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Optical Pulse Power Analysis Using Fabry Perot Tunable Filter for 10 Gbps WDM PON Architecture

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Abstract: In the evolution of broadband networks, the WDM PON access network still needs to be upgraded; it should efficiently utilize the entire bandwidth dynamically for maximum number of end users/ONUs. For Dynamic Bandwidth Allocation (DBA), the Optical Line Terminals (OLT), Dynamically Allocate Wavelengths (DWA) to all ONUs and will uniformly distribute the powers with power splitters at remote node. Even though allocating bandwidth uniformly as per user demands is essential, it is necessary to take care of effective utilization of wavelength individually during wavelength allocating process with single hardware component and less cost. In view of this, it is essential that the Fabry Perot Filter (FPF) is considered as tunable filter/ tunable transmitter for replacing more fixed laser sources. Also, it is a low cost device to resonate number of wavelengths dynamically by changing its tunable parameters. In this study, the importance of effective utilization of wavelength using fabry perot filter at OLT has been experimentally analyzed and found that the optimal wavelengths or pulse suited for 10Gbps WDM PON and above for the cost trade off.

Key words: FPF, OLT, ONU, DBA, DWA, Low Pass Gaussian Filter (LPGF), Passive Optical Networks(PON), Time Division Multiplexed PON (TDM PON), Wavelength Division Multiplexed PON (WDM PON), remote node, cost-trade off, optical power loss, optimal optical pulse

NTRODUCTION

A Passive Optical Network (PON) is one of the major broadband access service networks with Point to Point (P2P), Point to Multipoint (P2MP), Multipoint to Point (MP2P) and Multipoint to Multipoint (MP2MP) architectures with the support of different topologies like star, bus, ring, mesh, etc., in its structure to provide triple play services to the Voice, Video and Data (VVD) in future Fiber-to-the-Home (FTTH).

At present, TDM PON architecture is having drawback during DBA since it suffers from bandwidth limitations of average bandwidth per user (downstream upto 40Gbps and upstream is few tens of Mbps), packet loss, time delay, larger buffer memories for users and limited in Quality of Service (QoS) though error free optical transmission with guaranteed excellent PON infrastructure (Lee *et al*., 2006; Maeda *et al*., 2001). To overcome above TDM PON issues, mainly offering of unlimited bandwidth dynamically with high cost maintenance, the WDMPON is taking a major part in future broadband access networks (Gulietvrez *et al*., 2005). Compared with all other PONs, the WDM PON including DWDM PON and Long Reach PON (LR PON) specifically constraints in architecture design to entirely replacing fixed laser source in transmitter side and photo detector in receiver sideat all sONUs including OLT. The cost reduction of DBA of WDM PON is attempted with IPACT-ST algorithm (Michael *et al*., 2006), similarly SUCCESS WDM PON or HPON is attempted with scheduling algorithms and architecture modification by choosing tunable transceivers at OLT and ONUs (Kim *et al*., 2005). In the upgradation of WDM PON set up, low cost tunable filter designs at OLT dynamically produce, transmit and receive more number of wavelengths are essential to provide maximum bandwidths to more number of ONUs using 1x N optical splitters at remote node. Based on the above issues and requirements, Fabry Perot Filter (FPF) has been proposed and chosen as a better tunable filter, since it is cost effective having wide tuning range of 500nm and wavelength selective accuracy (Fu-Tai *et al*., 2005; Banetrjee *et al*., 2005) . In this study, the downstream transmission (OLT to ONUs) has been carried out.

