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Performance Enhancement of DCF Based Wavelength Division Multiplexed Passive Optical Network (WDM-PON)

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Abstract—We Proposes a Dispersion Compensation Fiber (DCF) based Wavelength Division Multiplexed Passive Optical Network (WDM-PON) architecture which is demonstrated/simulated to provide 20Gb/s downstream and 20Gb/s upstream bandwidth. This prototype system provides good Q-Factor and acceptable BER for 50Km that is significantly higher than Conventional architecture.

Index Terms-C-band WDM-PON, tunable receiver and transmitter, WDMmux/demux, Dispersion Compensation Fiber (DCF).

1 INTRODUCTION

FOR Optical access networks, Wavelength-division multiplexing passive optical network (WDM-PON) is considered as the most promising candidate for the next generation technology to fulfill further network demands. Passive optical network (PON) technology has been recognized as an efficient solution to facilitate high bandwidth, low cost and fault-tolerant next generation broadband access networks [1]. However, it is widely predicted that Time Division Multiplexed (TDM) based passive optical networks (PONs) has difficulty in fulfilling the bandwidth requirement. Wavelength-division multiplexed is thus being considered as the key solutions of the next generation PONs by using multiple wavelengths and using wavelength division multiplexer (WDM Mux)/ demultiplexer (WDM DeMux) at server end, user end and remote node to distribute wavelength [2]. As a future-proof solution, the WDM-PON should be scalable in terms of number of user-nodes and bandwidth. Wavelength-division multiplexing (WDM) is a method of combining multiple laser wavelengths for transmission along optical fiber media. WDM allocates operational wavelengths to users in a systematic manner. The wavelength spacing for WDM networks can be categorized as either Coarse WDM (CWDM) with around 20nm spacing, or dense WDM (DWDM) with less than 1nm spacing. At the central office (CO), on-off keying (OOK) is most commonly used modulation technique. In WDM PON, the effect of different data rates indicate that for 1.25Gbps, the required power is approximately 0.6dB less as compared to 5Gbps for the same performance [3]. The proposed Dispersion Compensation Fiber (DCF) based Wavelength Division multiplexed passive optical network (WDM-PON) architecture provides 20Gb/s downstream and 20Gb/s/ upstream bandwidth which is best suitable for commercial business network environment where upstream data rate is equally important as downstream data rate. Different PON architectures of WDM PON with their merits and demerits are shown [4].WDM PON architecture can also be formed with cascading the two AWG to handle the multiple users. The design and the cost are analyzed [5]. In this work we review the WDM-PON using DCF. Section II introduces the proposed WDM-PON architecture. Section III shows simulated prototype design in Optiwave Photonic Design Software. Section IV shows simulated result and discussion on performance of the system. Section V brief calculation of the power budget of the prototype. Section VI concludes this paper.

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2 SYSTEM ARCHITECTURE

The key feature of a PON is the presence of only passive components in the field, i.e. elements that operate without any electrical power. There are no amplifier or repeater elements in the field, and no need for electrical supplies. As such, PON architectures offer great advantages like low cost, high reliability and easy maintenance for network operators. Fiber connectivity is established from the optical line terminal (OLT) at central office (CO) to the optical network units (ONU) at customer premises. The passive elements are placed at the remote node (RN), which sits close to ONU. The data traveling from user-end towards OLT is known as upstream traffic, and the data traveling to the user-end nodes is known as

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downstream traffic. Wavelength division multiplexing is the ultimate solution for fast, efficient and secure Bandwidth allocation in passive optical networks, and the subject of research proposals for next generation broadband access.

System architecture of the proposed design is shown in Fig.1 as given below. Proposed architecture utilizes the four wavelengths and each transmitting at 5Gbps to give the total 20Gbps capacity. For generating these wavelengths four transmitters at central office are required. These wavelength signals are multiplex with the help of wavelength division multiplexer (WDM) and transmitted on the channel. To handle the dispersion at 20 Gbps, a dispersion compensation fiber (DCF) is used and cascaded with the single mode fiber (SMF). The designing of the DCF is based on the dispersion and its slope occurring in the used SMF. Dispersion of DCF is chosen in such a way that overall dispersion of the system becomes zero. At receiver side these wavelength signals are demultiplexed and given to different ONUs. The performance of the system is analyzed with the help of bit error rate analyzer and compared with the input signal.

