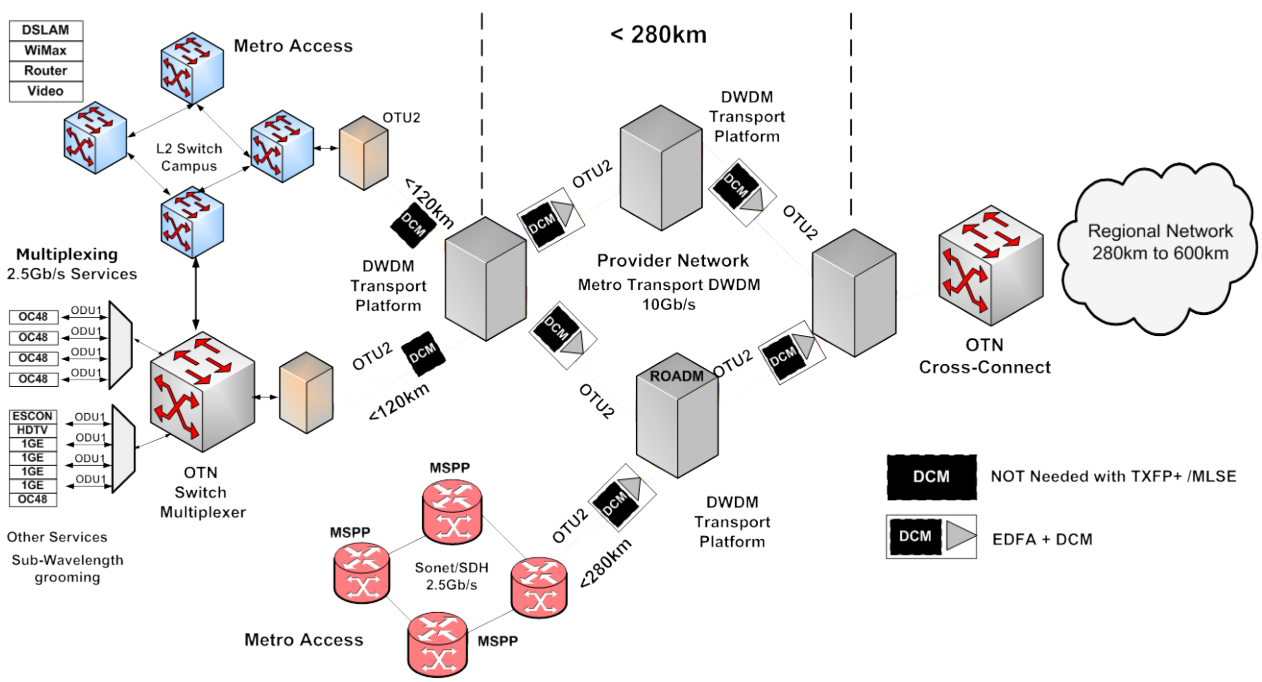

Figure 6.0 Upgrading links from 2.5Gb/s to 10Gb/s in the Metro Access and Metro Core

