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Performance enhancement with square root module for WDM RoF-EPON link

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ABSTRACT

In this paper, the performance of WDM Ethernet Passive Optical Network (EPON) with radio over fiber (RoF) optical link is enhanced by using a square root module (SRm) at the receiver side. We have proposed that a square root (SQRT) module compensates the square law characteristics for improving the performance of WDM RoF-EPON. The improvement in the performance has been reported four times for successful transmission over the distance of 20 km that has been witnessed by BER, Q factor and eye opening. Moreover the significant improvement in the signal power has been noticed which is 4.675, −47.118 dBm with SRm and −20.563, −84.896 dBm without SRm for ONUs and OLT respectively.

1. Introduction

EPON technology, which combines a mature Ethernet technology and high-bandwidth PON technology [1,2] is an ideal access method to achieve integrated services. Ethernet passive optical networks (EPONs) have been widely considered as a promising solution to the 'last mile' problem in broadband access networks [3,4]. An EPON is a point-to-multipoint optical network [5–7], which typically consists of one optical line terminal (OLT) and multiple optical network units (ONUs), and employs only passive optical components (i.e. fibers and passive star coupler) in the transmission path from source to destination. Bandwidth in a PON can be distributed between various users by Time Division Multiplexing (TDM) and Wavelength Division Multiplexing (WDM). The protocol needed to implement TDM and dynamically allocate bandwidth is very complicated and not easy to realize. One possible way of separating the channels is to use WDM, which can provide much higher bandwidth compared to the standard EPON. WDM-PON gives longer transmission distance and easy to implement as compared to TDM-PON. WDM-PONs offer many other advantages including large capacity, easy management, network security, better privacy and upgradeability [8–10].

Radio-over-fiber (RoF) technology entails the use of optical fiber links to distribute radio frequency (RF) signals from a central location to the remote antenna units (RAUs). RoF makes it possible to centralize the RF signal processing functions in one shared location (headend), and then to use optical fiber, which offers low signal loss (0.3 dB/km for 1550 nm, and 0.5 dB/km for 1310 nm wavelengths) to distribute the RF signals to the RAUs (Remote Access Units). RAUs are only needed to perform optoelectronic (O/E & E/O) conversion and amplification functions [11]. The centralization of RF signal processing functions enables equipment sharing, dynamic allocation of resources, and simplified system operation and maintenance. The cell radius will also become relatively small, so that large number of BS's can be accommodated to ensure adequate radio coverage by making low-cost BS's essential [12].

The application of WDM in ROF networks have many advantages including simplification of the network topology by allocating different wavelengths to individual BSs, enabling easier network and service upgrades and providing simpler network management. Optical mm-wave signals from multiple sources are multiplexed and the composite signal is optically amplified, transported over a single fiber and demultiplexed to address each BS.

This paper is organized as follows. Section 1 briefly describes the overall idea of WDM-EPON technology and the radio over fiber architecture. The model description has been motioned in Section 2 and their after the results are discussed in Section 3. Finally the conclusions are drawn in Section 4.

2. Model description

We developed a model based on Ethernet passive optical network (EPON) architecture for radio frequency using commercial