GBPS WDM PON FUNCTIONS AND PROBLEM FORMULATION

Recent WDM /DWDM PON architecture OLT design (Michael *et al*., 2006) is to be modified with tunable

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filter designs for tunable transceivers. Tunable filters have ability to change wavelengths, they select dynamically in contrast to fixed filters. A set of wavelengths enters the tunable filter and a control mechanism guides the filter in its dynamic selection of the desired individual wavelength. OLT and every ONUs of WDM PON with a tunable optical filter (using tunable mechanism) are to select the desired optical pulse or wavelength for reception and transmission. The WDM PON architecture's simplification and performance, OLT design requires to operate multi-wavelengths using tunable transmitters or receivers, are one of the cost reduction techniques comparatively while providing individual wavelength (laser) source or detector (receiver) at the ONUsor end user node. Based on above references in this work, FPF have been chosen as tunable optical filter, tunable transmitter or multi-wavelength source with tunable mechanism. Also, it has been chosen here to produce more number of optical pulses. Every optical pulse responds to carry 10Gbps bit rate for downstream transmission from OLT to ONUs of WDM PON at OLT. The OLT considered with Pseudo Random Bit Sequence (PRBS) pattern from PRBS generator is to generate 10Gbps bit rate transmission as encoded in Non-Return to Zero (NRZ) signal. The OLT set up consists of FP filter with optical filter analyzer. Four wavelengths λ1, λ2, λ3 and λ4 in 1550 nm ranges which is 1550.12, 1550.92, 1551.72 and 1552.52nm with channel spacing of 0.8 nm (bandwidth of 100 GHz)tunedby FPF filter as input wavelengths from the OLT set up. The NRZ signal and tuned wavelengths are modulated and transported to Remote Node (RN) using AM modulator. The RN has been linked with SMF at a distance of 15 km from Central Office (CO). The remote node has been structured here with 1×8 splitter and every splitter output is again considered with 1×4 WDM demux to provide bandwidth maximum of 32 ONUs as shown in Fig. 1. Every ONU connected in a distance of 2 km from RN , which consists of anAPD along with two stages Low Pass Gaussian Filter (LPGF) and 3R (regenerate, retime and reshape) as shown in Fig. 2. The simplified WDM PON architecture is considered here as cost trade-off one, avoiding more fixed laser sources for the benefit of compact size of WDM PON architecture and device management control. In this research, the problem has beenproposed is the analysis of optical pulse power losses for every wavelength during 10 Gbps bit rate transmission; since optical link power budget analysis for WDM PON is also an important case while transmitting and allocating more wavelengths for DBA operating with single FPF as wavelength resources at OLT (Wei-ping *et al.*, 2007). From the above problem, it is necessary to formulate link power analysis to select optimal optical pulse for the requirement of minimum link power per pulse using tunable fiber source (or) tunable filter. Its design has been considered for dynamically allocating (or) selecting wavelengths at OLT for DBA in WDM PON Architecture. The Table 1 describes the parameters which are used for the entire WDM PON architecture performance.

Table 1: Specificationsusing for 10Gbps WDM PON architecture

Parameters	Ranges with unit
Fabry-Perot Filter:	
Filter centre wavelength	1551.32 nm
3dB filter bandwidth	20 GHz, 40 GHz, 50 GHz, 55 GHz
Insertion loss	0 dB
Depth	100 dB
FSR	100 GHz
Optical filter analyzer:	
Filter centre wavelength	1551.32 nm
Minimum value when using log scale	-100 dBm
3dB filter bandwidth	400 GHz
Pseudo Random Bit Sequence generator(PRBS)	
Bit rate	10Gbps
Probability of 1's in the sequence	0.5
NRZ pulse generator	
Amplitude	1 a.u.
Bias	0 a.u.
Rise time	0.05 bit
Rectangle shape	Exponential
Fall time	0.05 bit
Amplitude modulator	
Modulation index	1
Reference wavelength	1550 nm
SMF	
Length	15km, 2km
Dispersion	17 ps/nm-km
Group delay	0.2 ps/km
Attenuation α	0.2 dB/km
1×8 Power splitter	
Loss	0 dB
1×4 WDM Demux	-------
3 dB filter bandwidth	10 GHz
APD photo detector	
Ionization ratio	0.9
Responsibility	1 A/W
Dark current	10 nA
Avalanche Multiplication factor	3

RESULTS AND DISCUSSION

Input power consideration of FPF at OLT: The input wave form of FPF for 4 wavelengths (λ1, λ2, λ3 and λ4) at OLT were resonated, sourced and obtained by the simulation using Optisystem 6.0 for different reflectivities as in Fig. 1a. The design has been considered to tune the different wavelengths from FPF by properly choosing differentchannel spacing as 20, 40, 50 and 55 GHz of its corresponding reflectivities are 0.34, 0.5, 0.75 and 0.91 respectively. All resulted waveforms compared with mathematical modeling of power transfer functions