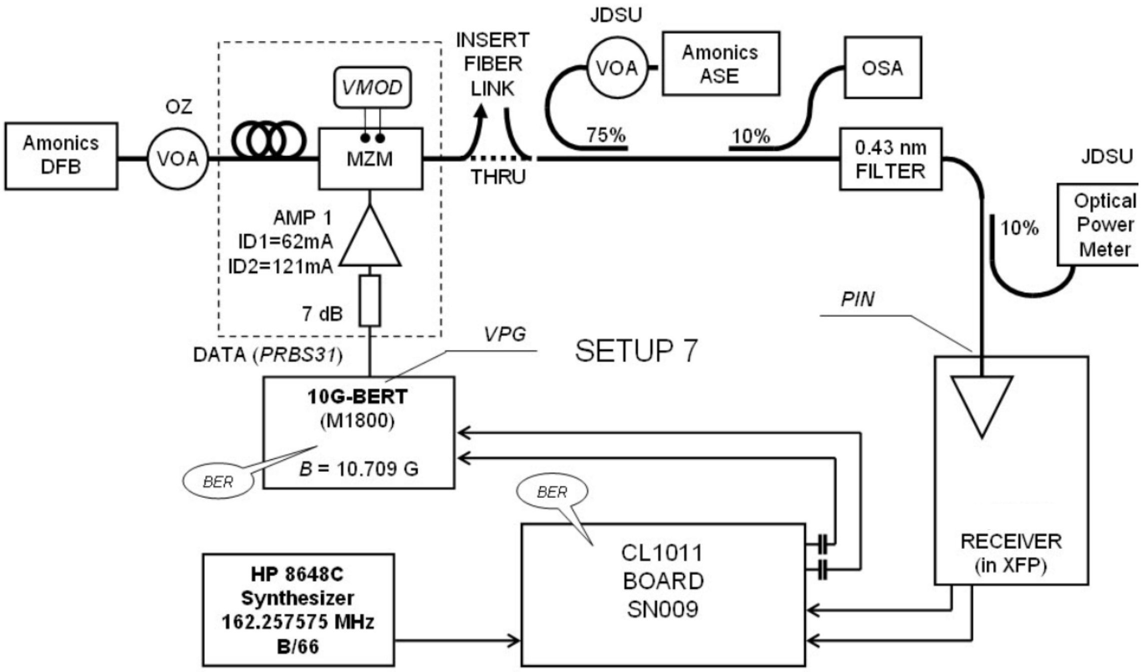

Figure 7.0 Test Setup for 300km link [2]