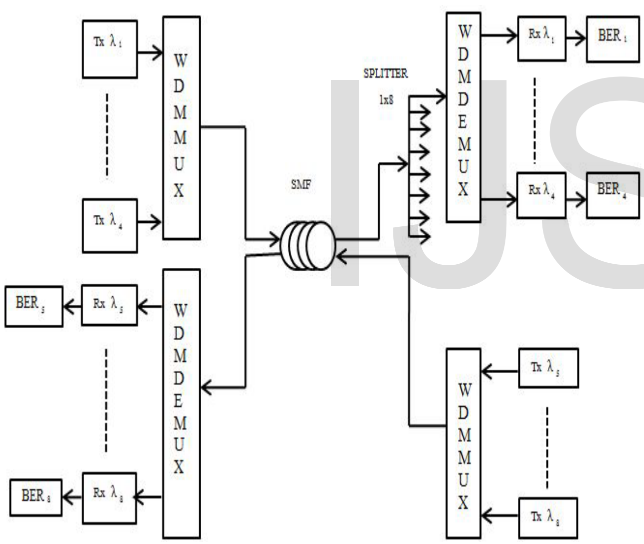

Fig. 1: Proposed system architecture of WDM PON

3 SIMULATED PROTOTYPE DESIGN

We are using Optiwave Photonic Design automation software Optisystem 12.0 to design and simulate the C-band WDM-PON prototype as shown in Fig. 2. Optisystem 12.0 is an innovative optical communication system simulation package that designs, tests, and optimizes virtually any type of optical link in the physical layer of a broad spectrum of optical networks.

In this layout conventional C band wavelengths from 1560nm to 1563nm are used for downstream and 1550nm to 1553 nm for upstream with 1 nm spacing in each by using WDM transmitter block. Each wavelength carries 5 GB/s data. Downstream data rate is 20 GB/s and upstream data rate is 20 GB/s.

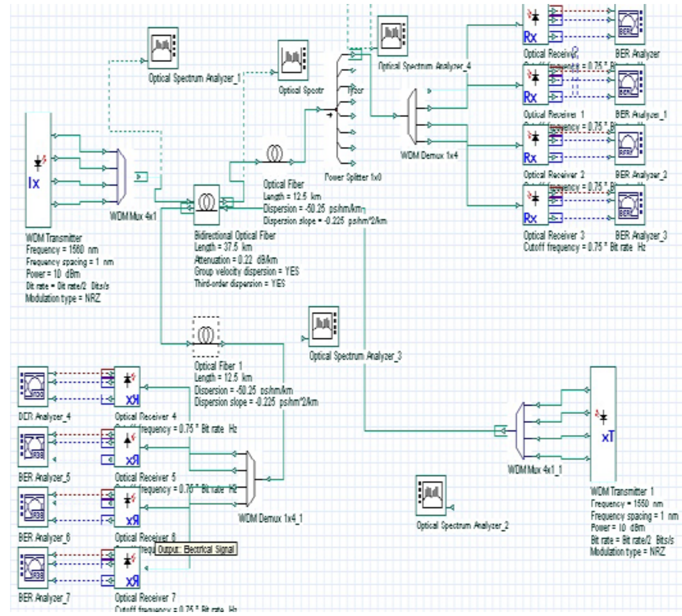

Fig. 2: Simulated Prototype of WDM PON layout

OLT transmitter diagram is as shown in Fig. 3 pseudo-random-bit-sequence-generator (PRBS) block generates random bits and these train of bits are given to the NRZ pulse generator. The output of NRZ pulse generator is then modulated by Mech-Zehnder modulator (MZM) which is intensity modulator based on an interferometric principle. Modulated signal from output port is fed to the WDM multiplexer using single mode fiber (SMF) optical fiber. In WDM multiplexer the four input signals are filtered by an optical filter and are combined into one signal.