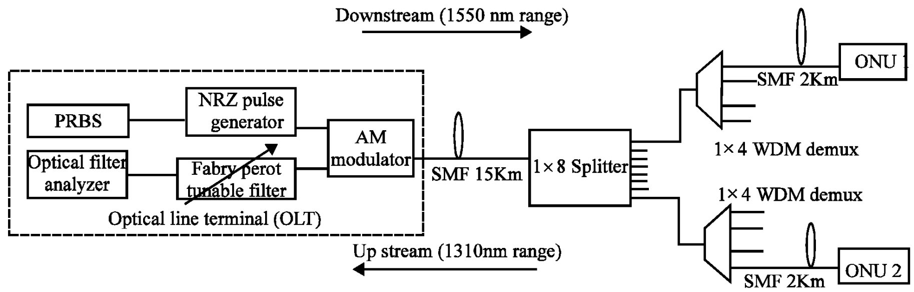

Fig. 1a: Detailedstages of 10Gbps WDM PON functionswith fabry perot filter at OLT to resonating different wavelengths, SMF-Single Mode Fiber, ONU-Optical Network Unit, NRZ-Non Return to Zone

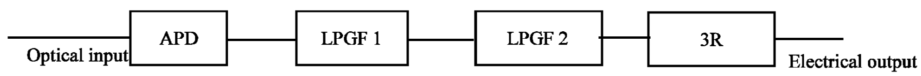

Fig. 1b: Detailed block stages considered for ONUs of WDM PON, APD-Avalanche photo detector LPGF-Low pass gaussian filter 3R-regenerate, retiming, reshaping

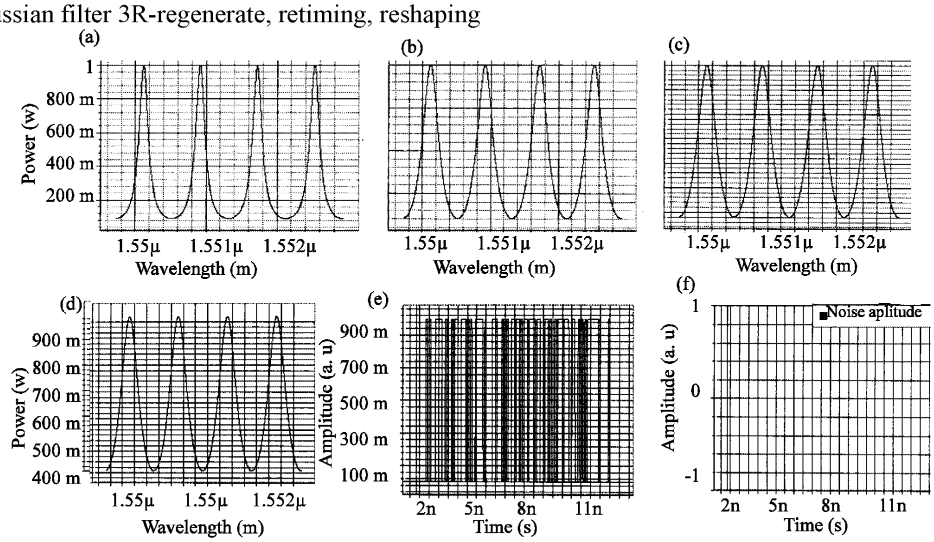

Fig. 2: Input waveform for different reflectivities(R): (a) R = 0.34 (b) R = 0.5 (c) R = 0.75(d) R = 0.91 (e) 10 Gbps NRZ signal and (f) Noisy level of input signal

(Rajiv and Srinivasan, 2002). The maximum powers are obtained for the reflectivities of 0.34 is 100 mW to 1W and 0.5 is 240 mW to 1W, whereas minimum powers are obtained for reflectivities of 0.75 is 380 mW to 1W and 0.91 is 440 mW to 1W(consumed 350 mW optical power). By these comparisons, selection of FPF for WDM PON at OLT, higher and lesser input optical power preference is inversely proportional to reflectivities as shown in Fig. 2 (a-d). The Fig. 2 (e) and (f) are corresponds to NRZ for 10Gbps signal and noisy level of input signal.