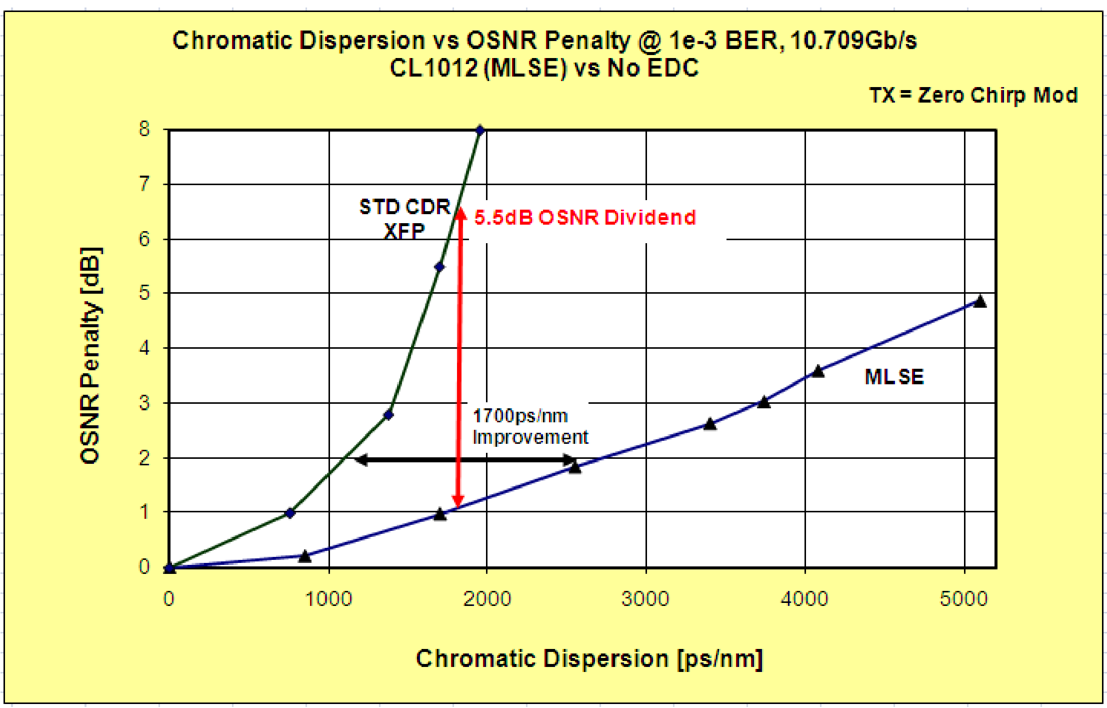

Figure 8.0 Chromatic Dispersion vs ONSR Penalty with MLSE [2] vs Standard CDR

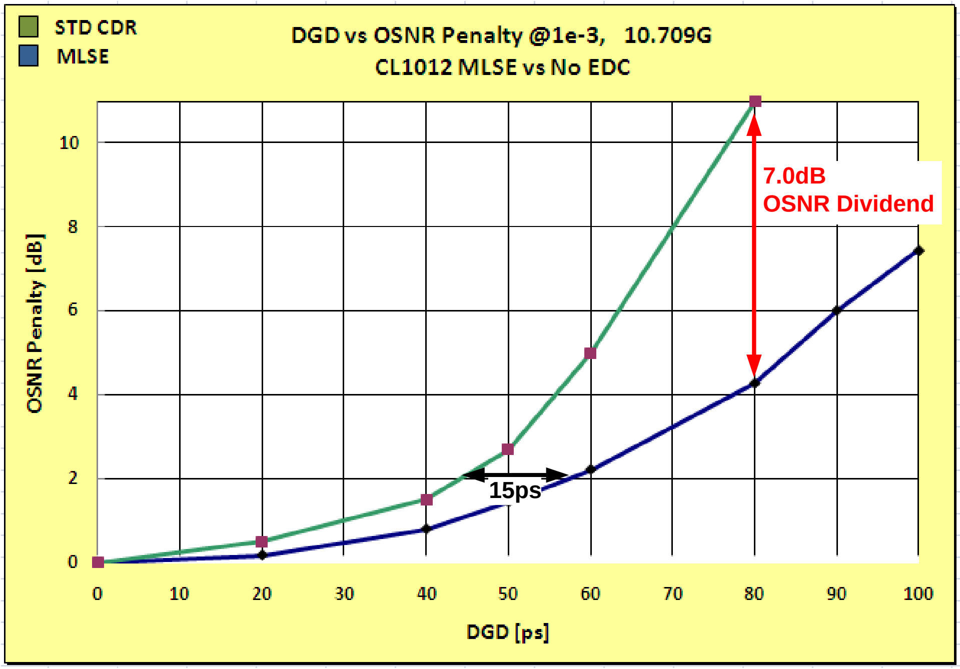

Figure 9.0 DGD vs OSNR penalty with MLSE vs Standard CDR

9. Dark Fiber Applications (Point to Point Networks) – Carrier / Metro Ethernet / Metro Transport

Dark fiber is unlit installed fiber not connected to anything. This fiber can be leased from the service provider. There is a growing need for large and medium-sized companies to increase speed and bandwidth services within their own organization. Some examples would be hospitals, healthcare and financial institutions, governments, and emergency services. These companies or institutions have a common theme, more speed and bandwidth with flexibility and affordability to upgrade their own systems. They have a need for offsite storage, data centers, and a high speed interconnection between offices. A dark fiber network is created to connect several major buildings or facilities within a 300 km radius. Government and financial services companies realize their connectivity and security goals with dark fiber. Because of the availability of dark fiber and the ability to upgrade bandwidth and service without incurring additional cost, many customers find a custom dark fiber network is the best connectivity option. Financial services companies, through their enhanced networks, are also able to handle increasing volumes of time-sensitive traffic and implement critical, robust enterprise applications such as data mining. Specifically, dark fiber enables financial service companies to meet each of their connectivity goals: Enhanced Security: With physical-layer isolation, companies comply with government regulations and enjoy a heightened level of network security. Increased Scalability: Dark fiber enables customers to upgrade bandwidth and service without incurring additional cost.[4] The protocol of choice is 10G Ethernet over OTN (G.709), OTU2e. The FEC plus overhead provides added gain plus performance monitoring and provisioning of the link, see below in Figure 10.0 for application. Point to Point networks are becoming more common. The metro/carrier Ethernet market is enabling these links. Ethernet with OTN extension is providing the right mixture of low cost and high performance link.

