Implementation of Extended Reach Hybrid TDM-PON for 1:128 split ratio

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***Abstract*— Optical communication technology has been developed rapidly to achieve larger transmission capacity and longer transmission distance. In this paper we demonstrated optical time division multiplexing extended reach 10 Gb/s passive optical network (PON) architecture of 100 km length with 1:128 split ratio. The 100 km system is enabled by the use of corning nexcore fiber and corning SMF-28 fiber with attenuation of 0.21 dB/km and downstream transmission with NRZ and duo binary format, and signals are demultiplexed by semiconductor optical amplifiers (SOA's). SOA can be used for both amplification and attenuation of an optical signal, by turning the gain on and off. The TDM – PON takes advantage of the development of digital transmission and synchronous optical multiplexing. How much amount of power and loss is required in the fiber link calculated by using link power budget analysis.**

Keyword- Corning nexcore fiber, Duo binary, Mach Zehnder Interferometer, NRZ, Passive Optical Networks, Semiconductor Optical Amplifier

I. INTRODUCTION

The various PON technologies make use of different multiplexing techniques to allow shared access to the fiber media. TDM based PONs and WDM based PONs are two broad categories. The various PON technologies also differ in available digital capacity, how they dynamically allocate upstream bandwidth to subscribers, and embedded. The vast majority of PON systems deployed today are TDM based PON systems i.e., B (Broad Band)-PON, E (Ethernet)-PON, and G (Gigabit)-PON. They almost exclusively operate on a single fiber, with WDM used to provide bidirectional transmission. As demand for greater bandwidth to the home continuous grow, and the bandwidth available to the end user has generally increased with successive TDM – PON architecture start with broadband PON (BPON) with 622 Mb/s downstream transmission, 155 Mb/s upstream transmission, Ethernet PON (EPON) with 1.244 Mb/s downstream transmission and now Gigabit PON (GPON) with 2.5 Gb/s downstream transmission detailed overview as shown in Fig. 1

Many lower speed data streams can be multiplexed into one high speed data stream by means of Optical time division multiplexing (OTDM), such that each input channel transmits its data in an assigned time slot. This assignment is performed by a fast multiplex switch (mux). Functionally, optical TDM (OTDM) is identical to electronic TDM. The only difference is that multiplexing and demultiplexing operations are performed entirely optically at high speeds. Power margin represents the amount of power available after subtracting linear and non–linear span losses from the power budget. Loss budget calculation analysis is the calculation and verification of a fiber optic system's operating characteristics. Receiver sensitivity, transmitter launch level power and dynamic range are necessary number used in span analysis. The total span loss or link budget can be determined by using an optical power meter to measure the true loss. The most important aspect of PON architecture is its simplicity. The Optical Line Terminal (OLT) is the main element of the network and it is usually placed in the Local Exchange. Optical Network Units (ONUs) serve as an interface to the network and are deployed on a customer's side. ONUs are connected to the OLT by means of optical fiber and no active elements are present in the link.