Channel (SMFs) and ONUs Power performance analysis

Channel output power results: The 4 wavelengths ($\lambda 1$, $\lambda 2$, $\lambda 3$ and $\lambda 4$) are considered as 4 channels, the output powers of 1×4 WDM DEMUX for the reflectivities R=0.34 is 200iW, which are same almost up to R=0.91. The power across each channel is same, but the pulse shapes are changed due to variations in reflectivities, this is proportional to bandwidth selection and SMF parameters. The inference from the analysis, the output power is reduced from mW to μW range compared with input power (Fig. 3a-d).

Power penalty analysis without filter: The Eye Opening Power (EOP) penalty is one of the major results for any link power analysis. In this research, the output of APD

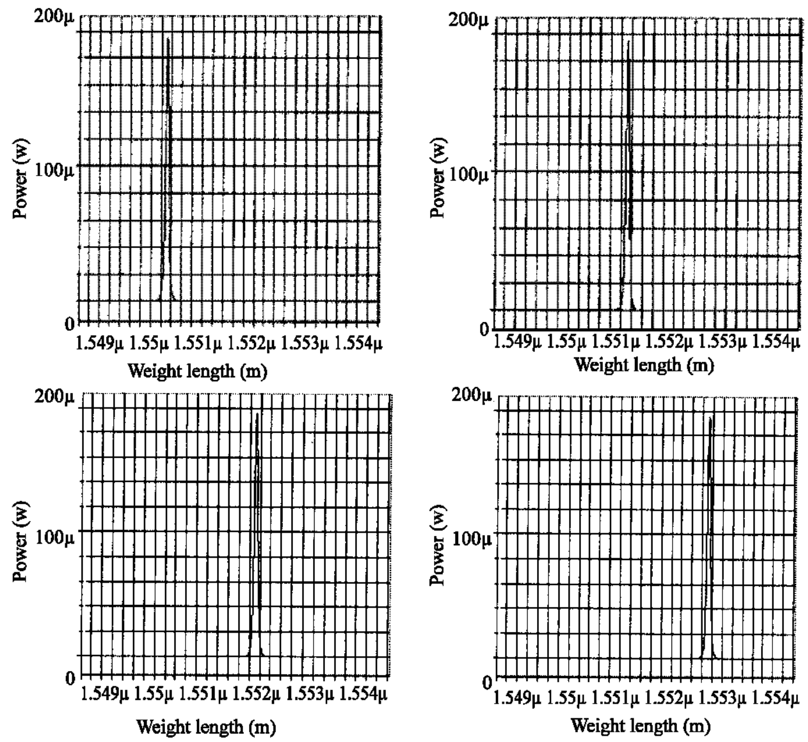

Fig. 3: Output waveform for all reflectivities: (a) Channel 1 = 1550.12nm (b) Channel 2 = 1550.92nm (c) Channel 3 = 1551.72 nm and (d) channel 4 = 1552.52nm