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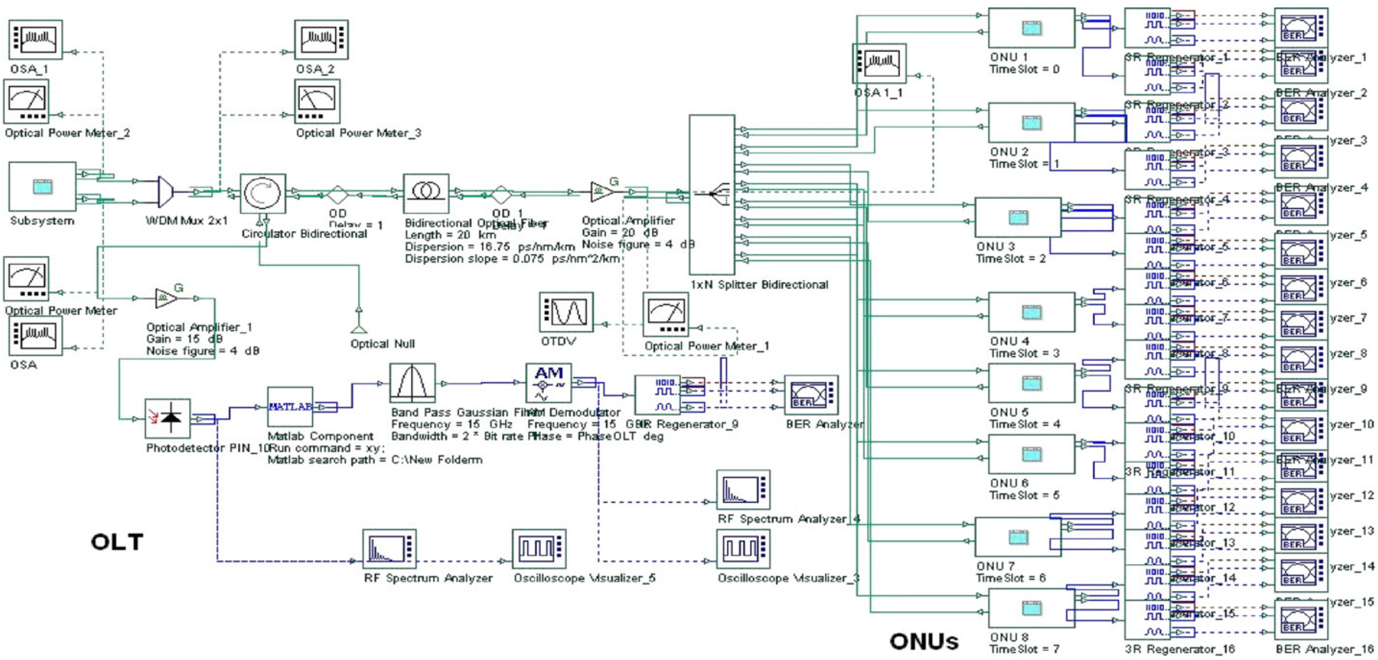

Fig. 1. EPON model for radio frequency with SQRT Matlab component.

simulator optisystem^{TM} as shown in Fig. 1. All the parameters for the designing are taken according to IEEE 802.3 ah standard [13]. Here eight ONUs are connected with a central office (OLT) via an optical fiber access network employing WDM technology. A 20-km of single mode fiber (SMF) was used as the feeder and 2 km of SMF was selected for the distribution fiber. Many parameters have been taken under variation to get the best BER pattern. Design parameters are shown in Table 1. Results are compared for different fiber lengths and different input powers of both the transmitters.

Radio frequency signals of 15 GHz are modulated using Mach–Zehnder modulator with carrier frequencies 193.1 and 193.2 THz as shown in Fig. 2. The parameters which are taken for radio modulation are shown in Table 2.

WDM MUX is launched to combine the signals for the further transmission. The output of WDM MUX is transmitted through bi-directional optical fiber and then amplified by an optical amplifier of 20 dB gain and 4 dB noise figure. Now the output is equally distributed through 1:8 splitters to eight ONUs. Design inside ONU1 is shown in Fig. 3. To detect the signal at receiver side WDM DEMUX

Table 1
Design parameters for ROF.

Parameter	Value (IEEE 802.3 ah standard)
Maximum downstream bit rate	1.25 Gbps
Maximum upstream bit rate	1.25 Gbps
Downstream wavelength	1550 nm
Upstream wavelength	1300 nm
Traffic mode	Ethernet
Modulation format	NRZ
OLT power	0 dBm
ONU power	0 dBm
Insertion loss (circulator bi-directional)	3 dB
Length (bi-directional optical fiber)	20 km
Dispersion (bi-directional optical fiber)	16.75 ps/nm/km
Dispersion slope (bi-directional optical fiber)	0.075 ps/nm^2/km
Attenuation constant (bi-directional optical fiber)	0.2 dB/km
Insertion loss (bi-directional splitter 1:8)	1.5 dB
Effective area (bi-directional optical fiber)	80 μm^2
Differential group delay (bi-directional optical fiber)	3 ps/km

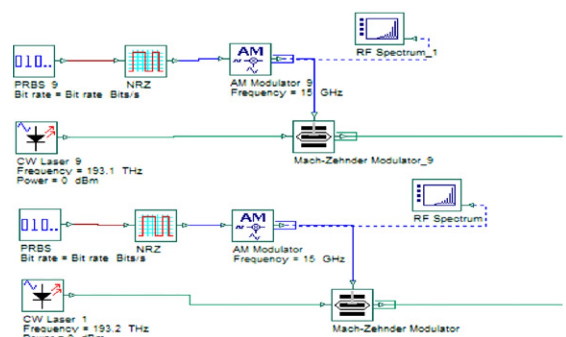

Fig. 2. RF modulation (design inside subsystem).