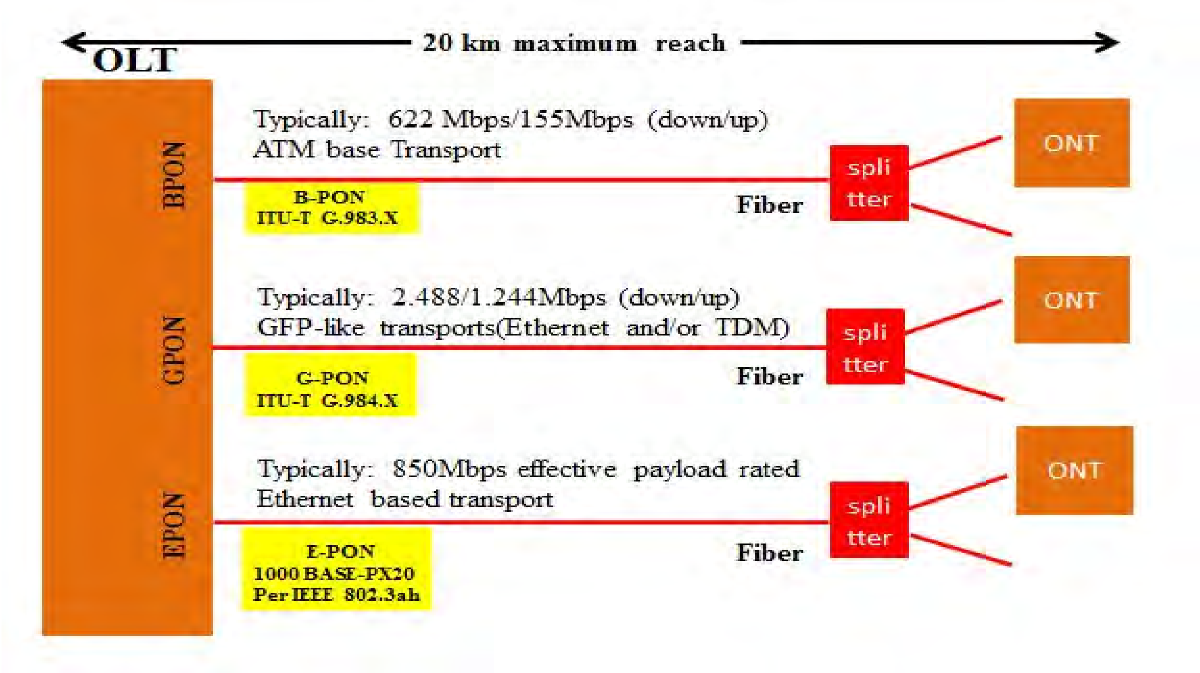

Fig. 1. TDM-PON architecture and Technologies

II. OVER VIEW OF CODING TECHNIQUES

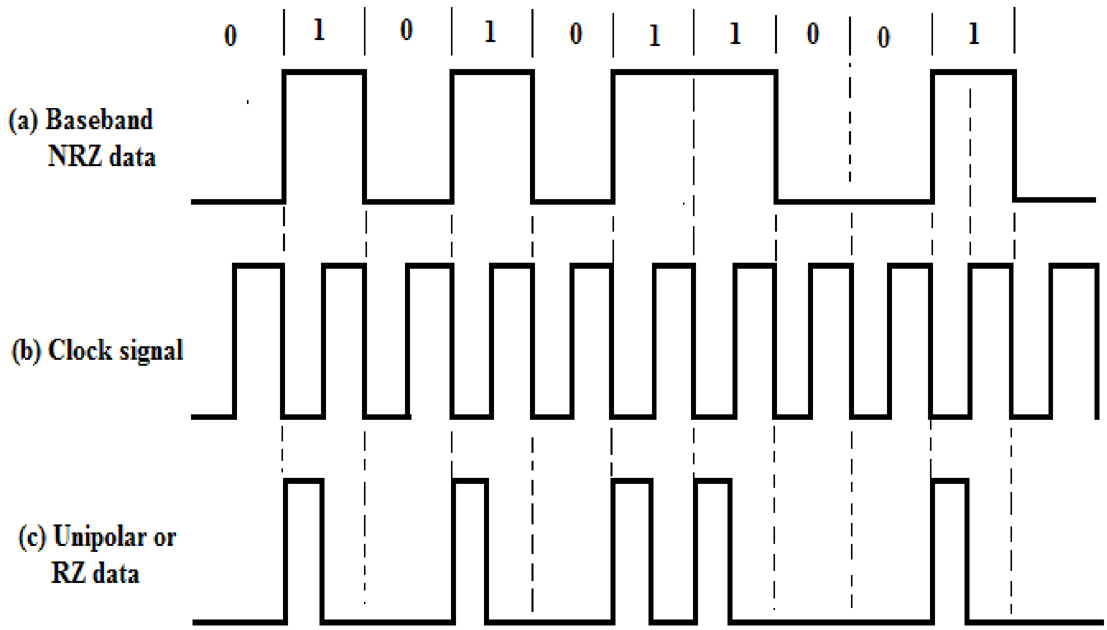

Fig. 2. Various Coding Techniques

Line coding defines the arrangement of symbols in a particular pattern for transmission that represent binary data. Line codes are used to provide particular spectral characteristics of a pulse train. It will ensure that we have enough flips between 0's and 1's and enough changes so that synchronization can be maintained. Advantages of using coding techniques are power efficiency for given bandwidth and a specified detection error probability should be as small as possible. Error detection and correction capability.

A. NRZ Coding

NRZ coding is a line code in which binary value '1' is represented by positive voltage and '0' is represented by negative voltage. The pulses have more energy than others. It requires only half the bandwidth than other coding. This is for Bipolar NRZ coding. There is also another type called unipolar NRZ coding, represented by '1' is represented by positive voltage and '0' is represented by DC line.

B. RZ Coding

In RZ encoding, a binary 1 is represented by first half of the bit duration, during the second half the level returns to zero. Absence of a pulse represents a binary 0, during the entire bit duration. Twice the bandwidth is required for RZ coding.

III. TDM-PON SYSTEM EXPERIMENT AND RESULTS

The OLT transmits TDM traffic in the downstream direction, and it manages the upstream traffic. In the downstream direction, TDM traffic from the OLT reaches over a fiber 1 to N optical splitter as shown in Fig. 3 That is, all N outputs of the power splitter carry the same TDM traffic.

TDM	Time Division Multiplex
CC	Cross Connect
BB	Broad Band
NB	Narrow Band
OLT	Optical Line Termination
ONT	Optical Network Termination