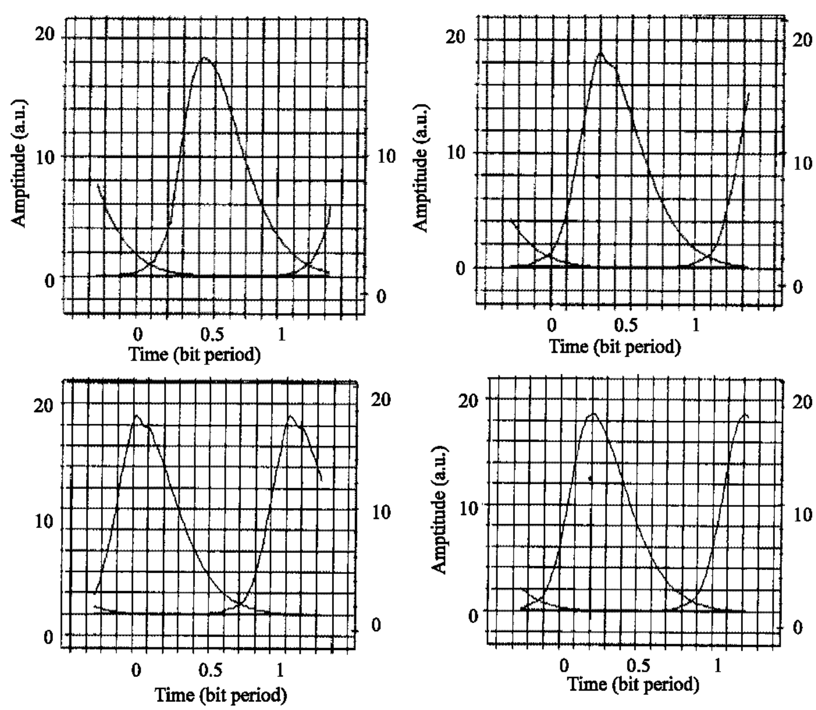

Fig. 4: EOP for all reflectivities without LPGF - (a) Channel 1 = 1550.12 nm (b) Channel 2 = 1550.92 nm (c) Channel 3 = 1551.72 nm and (d) Channel 4 = 1552.52 nm

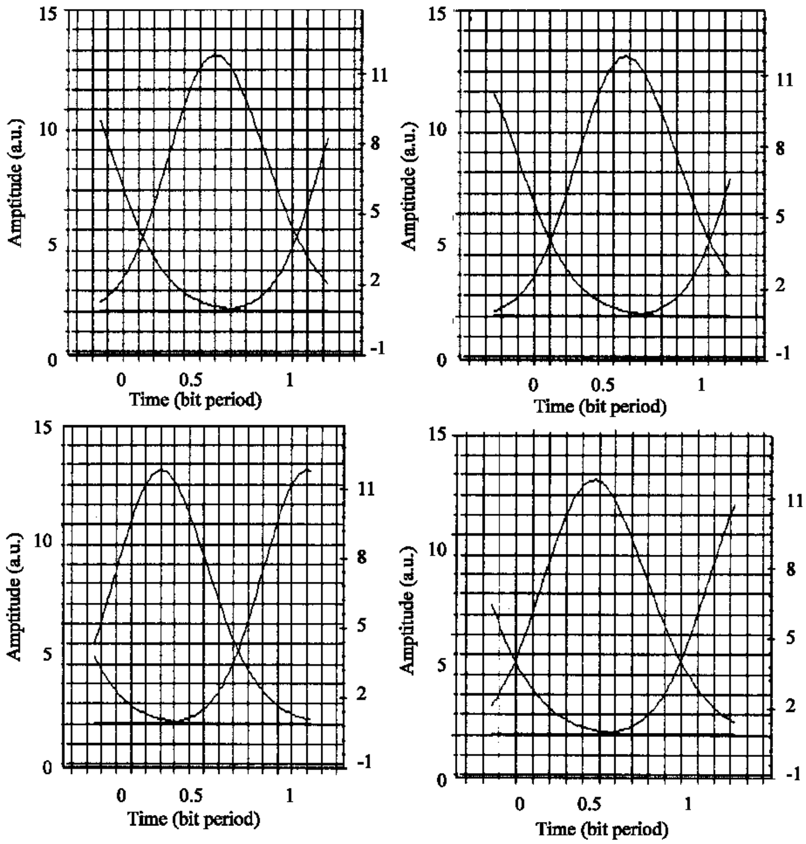

Fig. 5: EOP for all reflectivities with LPGF -(a) Channel 1 =1550.12 nm (b) Channel 2 = 1550.92 nm (c) Channel 3 = 1551.72 nmand (d) Channel 4 = 1552.52 nm

without filter stage (at ONUs), the amplitude of all channels is almost 18 a.u. with maximum time is taken in the range of 0-1 bit period for all channels. From the result, poor response and shift taken place in time level of all four channel responses through eye pattern shape of APD as shown in Fig. 4 (a-d). So, it is necessary to attempt with filter and introduced 2 stages LPGF to obtain better power response analysis.

