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High efficient Fibre Plant Utilization by Multiple PON infrastructure based on Frequency Re-use Approach for Scalable FTTH Networks

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Abstract— We have proposed a hybrid time-division multiplexing (TDM)/dense wavelength-division multiplexing (DWDM) scheme in order to build a scalable and flexible passive optical network (PON) that satisfies current and future bandwidth demands. Increasing efficiency and capacity in PON networks were our main objectives. To this end, we proposed to involve an arrayed waveguide grating (AWG) in the proposed configuration and exploit its two properties of wavelength cyclic (WC) and free spectral range (FSR). Wavelength cyclic property has been exploited in order to allow different bit rate optical line terminals (OLTs) to use the same frequency band and handle their traffic over a common fibre. Free spectral range has been targeted in order to allow each optical network unit (ONU) to handle its traffic via the same AWG input/output ports as well as to multiply system capacity. The performance of the proposed PON architecture has been examined by using OptiSystem and Matlab software packages under BER constraints. It has been verified that the architecture was able to transmit different bit rate services simultaneously (622Mbps, 1Gbps, 2.5Gbps and 10Gbps) over a 24Km shared feeder. This variety of service is provided to 16 passive remote terminals (PRTs) with 16 ONU group for each. Each group can accommodate up to 16 ONU, total of 256 ONU/PRT, resulting in over all system capacity 4096 ONU.

Index Terms— Arrayed waveguide grating, Fiber-to-the-home FTTH, Free spectral range, Optical hybrid schemes, TDM-PON, WDM-PON, Wavelength cyclic property.

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1 Introduction

Modern telecommunication network is customary divided into three main segments; access, metro and backbone segments. Access segment is the basic level in which service is provided to end users through central office while metro and backbone segments are the main two higher levels that are respectively responsible for multiplexing functions and long-haul transmission. Twisted pairs and coaxial cables have been traditionally exploited in access segment while optical fibers have been exploited in metro and backbone segments for long time due to their very huge capacity and low losses. Figure 1 shows schematically the aforementioned levels of a modern telecommunication network.

Along with the continuous development of new services and applications such as digital TV and VoD, the demand for broader bandwidth per user increases rapidly. Therefore, copper-based access networks become not able to satisfy such increasing demand. Thus evolution to fiber-based access networks becomes inevitable. The history of passive optical network standardization began in 1990 when there was an expected growth of bandwidth demand. In 1995, FSAN held its forum including some popular operators such as British Telecom, NTT and Bell South in order to develop a common standard of optical access systems. Later, FSAN recommendations have been adopted by the International Telecommunication Union ITU [1] [2] [3] in the form of ITU-T G.983 standard which is known as broad band passive optical network (BPON). BPON provides 622Mbps and 155Mbps for downstream and upstream respectively over 20 km between 32 Optical Network Unit (ONU) and one Optical Line Terminal (OLT).

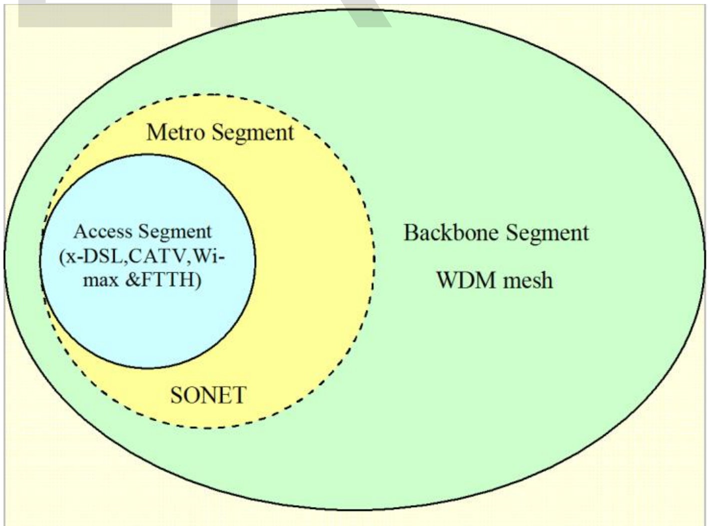

Figure 1.Schematic diagram of three level telecommunication networks

In 2001, IEEE802.3 standard group began to invest their efforts in order to develop a P2MP PON standard (IEEE802.3ah) to be agreed up on later in 2004 [4]. IEEE802.3ah provides 1Gbps for both Downstream and Upstream respectively over 10-20 km between 16 ONU and one OLT. ITU-T study group 15 (SG15) was also working in parallel with IEEE802.3 standard group to develop new PON standard [5] [6] [7] called gigabit PON (G.984). GPON provides 2.5Gbps for Downstream and 1.25Gbps for Upstream between 64 ONU and one OLT.