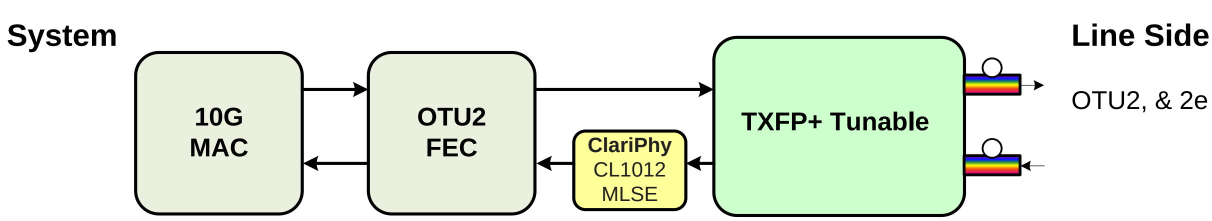

Figure 10.0 -10G Carrier/Metro Ethernet Solution with TXFP+ Ecosystem

Figure 11.0 is an example of a Metro/Carrier Ethernet application using OTU2 transmission (10.709/11.095Gb/s) over a 240km point to point (Dark Fiber) link. For this application only EDFA's are needed for signal attenuation. DCM modules are not needed when using the TXFP+ ecosystem. The CL 1012 (MLSE) mitigates chromatic dispersion. This will save on both CAPEX and OPEX. The majority of Point to Point links are not ONSR limited only dispersion limited. So the network engineer responsible for this link would need to understand the performance of TXFP+ ecosystem, dispersion penalty vs span. Usually in this case OSNR would not go below 25dB. Figure 12.0 is graph of dispersion penalty (RX Power) vs span (chromatic dispersion) for a BER =1e-4 with a fixed ONSR set to 25dB at baud rate of 10.709Gb/s. The data shows a 4dB optical RX power penalty for a 294km link. Without MLSE technology the link budget would be 94km link vs 294km. There are ways one can extend the reach by adding negative chirp to the transmitter signal. The 94km link without MLSE could be extended to 120km but still falls way short of the 294km.

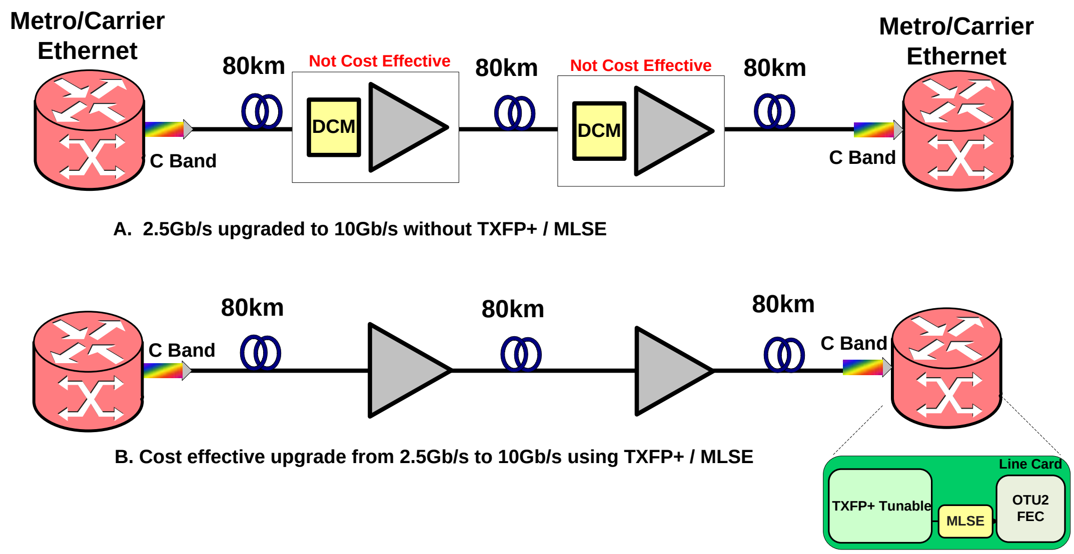

Figure 11.0 Comparison with and without TXFP+ Ecosystem for a 240km Dark Fiber Link

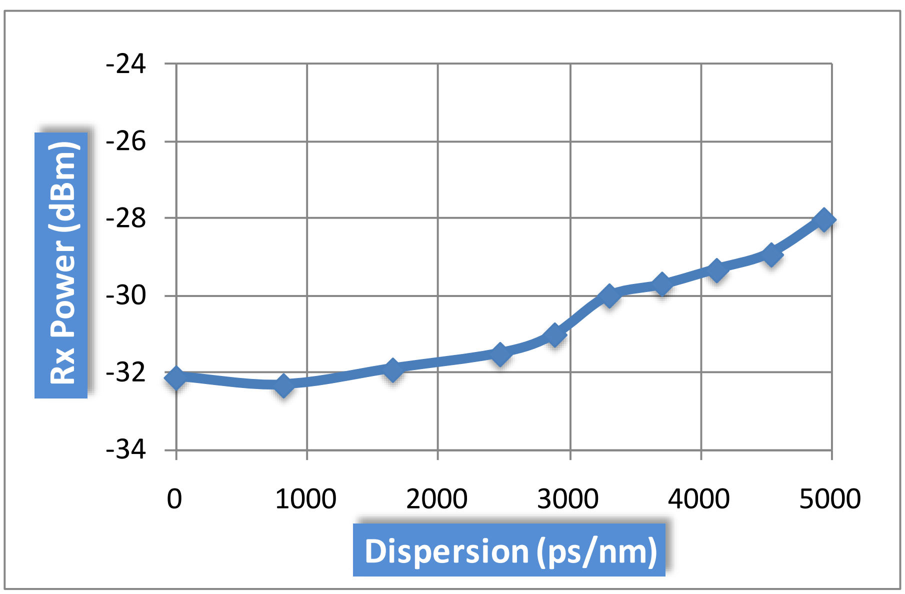

Figure 12.0 RX Receive Power vs Span, Fixed OSNR of 25dB [5]