Power penalty analysis with filter: Better EOP penalties obtained of each channel which is shown in Fig. 5(a-d). Again with filter also EOP is almost equal in its amplitude level of 13a.u. whereas the time level in bit period is shifted with respect to amplitude i.e. eye height for every channels as 0.6(1550.12 nm), 0.7(1550.92 nm), 0.3(1551.72 nm) and 0.5(1552.52 nm) with reference to time in bit period 0.5. This focuses the importance and improvement of 2 stages LPGF to consume maximum power 5a.u. in the amplitude level by obtaining better eye opening result.

Spectrumanalysis ofAPD output with out filter: The electrical output of APD is found out using Radio Frequency Spectrum Analyzer (RFSA) for the frequency range 0-300GHz as shown in Fig. 6(a-d), the Signal Spectrum Power (SSP) level almost in allchannels -60dBm, fluctuated Noise Spectrum Power (NSP) occurred in the ranges of -85 dBm whereas the signal + Noise Spectrum Power (SNSP) occurred which is slowly decreased maximum from 10 dBm to minimum of -85dBm. This shows the SSP almost minimized by NSP, from the graphical result the SNSP slowly decreasing due to major impact of NSP especially in channel 3 and 4 affecting SSP almost in equal. From this analysis, it is essential to go for 2 stages LPGF which is explained in following topic.

Spectrum analysis of APD output with filter: The electrical output of APD with 2 stage LPGF is found out using RFSA for the frequency range 0 – 300GHz as shown in Fig. 7(a-d), SSP and SNSP are almost same in allchannels but sudden decay in response from 10dBm to the frequency range 0-22 GHz and both values are at-100dBm approximately constant for the frequency range 22-300GHz. The NSPfluctuation is very less and entire NSP occurred with very minimum value in the range of -80 to -100dBm approximately for almost all channels. This

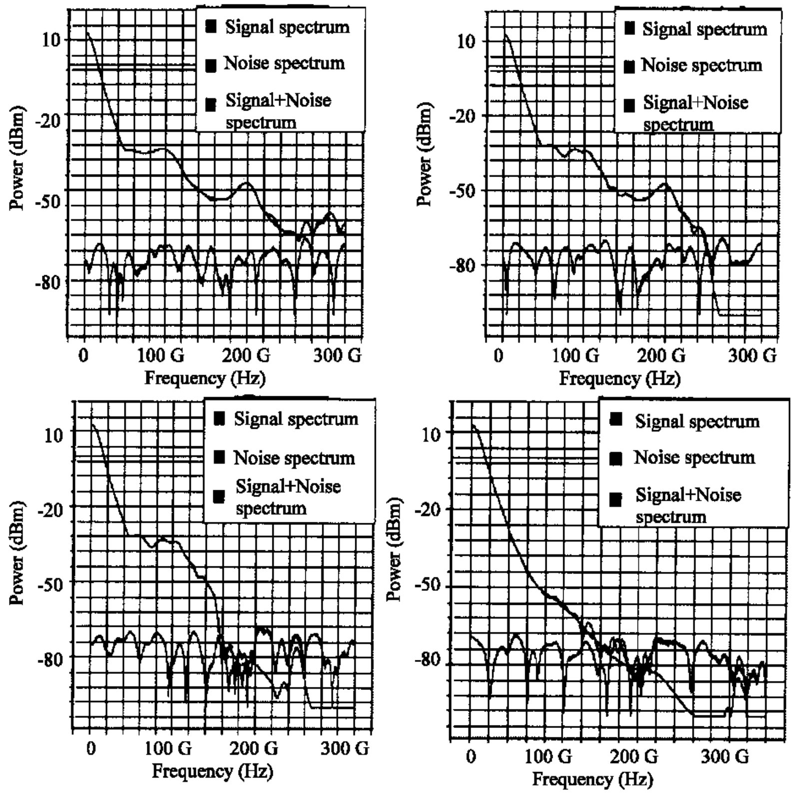

Fig. 6: RF spectrum output at APD for all reflectivities- (a) channel 1 = 1550.12 nm (b) channel 2 = 1550.92 nm(c) channel 3 = 1551.72 nm and (d) channel 4 = 1552.52 nm