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Along with the ever-increasing demand for broader bandwidth as a result of the continuous development of new bandwidth-hungry services such as HDTV and 3D-video, evolution to next-generation PON becomes more and more insistent. To this end, IEEE [8] and ITU-T [9] have ratified their new standards, IEEE802.3av (10G-EPON) and ITU-T G.987 (XG-PON) in 2009 and 2010 respectively. IEEE802.3av specifies symmetric 10Gbps for downstream and upstream, and asymmetric 10Gbps downstream and 1Gbps upstream. ITU-T G.987 also specifies symmetric 10Gbps for both downstream and upstream, while asymmetric 10Gbps downstream and 2.5Gbps upstream. Although all of the aforementioned PON standards specify TDMA as an access technique, each one uses a different data framing technique. For example, G.983 specifies ATM for data framing whereas IEEE802.3ah specifies Ethernet as data framing technique while G.984 specifies another data framing technique called G-PON encapsulation mode (GEM). Although TDMA PON offers a cost-effective approach as service is provided over a common wavelength, its main drawback is the sharing-nature which posses a real challenge towards future upgrade. Figure 2 shows a schematic diagram of TDM-PON.

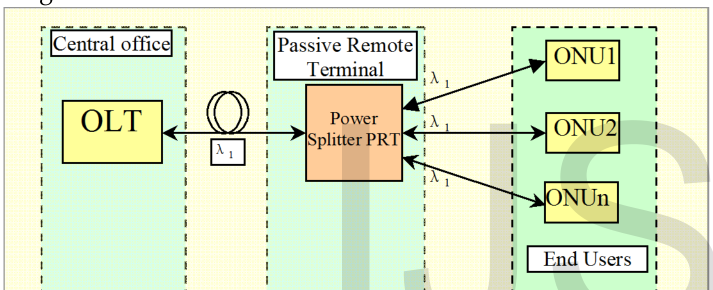

Figure 2.Schematic Diagram of TDM-PON with Power Splitter as a Passive Remote Terminal

Another technology competing towards next-generation optical access adoption is WDM-PON. WDM-PON was initially proposed based on exploiting the large counts of wavelength available in optical fibers. It is deemed as more securable than TDM-PON as it provides a virtual P2P connection (dedicated pair of wavelength for each ONU). Additionally, it is more scalable than TDM as it ensures self upgradeability for each ONU. Moreover, it allows coexistence over an open access environment where optical distribution network can be shared by different operators. However, the main challenges in adopting WDM-PON in the next-generation PON was based on cost consideration. Since WDM-PON relies on narrowband filtering, each ONU will be enforced to handle traffic over a stable pair of wavelength, which imposes additional requirements on the transmitter. Figure 3 show a schematic diagram of WDM-PON. To exploit high data rate provided by TDM-PON and large number of wavelengths offered by WDM-PON, a hybrid TDM/WDM-PON was proposed. In accordance with the wavelength grid used, TDM/WDM-PON can be categorized either as TDM/CWDM-PON or TDM/DWDM-PON. The first commercial colorless gigabit TDM/WDM-PON was proposed by Lee et al [10] for Korea Telecom. The contribution of this paper is to develop a new optical access scheme that is able to satisfy current and future demands. The design was based on study the characteristics of different optical components including arrayed waveguide gratings (AWGs) and the possibility to integrate them together in order to build a scalable and flexible TDM/DWDM-based passive optical network. Focus on AWG properties of wavelength cyclic (WC) and free spectral range (FSR) was made in order to: realize frequency re-using by several OLTs, enable each ONU to handle its traffic over a same input output port and multiply system capacity.