with same channel frequency is used. PIN photo-detector with 800 GHz sample rate, 1 A/W responsivity and 10 ηA dark current, band pass Bessel filter with 15 GHz frequency and 2.5 GHz bandwidth and AM demodulator with 15 GHz frequency and 0.9375 GHz cut-off frequency are selected for the electrical transmission. For analysis purpose at the receiver side we have connected two 3R regenerators and BER analyzers for two different carrier frequencies. So we can simultaneously divide the input signal into sixteen different users.

The PIN photo-detector produces a modulus square operation to the incoming optical power (i.e. $I_{RX} = |E_{in}|^2$) [14], where E_{in} is the input incoming power and I_{RX} is the detected electrical current. Due to optical square-law operation the optical effects generating

Table 2
Design parameters for ROF.

Parameters	Value (IEEE 802.3 ah standard)
Frequency (AM modulator)	15 GHz
Carrier frequency (first Mach–Zehnder modulator)	193.1 THz
Carrier frequency (second Mach–Zehnder modulator)	193.2 THz
Bandwidth (WDM MUX 2:1)	10 GHz

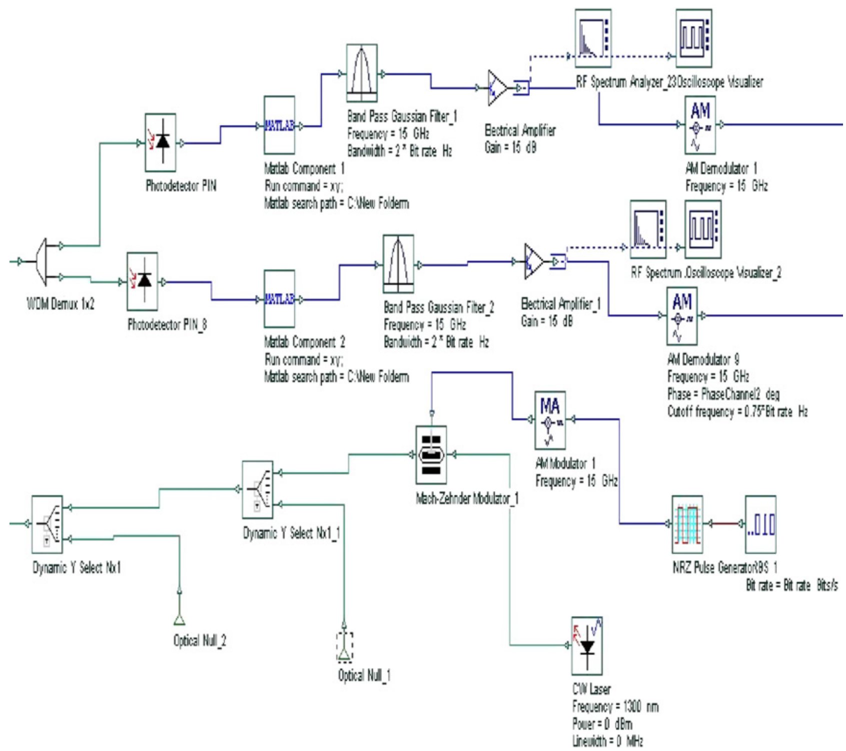

Fig. 3. Designing inside ONU1.

ISI (Intersymbol Interference) are not linear any more [15]. Square root (SQRT) module is designed using Matlab programming and placed after photodiode at both OLT and ONU sides to compensate the square-law characteristics of photodiode. All physical effects in the fiber are taken into account like attenuation, dispersion, Polarization Mode Dispersion, four wave mixing, self/cross phase modulation, Stimulated Bernoulli Scattering (SBS), Stimulated Raman Scattering (SRS) etc. Results are obtained through different measurement components like optical and electrical spectrum analyzers, power meters and BER analyzers.

3. Results and discussion

Two signals of 15 GHz radio frequency, modulated with wavelengths 1552.5 and 1551.7 nm having 0.8 nm channel spacing is transmitted over a distance of 20 km with and without SRm (see Fig. 4). Optical power at the transmitter section was 0 dBm and the optical power at ONU 1 (output of WDM DEMUX) is −32.16 dBm.