Table 2: Comparisons of optical input powers for different wavelengths (four channels)

Band width (GHz)	Reflectivity	Wave length (nm)	Input power Signal power (dBm)	Noise power (dBm)	OSNR (dB)
20	0.34	λ1	41.65	48.4	-6.75
40	0.5	λ2	46.63	50.71	-4.088
50	0.75	λ3	47.91	51.37	-3.2187
55	0.91	λ4	48.409	51.28	- 2.87

Table 3: Comparisons of optical output powers for different wavelengths (four channels)

Band width (GHz)	Reflectivity	Wave length (nm)	Input power Signal power (dBm)	Noise power (dBm)	OSNR (dB)
20	0.34	λ1	-51.34	-38.25	-13.08
		λ2	-32.14	-1.47	-30.67
		λ3	-32.03	-2.04	-29.99
		λ4	-51.3	-38.30	-12.98
40	0.5	λ1	-46.36	-35.85	-10.51
		λ2	-27.17	0.14	-27.31
		λ3	-27.06	-0.34	-26.72
		λ4	-46.33	-35.85	-10.48
50	0.75	λ1	-44.07	-35.41	-9.66
		λ2	-25.88	0.407	-26.28
		λ3	-25.76	-0.06	-25.70
		λ4	-45.03	-35.38	-9.65
55	0.91	λ1	-44.55	-35.26	-9.32
		λ2	-25.28	0.41	-25.88
		λ3	-25.28	0.03	-25.31
		λ4	-44.55	-35.23	-9.31

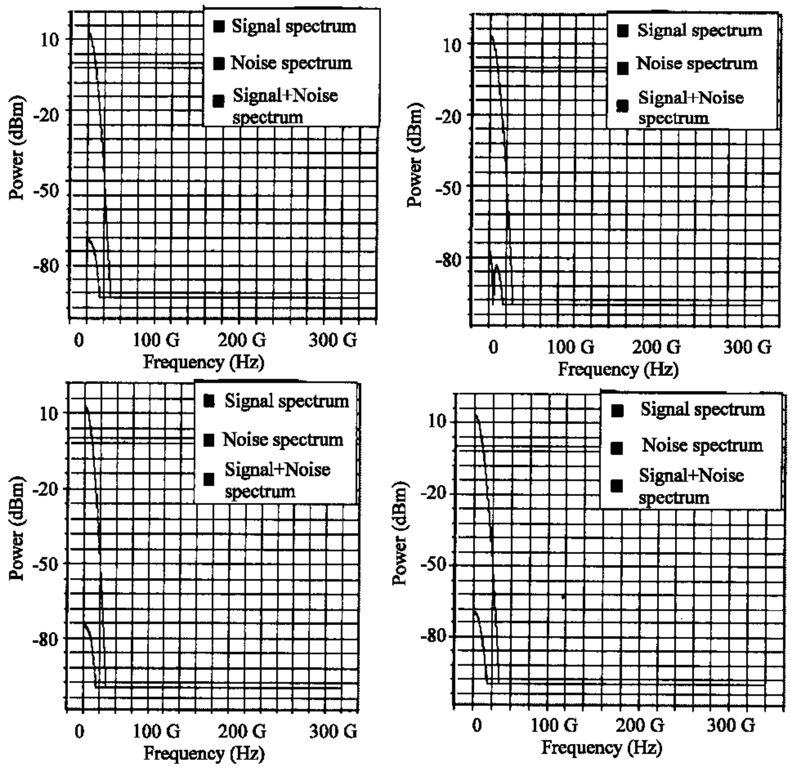

Fig. 7: RF spectrum output at LPGF for all Reflectivities-(a) Channel 1 = 1550.12 nm (b) Channel 2 = 1550.92 nm (c) Channel 3 = 1551.72 nm and (d) Channel 4 = 1552.52 nm

shows the SSP almost maximized with filtered out NSP by LPGF and flattened smoothsignal power occurred at the lower power level almost for all channels.