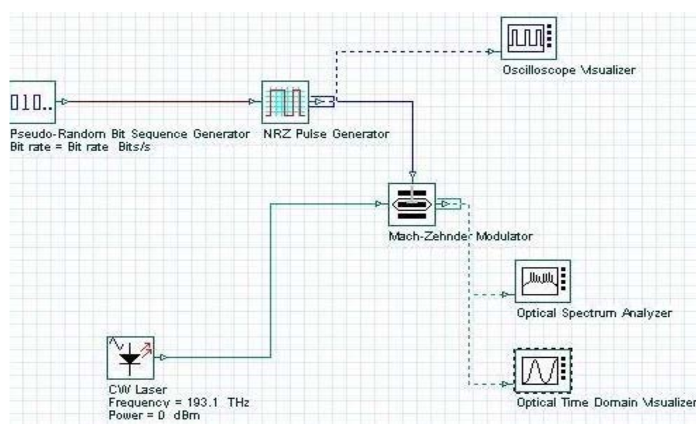

Fig. 3. OLT Transmitter

4 SIMULATED RESULT

WDM multiplexed signal at optical line terminal can be observed by spectrum analyzer as depicted in Fig. 4, where it can be analyzed that different multiplexed signal

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of wavelength 1560nm to 1563nm with 1 nm spacing with 10 dbm power each. For this layout different spectrum at different stages are given below.

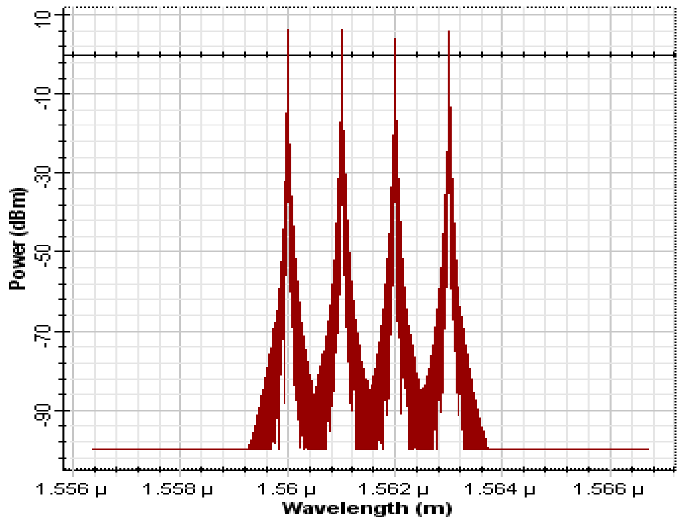

Fig. 4: Multiplexed signal at OLT

After travelling these multiplexed signal through 50km in fiber, due to attenuation and dispersion available in the fiber it reduces power of the optical signal as 0.22dB/km & 16.75 ps/nm/km respectively. Since at 5 Gbps dispersion dominant more so it is compensated by using dispersion compensated fiber as shown in fig 2. Scattered optical signals can be observed using spectrum analyzer as shown in Fig. 5.

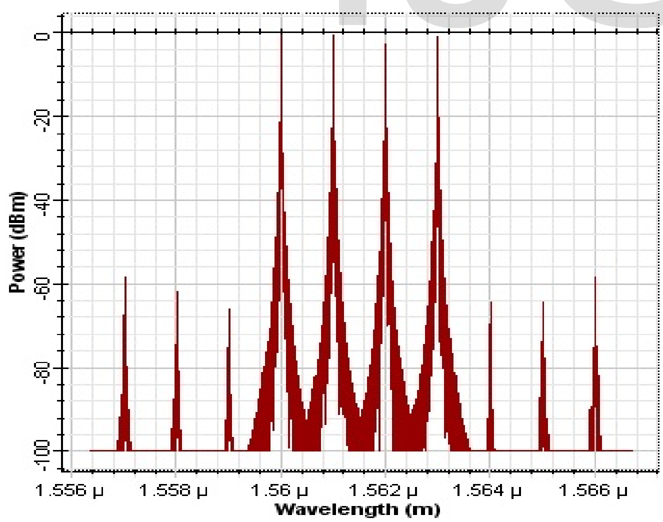

Fig. 5: Downstream optical spectrum at ONU DeMux.