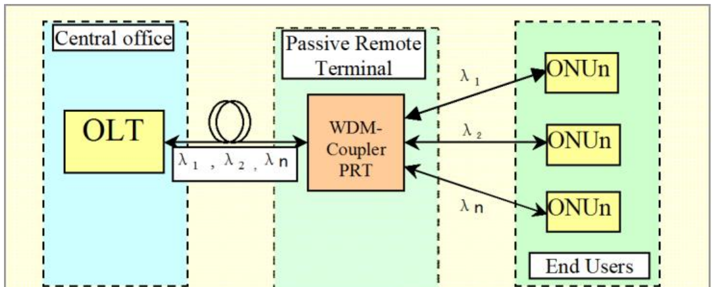

Figure 3. Schematic Diagram of WDM-PON with WDM-Coupler as a Passive Remote Terminal

2 AWG Architecture and Principles of Operation

AWG is an optical device, mainly consists of an array of different waveguide lengths and two propagation regions (slabs). The waveguide array is placed in the middle of the two free propagation regions. The difference in length between any adjacent waveguides is constant. Wavelengths that propagate in the first free propagation region (first slab) will arrive at the input of the second propagation region (second slab) with different phases due to different waveguide lengths. As a result, wavelengths will be demultiplexed over the output ports of the second slab. Based on the property of reciprocity, AWG can also be functioned as a Multiplexer. Kaneko et al [11] proposed a thermal AWG that offers high stable performance over a wide range of temperature, which is targeted at PON design. A Silicon-based AWG model with 1.26dB insertion loss has been developed by C2V Company. However, the main drawback of this model was its large size structure. Tippinit and Asawamethapant [12] spent their valuable efforts to overcome this drawback by proposing a new design through which a small size AWG with a low insertion loss (1.09dB) was obtained.

2.1 AWG Characteristics

Kaneko et al [13] reviewed the two main properties provided by the AWG. The first one is Wavelength Cyclic Property (WC) while the second one is Free Spectral Range Property (FSR). Wavelength Cyclic Property is the one in which a shift to the input port of the NxN AWG is followed by an opposite shift to the output port. In other words, if two identical wavelength aggregations incident on tow different input ports of an NxN AWG; they will be distributed among its output ports with non overlapping manner. One of the main objectives in this paper is to exploit this property in order to allow several OLTs to use the same frequency band, which multiplies the utilization of the fiber. Figure 4 shows a simple illustration of this property where a 4x4 AWG and 4 OLTs with identical wavelength aggregation for each are considered. Free Spectral Range is the property that identifies the periodic operating nature of the AWG. If two wavelengths enter from the same input port of an NxN AWG, they will come out from the same output port as long as they are separated by its periodic operating range (FSR). An AWG with large FSR is desirable in optical design to allow transmission over a wide range of bandwidth. Figure 5 shows a schematic diagram of this property where a 4x4 AWG with 400GHz Free Spectral Range is considered.