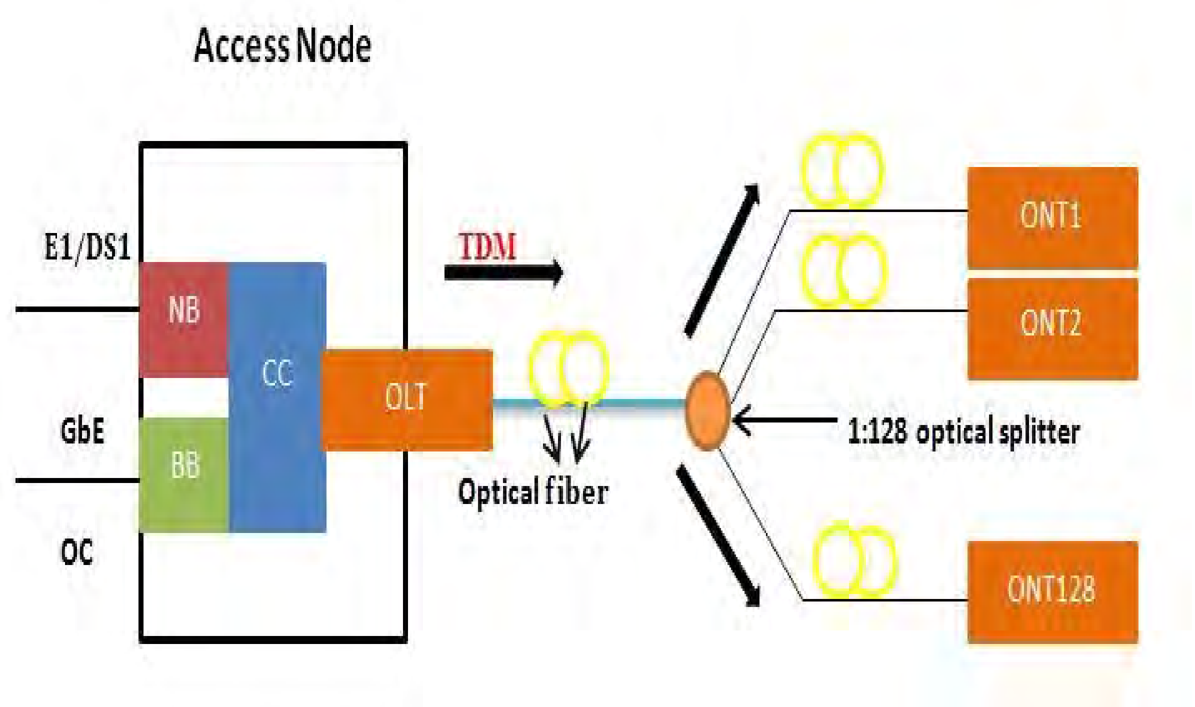

Fig. 3. Downstream transmission of TDM-PON architecture

However, a time slot is associated with a particular ONU, and thus each ONU finds its own time slot and extract the data from it. The routing at different data streams at the end of the TDM link is performed by a demultiplexer is employed by using MZI switch as it consist a semiconductor optical amplifier (SOA) and an optical coupler. The SOA based MZI switch consist of two Semiconductor Optical Amplifiers (SOA) at the two interferometer arms. It can be used for both amplification and attenuation of an optical signal, by turning the gain on and off. This can be explained in an effective way of switching by splitting an optical signal with a 3dB splitter, that's why the signal is amplified in one arm and attenuated in another arm. The first control pulse shown in Fig. 4 is responsible for modulating the gain and phase of the data such that a phase difference between both MZI arms (CW and CCW) leads to the transmittance of one bit of the channel that one wants to demultiplex at the transmitted port. The second control pulse is responsible for to produce a phase modulation of the data signal so that this phase difference is cancelled out. SOAs are amplifiers which uses a semiconductor to provide gain medium so that the gain reacts rapidly to changes of pump power or signal power and the changes of gain also cause phase change. The data signal injected from the input port are directed to the transmitted port or the drop port depending on the phase difference between the two SOAs then relative phase difference between CW and CCW pulses becomes π and the data will exit from the transmitted port as shown in Fig. 4