At the end of Fiber, it is terminated as the input of ONU. ONU demultiplex the signal. ONU is tuned to select and demultiplex one particular wavelength hence only desired wavelength has optimal power than the rest as we can observe in Fig. 6. Optical signal is then detected using PIN diode or APD and electrical signal is analyzed using eye diagram analyzer tool as shown in Fig. 7

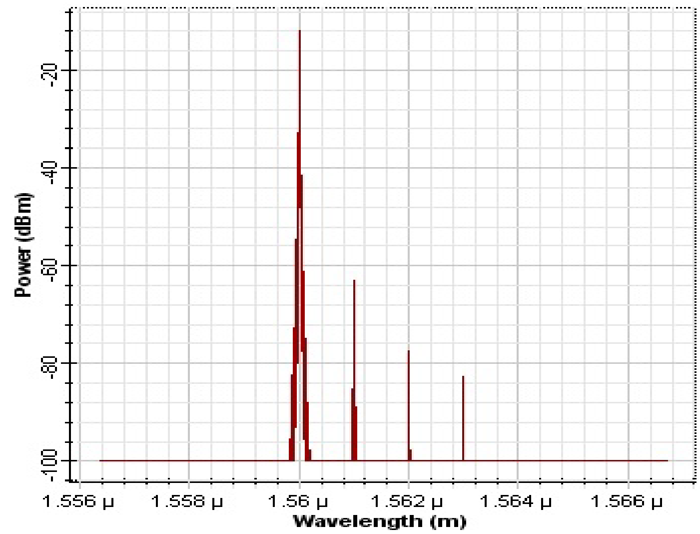

Fig. 6: Demultiplexed optical spectrum at ONU.

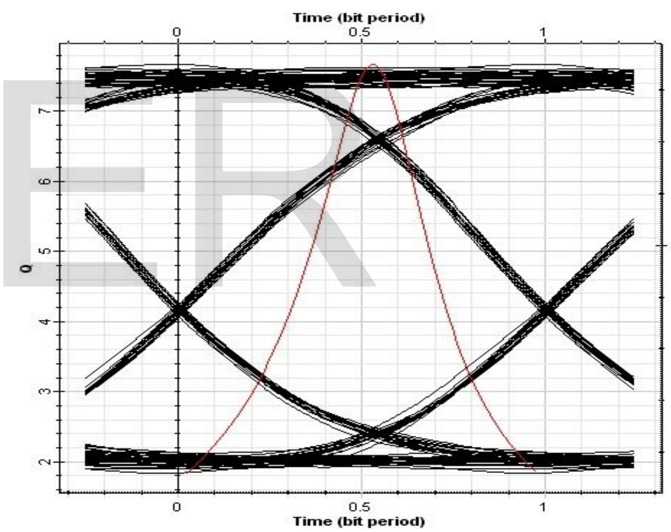

Fig. 7: Eye diagram at the ONU receiver.

Multiplexed signal at optical networking unit is shown in Fig. 8. Where it can observed that multiplexed signal of wavelength 1550nm to 1553nm with 1 nm spacing. After travelling 50 km in the fiber signal is degraded and dispersed and can be observed in spectrum analyzer at the input of OLT DeMux as shown in Fig. 9. Demultiplexed signal at OLT is shown in Fig. 10

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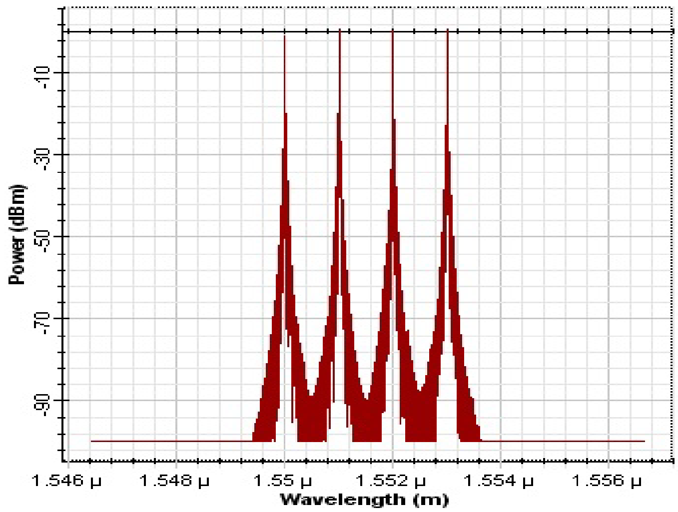