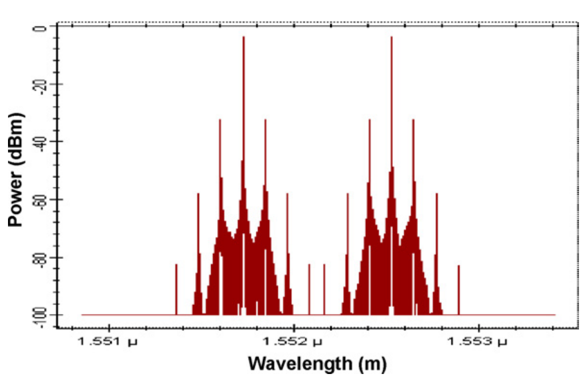

Fig. 4. Output spectrum at WDM MUX.

The total signal attenuation from fiber spans and splitters is about 32.16 dB. This value is within acceptable range.

The SQRT Matlab component is added at ONUs and OLT receivers as shown in Fig. 5. Results are compared through BER analyzers at Rx1 and Rx2 with and without SRm.

Fig. 5 shows the eye diagram at two different multiplexing and demultiplexing wavelengths 1552.5 and 1551.7 nm with and without SRm at Rx1 and Rx2. same analysis can be done for any receiver.

Similarly radio frequency signal (15 GHz) is modulated through optical signal having power (0 dBm) and wavelength 1300 nm at eight ONUs then combined through combiner and transmitted to the OLT side. At OLT total received power is −48.86 dBm. This value is again within acceptable range. The eye diagram at receiver side of OLT is analyzed with and without Matlab component, as shown in Fig. 6. The SNR is calculated at the output of photo-detector at both ONUs and OLT side.

We analyzed that the BER patterns are showing improved performance with the use of SRm and it can be observed in terms of signal power (measured before and after SRm) as shown in Table 3.

Results are compared for different fiber lengths at ONUs. It is shown in Fig. 7 for 1552.5 nm wavelength at Rx1 with and without SRm.

Results are also compared for different input powers of Tx1 and Tx2 separately. It is shown in Fig. 8 for different input power of Tx1 at Rx1 with and without SRm.

From Fig. 8, we analyzed that to obtain Q factor greater than 6, the performance of the system is quite good even if input power is in the range of −38 to 18 dBm with the use of SRm while this link is usable at input power of −7 to 8 dBm without SRm. Similarly for different input powers of Tx2, results are compared at Rx1 with and without SRm as shown in Fig. 9.

For Tx2, we analyzed that to obtain Q factor greater than 6, the performance of the system is quite good even if input power is in

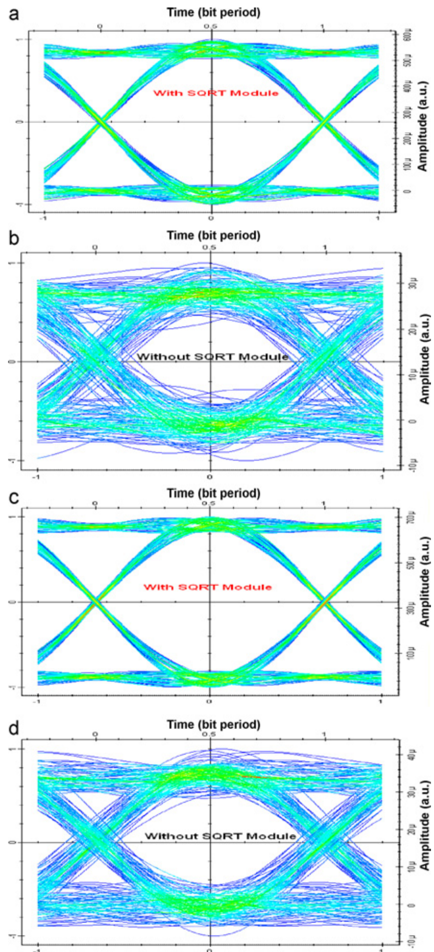

Fig. 5. Eye diagram (a) at Rx1 with SRm (b) at Rx1 without SRm (c) at Rx2 with SRm and (d) at Rx2 without SRm.