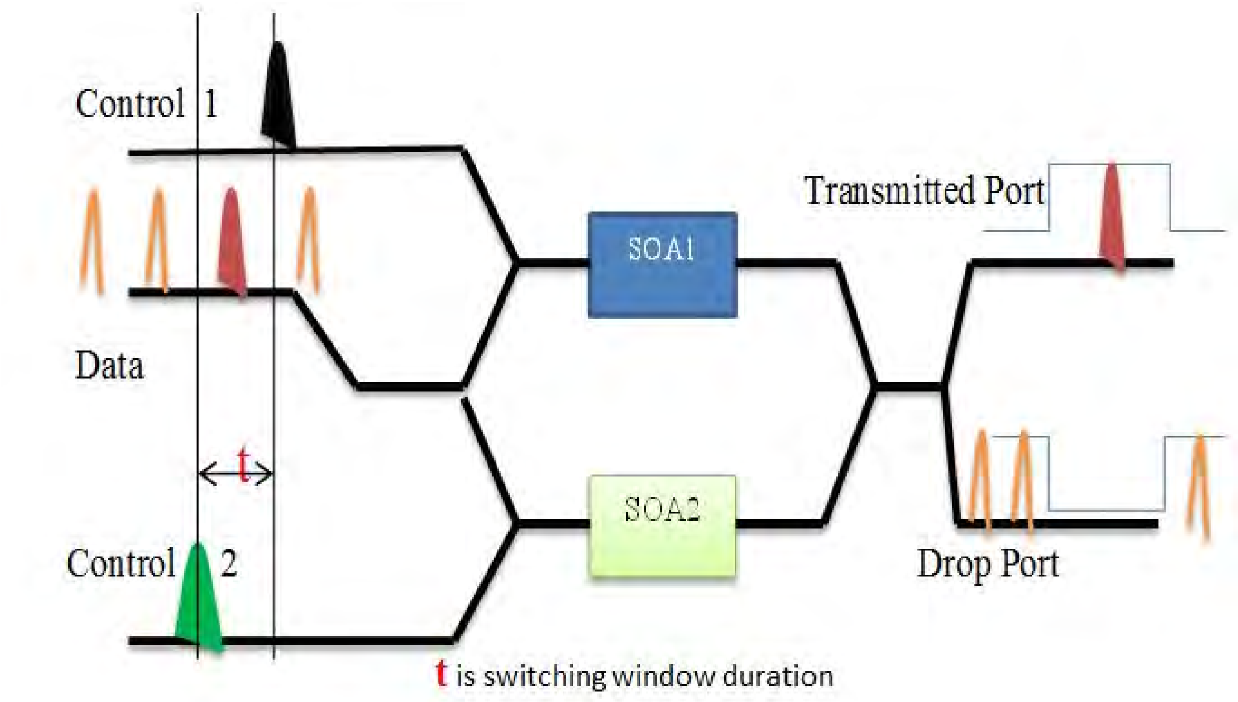

Fig. 4. Demultiplexing of channels by using two SOAs

If we consider Gaussian pulse as control signal from equation 1

$$P_{cp}(t) = \frac{E_c}{\sigma\sqrt{\pi}} \exp\left(-\frac{t^2}{\sigma^2}\right) \quad (1)$$

σ is related to full width half maximum (FWHM) by T_{FWHM} = 1.665 σ,

$$E_{cp}(t) = \frac{E_c}{2}\left(1 + \text{erf}\left(\frac{1.665\sigma}{\sigma}\right)\right) \quad (2)$$

$$E_{cp}(t) = \frac{E_c}{2}\left(1 + \text{erf}(1.665)\right) \quad (3)$$

$$E_{cp}(t) = 0.9907E_c \quad (4)$$

Where $E_{cp}(t)$ is the energy fraction contained in the leading edge of the pulse and E_c is the total energy of the control pulse. Then 99% of the pulse transmits through SOA proved by equation 4 without reflecting back. Typically the safety margin fix as 3dB. This number will vary for every organization. To guarantee error free transmission, a value no less than 1.7dB must be used. This safety margin factor is subtracted from the remaining power, still this number should be positive after all complete the calculation we can be assured that our fiber network will deliver the required performance over the life of the installation. By the transmitter, the power is generated at a particular wavelength used to launch the signal is known as the transmitter launch power. To achieve an acceptable Bit Error Rate (BER) or performance a minimum acceptable value of received power is necessary i.e., Receiver sensitivity. If the optical inputs are as high as –5dBm and as low as –30dBm then the receiver is coping with that optical input. The optical dynamic range of 25dB is necessary for a receiver. A span’s power budget, which is the maximum amount of power it can transmit, is calculated.

If we assume minimum transmit power and minimum receiver sensitivity data as worst case analysis in the design perspective. This provides for a margin that compensates for variations of transmitter power and receiver sensitivity levels. We have to calculate how much light is available by using minimum transmit power and receiver sensitivity. Factors that can cause span or link loss include fiber attenuation, connector loss, splice loss chromatic dispersion and non–linear and linear losses.

In this design the minimum transmitter power and receiver sensitivity is set as 0 and –34dBm. Consider the safety margin set as 3dBm and the available power budget for the designed architecture is 34dBm and dynamic range is 31dBm. The available split ratio is 1:128 and it affects the power budget.