Fig.8. Multiplexed signal at ONU

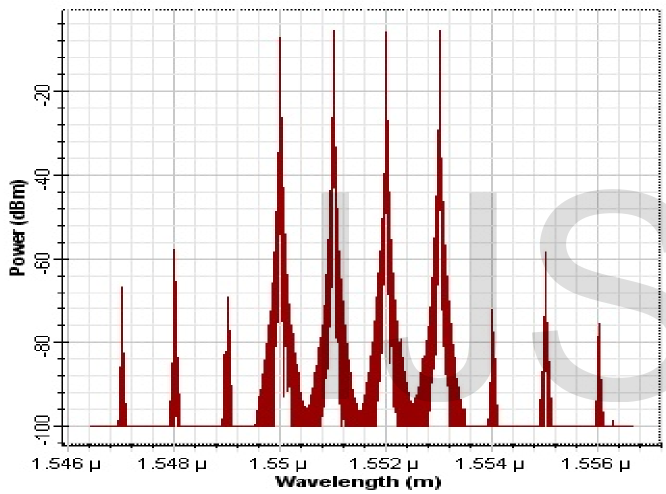

Fig. 9. Upstream optical spectrum at OLT DeMux.

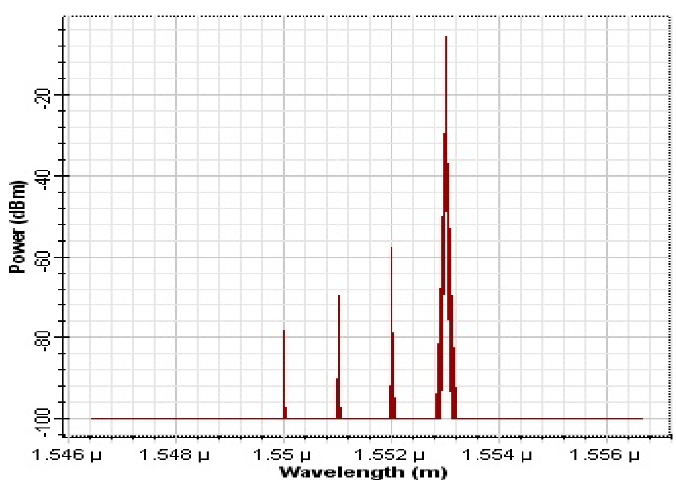

Fig.10. Demultiplexed optical spectrum at OLT.

Simulation is run in two steps, first keeping optical launch power constant at 10dBm and varying length of the optical fiber from 20Km to 50Km and observed the maximum quality factor (Max. Q-Factor). It can be observed that after 40km length, Max. Q-factor degrades below a threshold value in existing architecture while in proposed architecture length can be further increased by using dispersion compensated system and Q factor curve is shown in fig 11. Fig. 12 is the plot between min log of BER and fiber length. It can be noticed that after 40 km length Min. BER start increasing for conventional system while for proposed system it is acceptable till 50 km.