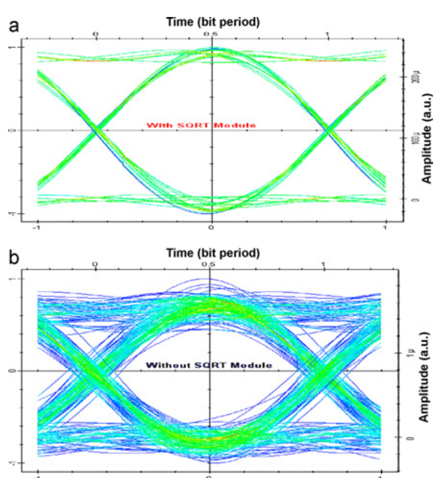

Fig. 6. Eye diagram (a) with SRm (b) without SRm.

Table 3
Signal power with and without SRm.

Receivers	Signal power with SRm (dBm)	Signal power without SRm (dBm)
ONU1	4.675	−20.563
OLT	−47.118	−84.896

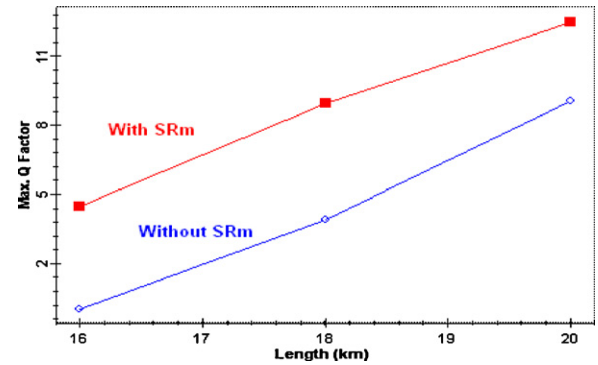

Fig. 7. Q factor vs. length for 1552.5 nm wavelength.

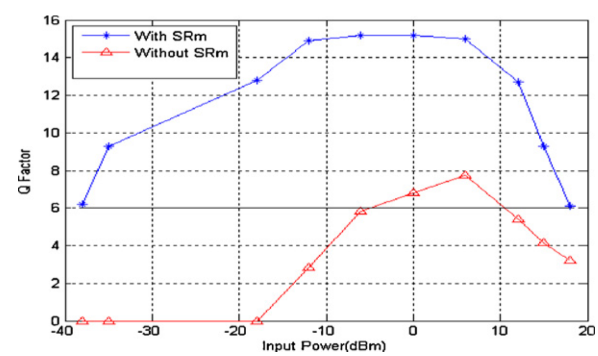

Fig. 8. Q factor at Rx1 for different input powers of Tx1 with and without SRm.

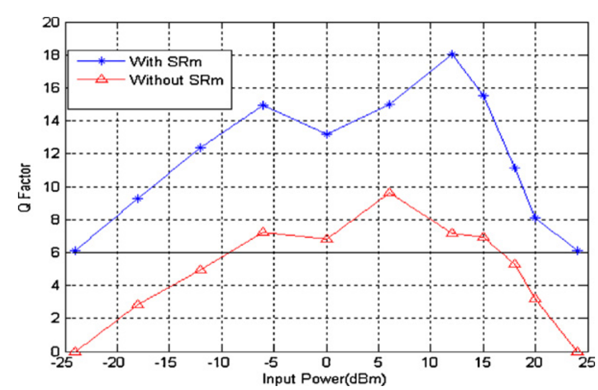

Fig. 9. Q factor at Rx1 for different input powers of CW2 transmitter with and without SRm.

the range of −25 to 24 dBm with the use of SRm while this link is usable at input power of −6 to 15 dBm without SRm. By comparing eye diagrams and Q factors at the receivers with and without SRm, we observed that SRm is an important component to enhance the performance of the system.

4. Conclusion

In this paper we developed a WDM-EPON simulation model based on radio frequency. The component parameters are selected according to IEEE802.3ah standard. Radio frequency is transmitted in both downstream and upstream direction. BER patterns have been obtained at ONUs and OLT side within appropriate range. In this simulation we used SRm at receiver side, which plays an important role to enhance the performance of WDM-EPON with ROF technology. The improvement in the performance has been reported four times for successful transmission over the distance of 20 km. Results are also compared for different fiber lengths and input powers with and without SRm at the receiver. This simulation helps us to focus on identifying the right designing and making the decision how to deploy this technology according to service needs. The demand of higher bandwidth from subscriber is rising the EPON can be upgraded towards 10G EPON.

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