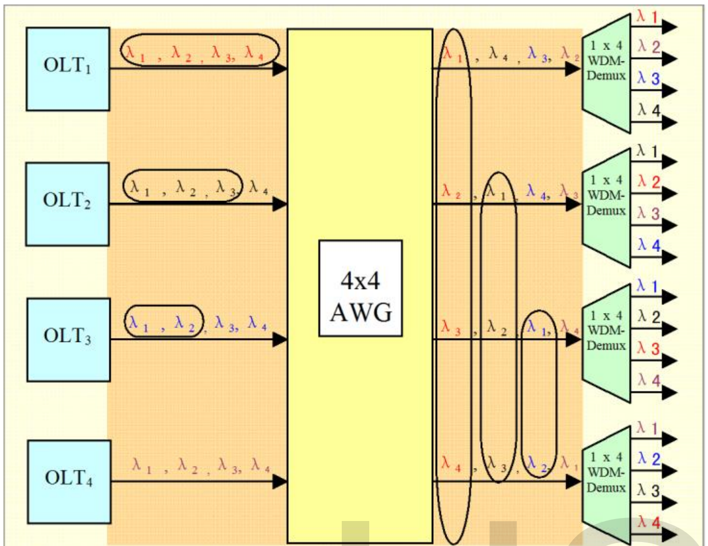

Figure 4. Schematic diagram of wavelength cyclic property

3 Proposed PON Architecture

The proposed PON architecture shown in figure 6 is a hybrid TDM/DWDM-based PON. It is mainly based on exploiting AWG properties. According to wavelength cyclic property (WCP), if an aggregation of wavelength (λ1 –λn) transmitted by OLT1 (Service Provider 1) enters the 1st port of the NxN AWG, it will be distributed among its output ports, each wavelength is then directed to a specific 1xJ power splitter which distributes it evenly among j-number of ONUs. If an identical aggregation of wavelength (λ1 –λn) transmitted by OLT2 (Service Provider 2) enters the 2nd input port of the NxN AWG, it will also be distributed among its output ports without overlapping with the 1st wavelength aggregation. Generally, if number m of identical aggregations (λ1 –λn) transmitted by m numbers of OLTs enter the N input ports of the NxN AWG, where m=n=N, they will be distributed on its output ports with no overlapping manner resulting to increase the utilization of the fiber as each AWG output port carries a replica of the same aggregation albeit from different OLTs. According to Free Spectral Range Property (FSRP), each ONU can handle its traffic via the same AWG input/output ports if downstream and upstream are separated by the periodic operating range of the AWG. Moreover, FSRP can be exploited in order to double the system capacity. For example, if 1st and 2nd FSRs are used by m OLTs, 3rd and 4th FSRs can be used by the same OLTs, which leads to double the over all system capacity. C-Band has been chosen for transmission because it is the lowest attenuation window for optical transmission. Moreover, transmission at 1550nm would allow using the well-known Erbium Doped Fiber Amplifier (EDFA) if future necessity arises. In order to verify feasibility of the proposed PON, performance has been examined using Optisystem and Matlab software packages under bit-error-rate (BER) constraints. Simulation results and discussion is provided in the next section.

4 Simulation Results and Discussions

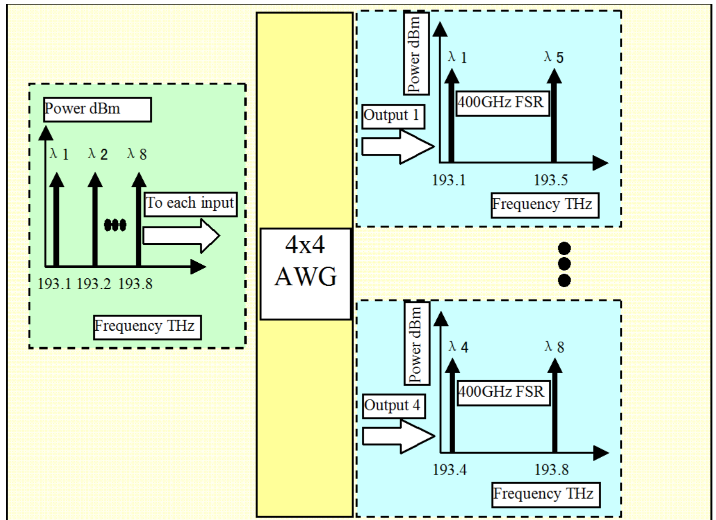

Figure 5. Schematic diagram of Free Spectral Range Property

Two simulations were conducted in order to verify feasibility of our proposed PON. In the first simulation, three different bit rate OLTs were considered, where 622Mbps, 1Gbps and 2.5Gbps were transmitted simultaneously. 10e-9 BER was chosen as a reference for operational requirement (maximum allowable value).

In the second simulation, 10Gbps OLT was included. Since forward error correction (FEC) is recommended at 10Gbps, a

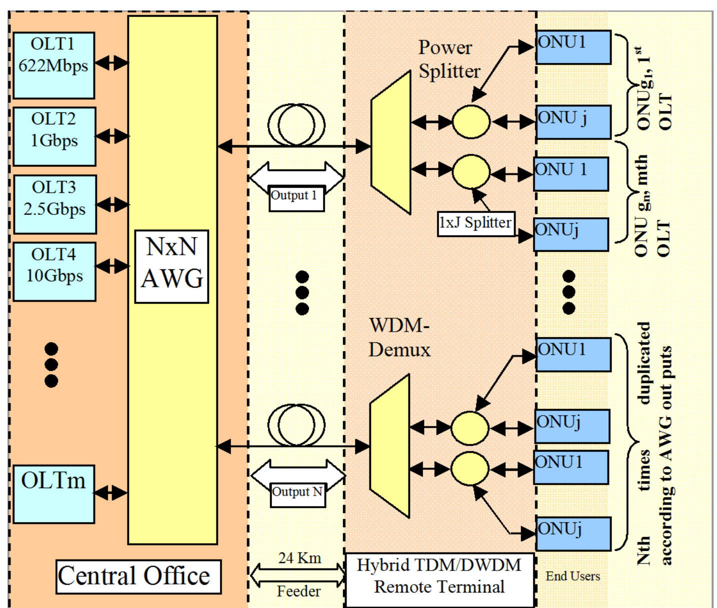

Figure 6. Proposed PON Configuration

BER of 2.9e-4 was chosen as a reference for operational requirement because it represents the pre-FEC BER required to achieve a post-FEC BER lower than 10e-9.