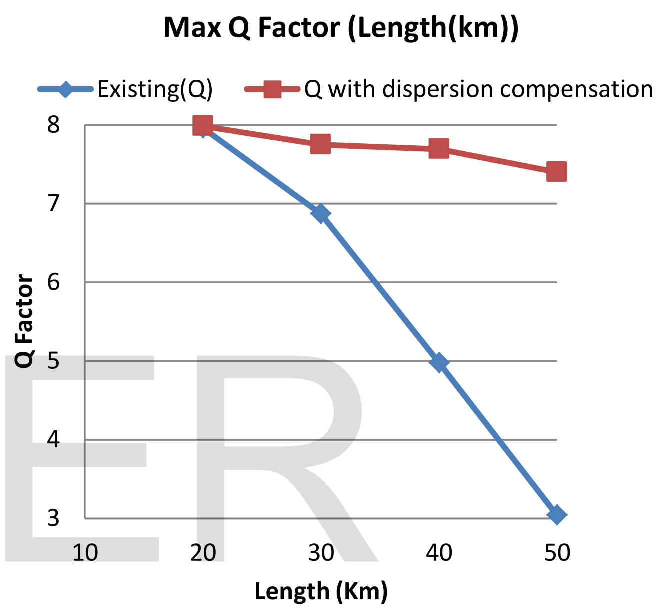

Fig.11. Q-factor Vs Length at 10 dBm

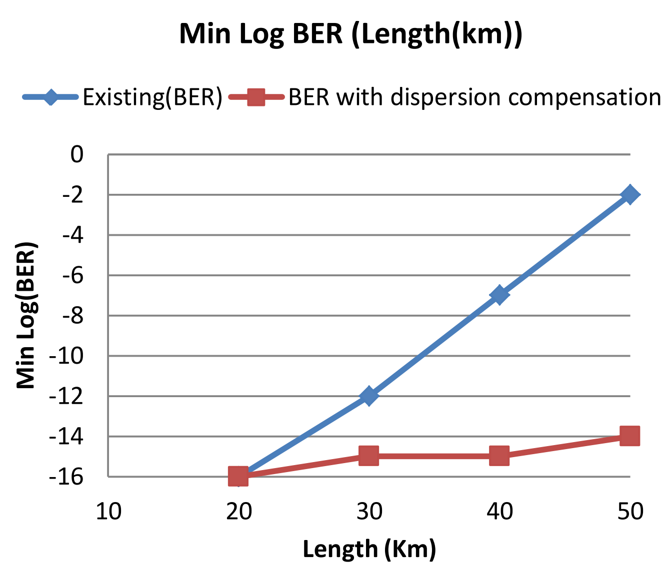

Fig.12. BER Vs Length at 10 dBm

Next step is keeping length of the fiber constant at 40km and varying power of transmitter from 0dBm to l0dBm and observed the Max Q-factor as shown in Fig.13. It can be observed that for proposed system Q factor is much higher than the conventional system. i.e. proposed system can work within low range of power and provides much power margin to the system that can be used to compensate the insertion losses at higher splitting ratios to serve more number of costumers.Fig.14 shows the plot between Min. Log BER and power. It can be observed that BER is under control after 3 dBm of power for proposed architecture.