10. MLSE provides the Network Engineer an OSNR Dividend

Clariphy's CL1012 delivers an OSNR dividend payback to the system through the use of electronic dispersion compensation (MLSE). This dividend can be used by the network engineer in a variety of ways to reduce cost or improve the capability of their product.

- reducing the number of EDFA/DCM huts required on a link
- enabling the use of a broader range of fiber types
- allowing less margin to accommodate aging or temperature variations
- using less expensive DCM's
- enabling more wavelengths per C band

Network engineers will generally determine the best way to use this dividend depending upon their specific requirements and the creation of other network building blocks. As the dispersion in the channel increases, the OSNR penalty begins to exceed the budget for all impairments making the link impractical for any commercial application. The MLSE Engine in the CL1012 product reduces this penalty by providing additional digital processing of the received signal prior to the FEC processing. It has demonstrated its ability to provide over 5.5dB of OSNR penalty improvement in optical systems.

MLSE compensation can provide over 5.5-9 dB of reduction in OSNR penalty. Hut spacing may be increased from 80km to >200 km while maintaining a similar BER over the link. This reduces the number of huts from 25 to 10 (2000km), and substantially reduces the capital expenditure necessary to install the huts and equipment and also reduces the operating expenses necessary to lease and maintain the hut and the equipment housed inside.

11. Conclusion

As a result of growth in communications, there is an ever-increasing demand for more bandwidth. The need for network upgrades from 2.5 Gb/s to 10 Gb/s is becoming more prevalent. This demand needs to be addressed with a bandwidth efficient system that has improved performance as well as reduced power and cost. Clariphy's MLSE engine and TXFP+ is the solution that meets these needs. The benefits of the TXFP+ ecosystem include a 2x increase in bandwidth with double the port density, tunability, pluggability and increased performance with lower power and lower CAPEX/OPEX. As shown there are two main applications, point to point links and Metro transport (Mesh or Ring). The point to point applications are in a high ONSR environment and are usually a dispersion limited link. For this application dispersion penalty vs. span at a fixed osnr is important. Data presented in this paper showed only a 4dB receive path penalty for a 294km link.

For DWDM architectures it is a combination of both dispersion and noise limited applications. Controlling OSNR penalties throughout the link is of vital importance for the network designer. Figure 8.0 shows CD vs. OSNR penalty with a BER of 10-3. OSNR penalty is the required extra OSNR with fiber installed to achieve the same BER performance back-to-back. For a fixed 2 dB OSNR penalty, CL1012/MLSE can tolerate additional 1700ps/nm more CD vs. a standard 10G CDR. For a fixed CD of 800ps/nm, CL1012 achieves a 5.50 dB OSNR dividend gain over standard 10G CDR. Figure 9.0 shows OSNR penalty vs. DGD performance for MLSE and STD CDR cases with a BER of 10-3. At a 2.0 dB of OSNR penalty, the CL1012 system provides 15 ps more DGD tolerance over a standard 10G CDR. Also, with 80 ps differential group delay caused by PMD, the CL1012/MLSE delivers 7.0 dB of OSNR gain.

12. References

[1] Ciena Application Note-Metro/Regional 10G Transport.

[2] Clariphy Test Setup and Data, Internal Document "P053-080403: BER vs. OSNR, 300km test "

[3] M. J. Donovan and K. Conroy, "Enabling the Cost-Effective Implementation of Metro-Ethernet for Optical-Based Metro and Long-Haul Transport Networks," in National Fiber Optic Engineers Conference,, paper JWA1222008,

[4] dark-fiber-resource-Various articles

[5] Robert A. Griffin *et al.*"Combination of InP MZM Transmitter and Monolithic CMOS 8-State MLSE Receiver for Dispersion Tolerant 10 Gb/s Transmission" OFC08

[6] John D. Downie and Jason Hurley, "Chromatic dispersion compensation effectiveness of an MLSE-EDC receiver for three variants of duobinary" TuA1.2