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4.1 First simulation

In this simulation, three different bit rate OLTs were considered, where 622Mbps, 1Gbps and 2.5Gbps NRZ Pseudo Random data were transmitted simultaneously at 0dBm. 16x16 AWG and 1x16 WDM-Demux with 1.26dB insertion loss for each was considered. 1x16 Power Splitter with 14.04dB Splitting/insertion loss was assigned. A frequency range of 1.5THz with 100GHz frequency spacing (193.1THz - 194.6THz) which represents an aggregation of sixteen wavelengths was allocated for each OLT as shown in figure 7.

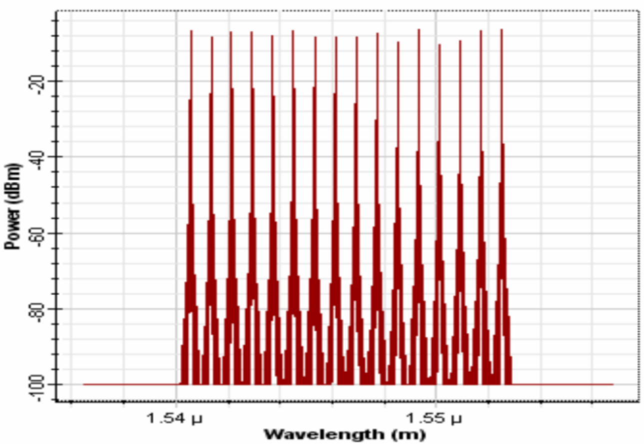

Figure 7. Optical spectrum from each OLT (193.1nm-194.6nm)

Variable length single-mode fiber (feeder fiber) with 0.2dB/km attenuation and 16.75ps/nm.km dispersion was considered. PIN photodiode was chosen for signal reception due to its low biasing voltage and low cost.

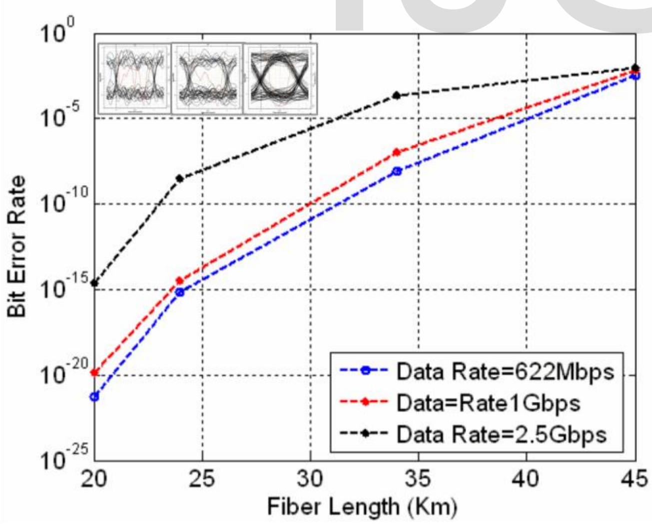

Figure 8. BER vs Fiber Length at 0dBm and Different Bit rates

Figure 8 shows BER against feeder fiber at 0dBm and three different bit rates, 622Mbps, 1Gbps and 2.5Gbps, where BER increases as feeder fiber increased until it reaches 10e-9 at 24Km/2.5Gbps, 30Km/1Gbps and 33Km/622Mbps, and then continuous to increase with the increase of the feeder fiber. Based on this result, we can conclude that transmission is possible over the proposed PON until 24Km (maximum allowable distance for transmission) as it is the lowest distance obtained for the simultaneous transmission.

4.2 Second simulation

In this simulation, a 10Gbps OLT was included. Since it is expected for any optical line to lose several dBs of its budget when bit rate increased to 10Gbps; alternative solutions were taken into account in order to compensate for such losses. To do so, we decided to: increase the input power, incorporate a 10GHz optical band-pass filter prior to the receiver, and use an optimized gain APD photodiode instead of PIN photodiode for signal reception. Figure 9 shows BER against input power at 10Gbps, 24Km feeder while using APD with gain (M=2), where decreasing BER values are achieved as input power increased. However, we prefered to keep away from higher values (more than 10dBm) where undesirable effects related to non linearity in optical fibers are expected as well as to comply with safety standards. Therefore we just increased the input power to 2dBm where a BER of 3.11e-3 which is higher than that is required for the pre-FEC was achieved.