Comparison input and output Power of differentoptical pulse / wavelengths: In this complete experiment, the entire simulation has been considered 15 and 2 Km SMF link distance without any optical amplifier chosen between OLT to RN and RN to ONUs respectively. The centre wavelength and FSR are chosen as 1551.32nm and 100GHz (0.8 nm) to select number of wavelengths Based on the optical link power estimation, compared input and output power for four different wavelengths with FSR, have been found out using WDM analyzer through simulations. Comparative values of both input and output optical powers are tabulated in Table 2 and 3 using performance parameters such as bandwidth in GHz, reflectivites and Signal power in dBm, Noise Power in dBm and OSNR in dB. The comparison of input power analysis from Table 2, the lower bandwidth with reflectivities 20GHz at 0.34 is proportionally obtained lower value of input power say OSNR value is -6.75 dB whereas higher bandwidth with reflectivities 55 GHz at 0.91 which is proportionally obtained for higher input power say OSNR value is -2.87 dB. This shows the input power almost maintaining its proportionality while tuning the four wavelengths with its tuning parameters.

Comparatively the overall power level of λ_1 and λ_4 and $\lambda_2$and $\lambda_3$are similar for all reflectivites for 0.34 to 0.91 is slowly increasing but in the case (i) at R = 0.34, for λ_1 and λ_4 the signal power, noise power and OSNR is -51.34, -38.24 and -13.08dB and for λ_2 and λ_3 is -32.17 -1.47, -30.64dB. Similarly in case (ii) at 55GHz, λ1 and λ_4 the signal power, noise power and OSNR is -44.55, -35.24, -9.31dBm and for λ_2 and λ_3 is -25.28, 0.03, -25.31dBm. From this, concluding the power level is increasing 7dBm. From this analysis, FPF does not require power penalty for all wavelengths independently. It is enough to manage two wavelengths power levels instead of four wavelengths ($P\lambda_i = P\lambda_1 = P\lambda_4$ and $P\lambda_j = P\lambda_2 = P\lambda_3$) which are formed as expressions (1) and (2) in general

$$\sum_{i}^{M} P\lambda_i i = 1, 4, 5, 8, 9, 12 \ldots M \quad (1)$$

$$\sum_{j}^{N} P\lambda_j j = 1, 4, 5, 8, 9, 12 \ldots M \quad (2)$$

Where $P\lambda i$ and $P\lambda j$ are periodically controlling lower and higher wavelength optical power for 1×N WDM demultiplexer in the ratio of 1×4WDM demultiplexer, M and N are integers.

CONCLUSION

The experiment has been simulated and concluded that the DBA selected for all ONUs which depends DWA by proper tuning and channel spacing among different wavelengths from the FPF. It should have less operating power, if analyzing the input power at OLT normally, whereas if seen the simulation results, the input power level was inversely proportional to the reflectivities while tuning wavelengths individually. Suppose if FPF connected with remote node along with ONUs of WDM PON set up, the input power is almost proportional to the reflectivities of FPF for all wavelengths. The power level proportionality changes, with and without SMF, confirming the importance of downstream power level. Based on electrical output power almost minimum power only occurred due to maximum impact of SNP which is suppressed by LPGF. Finally optimal output optical pulse analysis for 10 Gbps WDM PON downstream processes, 2 wavelengths are optimally selected and same 2 wavelengths change mutually one with another in power level among 4 pulses from the multi-wavelengths/ selective wavelength analysis. It shows that FPF tuning wavelengths with different channel spacing provides major cost trade – off by consuming 4 wavelengths power which is considered in the same level of 2 wavelengths powers. In future, with 3R processing set up to select accuracy of optimal optical pulse. The entire 10 Gbps WDM PON approach could be extended to long distance with optical amplifier to bring out effective optimal optical pulse for 40 – 100 Gbps high bit rate transmission in future FTTX applications. Finally, the above approach helps to suitably assign wavelengths dynamically for DBA. Also, upstream transmission can be carried out using FPF performance from ONUs to OLT.

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