TABLE 1 Link power budget for a span length of 100 km

Corning encore SMF–28e+ at 1550nm	100km×0.21dB/km	21dB
Fusion Splices	4×0.02dB/splice	0.08dB
Connectors	2×0.5	1dB
Dispersion Margin	1dB	1dB
PMD Margin	0.5dB	0.5dB
XPM Margin	0.5dB	0.5dB
SRS/SBS Margin	0.5dB	0.5dB
Splitter Loss	22dB	22dB
Safety Margin	3dB	3dB
Total Span Loss		49.58

Power budget (P_B) = Minimum transmit power (P_{TMIN}) – Minimum receiver sensitivity (P_{RMIN})
Power budget (P_B) = 34dBm

TABLE 2 Link Power budget calculation for varying distances

Distance (km)	Power Margin (dBm)
At 10 km	5.42
At 20 km	1.72
At 40 km	-2.98
At 60 km	-7.18
At 80 km	-11.38
At 100 km	-15.58

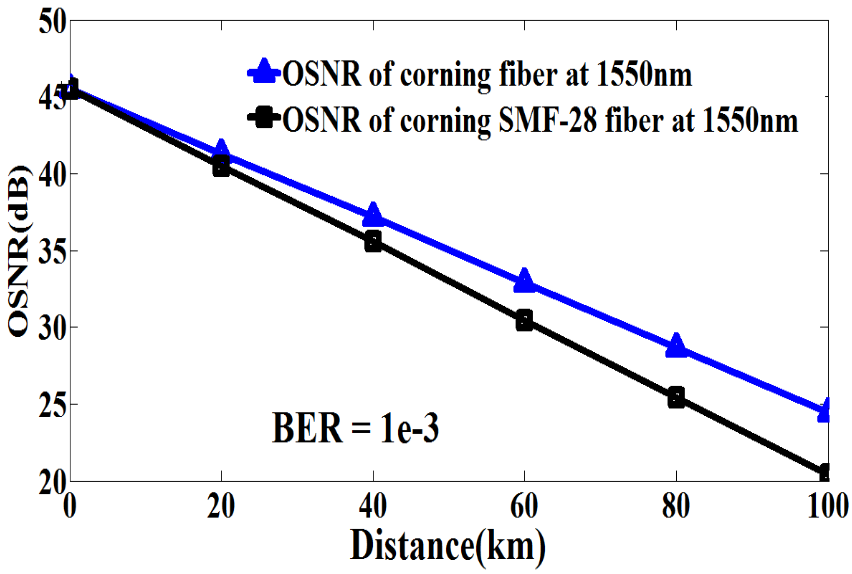

Fig. 5. Distance vs osnr over both fibers

The Fig. 5 depicts that as the distance increases the OSNR falls and the required OSNR to achieve a BER value of 10^{-3} with corning nexcore fiber and corning SMF-28 fiber over 100 km. The wavelength for all data was 1550 nm, modulated at 10 Gb/s.