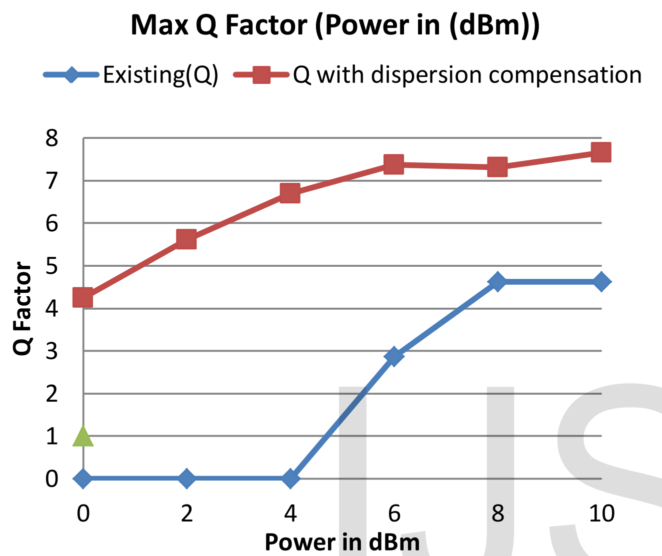

Fig.13. Q-factor Vs Power at 40 km

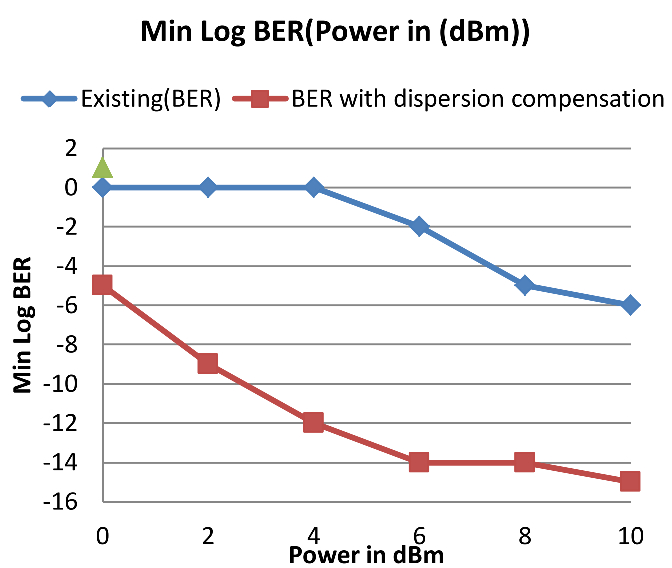

Fig.14. BER Vs Power at 40 km

5 POWER BUDGET CALCULATION

For the network design engineers a power budget analysis is highly recommended before designing and installing any passive optical network system, so that designed system will work within certain limits and gives the desired BER and Q factor. By power budget calculation we can know the input power range for a particular architecture for which particular signal quality at receiver is guaranteed. During calculation of power budget power margin is also considered for any future degradation as shown in (1). In any network Losses are of passive and active since prototype is made up of both the passive and active components. Active components are at the OLT and ONU. Passive components are in between the OLT and ONU. Passive loss dwell of fiber loss, connector loss, splice loss and couplers or splitters in the link. Active components losses are wavelength multiplexer, transmitter power and receiver sensitivity. Here in C-band WDM-PON prototype we are using bit rate of 20Gb/s for upstream and downstream hence power budget chart hold good for both upstream and downstream.

$P_{tx} = P_{rx} + C_L + Ms$ (1)

Where C_L is expressed as

$C_L = \alpha L + \alpha_{con} + \alpha_{splice} + \alpha_{splitter}$

α - Fiber attenuation (dB/Km)

L - Length of fiber (Km)

C_L - Channel loss (dB)

Ms – Safety Margin (dB)

Total system losses are depends upon fiber attenuation, length of fiber for which has to transmit different connector and splice losses and splitter losses. For a particular fiber its losses are fixed and one cannot change these losses. However number of connectors and output port of splitter can be minimized to reduce losses. In our system we have considered fiber losses of 0.22 dB/km so for 50 km length accumulated fiber losses are 11 dB. In our simulation we have considered the splitter losses of $3.5Log_2(n)$. Where n is the output port of splitter. So splitter losses are 10.5 dB and 7 dB for 8 ports and 4 ports respectively. Receiver sensitivity is taken at -31 dBm for PIN receiver to detect the signal at receiver within the acceptable range. We have given the input power from 0 dBm to 10 dBm. From the above equation

$0 = -31$ dBm $+11$ dB$+1.2$ dB$+ \alpha_{splitter} + M_s$

$\alpha_{splitter} + M_s = 18.8$ or

$\alpha_{splitter} = 18.8 - M_s$

by considering Ms = 6dB

$\alpha_{splitter} = 18.8 - 6 = 12.8$ dB

Similarly for 10 dBm input power

$10 = -31$ dBm $+11$ dB$+1.2$ dB$+ \alpha_{splitter} + M_s$

$\alpha_{splitter} = 22.8$ dB

From the above calculations we got the range of splitter losses that can be accommodated in the system without performance degradation is 12.8 to 22.8 dB. For this range value of n will be from 16 to 64. Means we can serve up to 64 users. If we keep n=16 than additional 8.8 dB can be used for increasing fiber length further up to 40 km in future.

6 Conclusion

A Dispersion Compensation Fiber (DCF) based Wavelength Division Multiplexed Passive Optical Network (WDM-PON) architecture has been proposed and analyzed based on simulation results. Proposed system provides provide 20Gb/s downstream and 20Gb/s upstream bandwidth by using only 4 wavelengths .i.e. each wavelength transmit at 5Gb/s. at higher speed the effect of dispersion becomes significant so dispersion is compensated by using dispersion compensated fiber. By dispersion compensation, dispersion effects are reduced and then we observed that proposed architecture provides good Q factor and acceptable BER for 50km that is significantly higher than conventional architecture.

As proposed system utilizes only four wavelengths at OLT it required less line cards to hold transmitters and receivers. So this architecture consumes less power. i.e. proposed architecture is more energy efficient and cost efficient than conventional architecture.

In future, data rates and reach can be increased further to handle future optical network. Energy consumption is also a very challenging issue as number of users is increasing day by day. So based on the above requirements some more new architectures may be proposed.

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