For further improvement in the performance, a 10GHz optical band-pass filter was incorporated prior to the receiver while optimizing the APD gain. Figure 10 shows BER versus APD gain (M) at 10Gbps, 24Km feeder and 2dBm, where a BER value of 2.78e-5 which is lower than that is required for the pre-FEC was achieved at M=6.

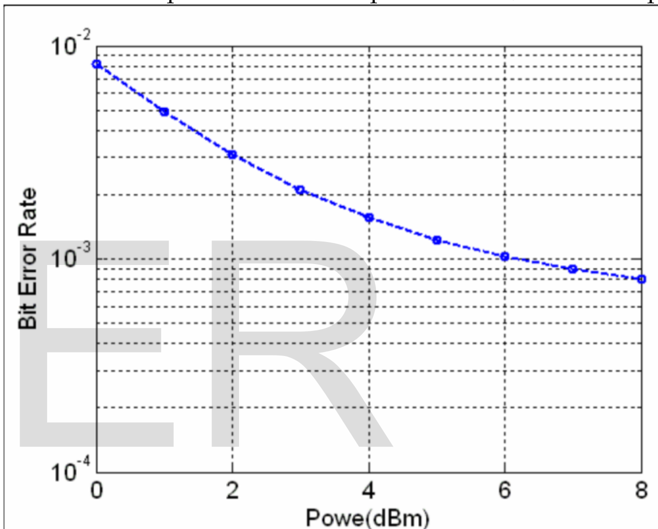

Figure 9. BER vs Power dBm at 10Gbps, 24Km feeder using APD (M=2).

5 Conclusions

A high scalable TDM/DWDM-based passive optical network has been proposed in which a variety of service can be provided to a large number of users. Different bit rat services can be provided simultaneously to 16 passive remote terminals over 24-Km feeders, each passive remote terminal can provide a variety of service to 16 ONU group. Each ONU group can accommodate up to 16 ONU, total 256 for each passive remote terminal, resulting in over all system capacity 4096 ONU. Incorporating AWG offers the following opportunities: First, the architecture enables each ONU to handle its downstream and upstream traffic through the same input/output ports. Second, the architecture is able to allow different bit rate OLTs to use the same frequency band and handle their traffic over a common fiber (Achievable Co-Existence and Increasable Fiber Utilization). Moreover, since each received wavelength refers to an individual OLT, each ONU can move to higher bit rate service simply by using a suitable filter and simple reconnection with out affecting the legacy ones (Achievable Self Upgradeability). This would allow gradual upgrade for the whole system to 10Gbps under seamless migration scenario. i.e. 622 Mbps will be dispensed with in the near future as it is the lowest bit rate service offered, later it will be followed by 1Gbps and 2.5Gbps respectively. Finally, the over all system capacity can be multiplied by exploiting several free spectral range periods (Increasable Scalability).

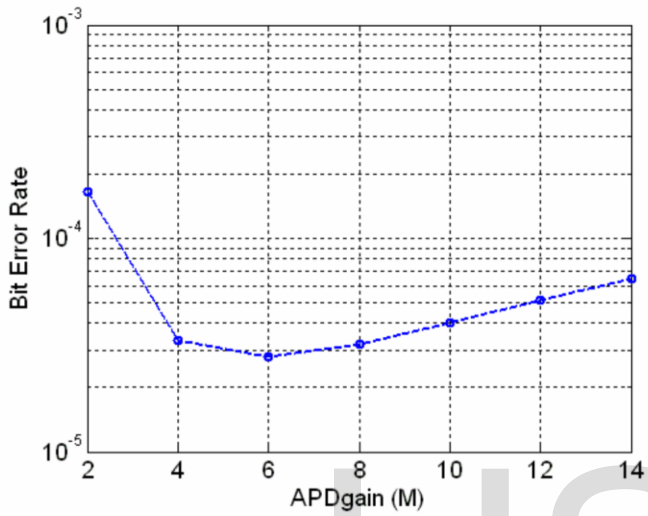

Figure 10. BER vs APD gain (M) at 10Gbps, 24Km, 2dBm and 10GHz optical Band-pass filter.

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