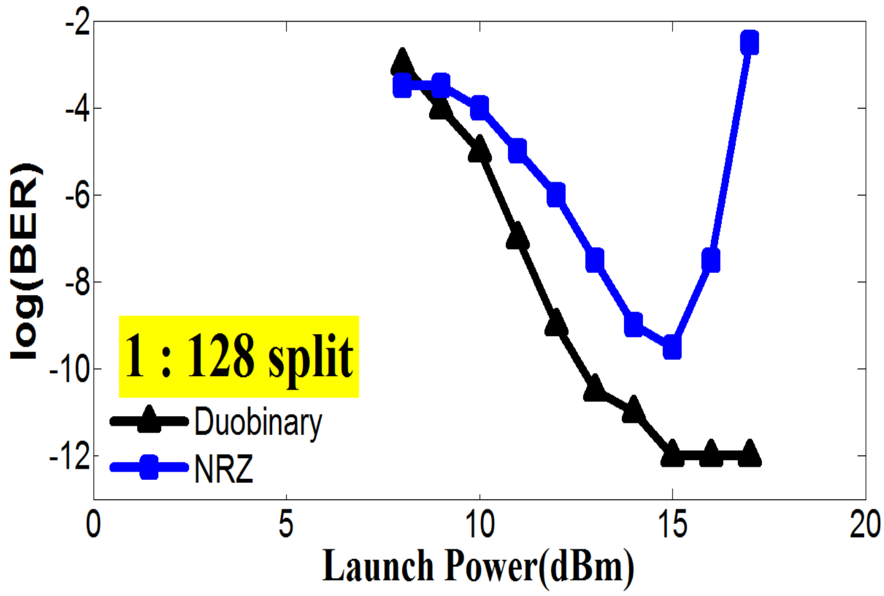

Fig. 6. Downstream signal transmission result for duo binary and NRZ with 1:128 split ratio over corning nexcore SMF-28e+ fiber

From Fig. 6 We compare the performance of NRZ vs. duo binary for 100 km corning nexcore SMF-28e+ fiber with a 1:128 split ratio. Duo binary proves that error-free transmission but NRZ is limited by Self Phase Modulation (SPM), dispersion to a minimum BER (Bit Error Rate) of value 10^{-3} at 17dBm launch power.

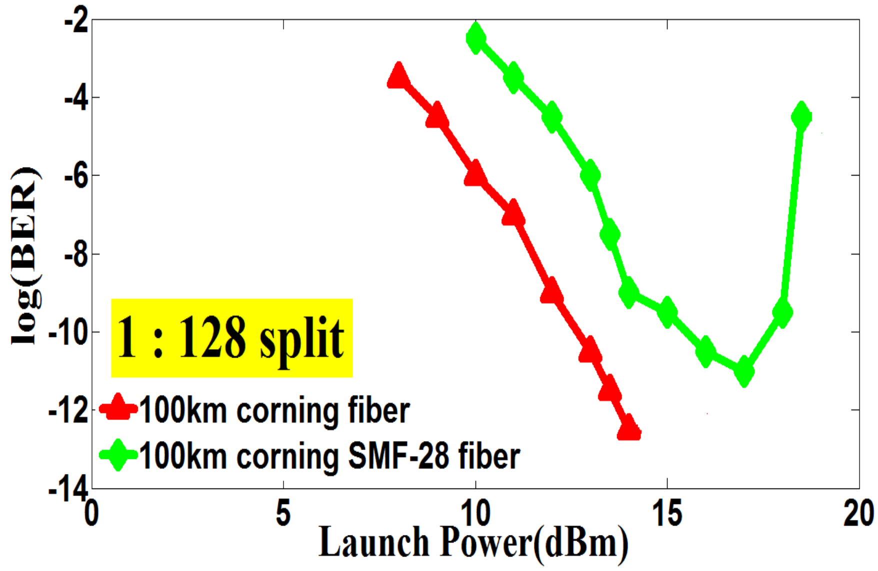

Fig. 7. Downstream signal transmission result for duo binary with 1:128 split ratio over both fibers

From Fig. 7 We compare the performance over two 100 km fiber spans it presents the data for duo binary system with 1:128 split ratios. Error free transmission is achievable over the corning nexcore SMF-28 fiber, but the standard corning fiber has 3dB higher loss i.e., not error free transmission because of dispersion and SPM effects, for this higher launch power is required.

IV. Conclusion

In this paper we have demonstrated the passive extended reach 100 km 10 Gb/s TDM-PON system enabled by the use of two different fibers with attenuation of 0.21 dB/km and downstream duo binary and NRZ signal transmission and also demonstrated that the error free signal transmission is achieved by using 100 km corning nexcore SMF-28 fiber in duo binary transmission. From Fig. 1. The maximum reach is 20 km between OLT

(Optical Line Terminal) at central office and ONU (Optical Network Unit) at customer premises, we calculated the link power budget for varying distances, at 20 km the value is 1.72dBm and it is acceptable value for error free transmission. As the length increases the link power budget value also increases i.e., for minimum number of errors present while transmission and achievable bit error rate is 10^{-9} to 10^{-3}.

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