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High Transmission Performance of Radio over Fiber Systems over Traditional Optical Fiber Communication Systems Using Different Coding Formats for Long Haul

Abd El–Naser A. Mohamed[1], Mohamed M. E. El-Halawany[2], Ahmed Nabih Zaki Rashed[3*] and Mohamed S. F. Tabbour[4]

[1,2,3,4]Electronics and Electrical Communications Engineering Department
Faculty of Electronic Engineering, Menouf 32951, Menoufia University, Egypt

***Abstract*— In the present paper, Radio over fiber (ROF) transport systems have the potential to offer large transmission capacity, significant mobility and flexibility, as well as economic advantage due to its broad bandwidth and low attenuation characteristics. We have investigated parametrically and numerically the high performance of Radio over fiber communication systems over traditional optical communication systems using different coding formats over wide range of the affecting operating parameters. Moreover we have analyzed the transmission bit rates and products per channel based standard single mode fiber made of both silica-doped and plastic materials with using modified Shannon technique in addition to use different coding formats such as Return to Zero (RZ) code, and Non Return to Zero (NRZ) code for ultra long haul transmission applications. We have taken into account the bit error rate (BER) for ROF systems with comparing it with traditional optical fiber communication systems as a proof for improvement of signal to noise ratio.**

***Index Terms*— Radio over Fiber Systems, BER, RZ Coding, NRZ Coding, Signal to Noise Ratio, Modified Shannon Technique**

I. INTRODUCTION

THE high data rate and broadband demands of wireless and wired line networks have rapidly increased in recent years. Radio over fiber and fiber to the home (FTTH) systems are promising candidates in wireless and wired line access networks, respectively [1]. The high cost of separated wireless and wired line access networks necessitates integration of the two distributed networks into a single shared infrastructure. The primary concern is to transmit both radio frequency (RF) and base band (BB) signals on a single wavelength over a single fiber in a cost-effective way with acceptable performance. Recently, the simultaneous modulation and transmission of RF signal and a BB signal has been demonstrated [2]. However, the generated hybrid BB and RF signals suffer from a performance fading problem caused by fiber dispersion. Therefore, a dispersion shifting fiber is employed to transmit the hybrid signals. This negative effect limits implementation to green field application only, rather than the most common application with already installed standard single-mode fiber.

Furthermore, only one signal is modulated on the optical subcarrier such that the BB and RF signals are identical after square law photo detector (PD) detection [3]. Hence, a simple and cost effective modulation and transmission of the independent BB and RF signals without periodical performance fading due to fiber dispersion are required [4].

ROF systems have been widely investigated due to such advantages of optical fiber as low loss, large bandwidth, and transparent characteristics for radio signal transmission. By utilizing ROF systems, various radio-frequency signals including cellular services and/or wireless local area network (WLAN) signals can be efficiently distributed to densely populated areas or outdoor ranges [5]. Furthermore, simultaneous ROF transmission of multi standard services has attracted attention because the fiber-optic infrastructure can be shared for multi services resulting in great system cost reduction. In order to achieve wide deployment of these systems, low-cost realization of optical components and fiber medium is a critical issue [6].

In the present work, we have analyzed and modeled the Radio over fiber communication systems compared to a traditional fiber optical communication system at long distances and high data rates using both RZ, and NRZ codes over wide range of the affecting parameters. The system can be limited either by the losses (attenuation limited transmission) or, assuming that the link is not limited by the source or detector speed by the dispersion limited transmission) and we have treated it with using modified Shannon technique .

II. LINK PERFORMANCE CHARACTERISTICS

The direct modulation technique is the preferred modulation method due to its relative high simplicity and low cost. The optical fiber link gain in this technique is increased by utilizing an optical laser with high slope efficiency. Alternatively, impedance matching circuits may be inserted both between the radio frequency source line and

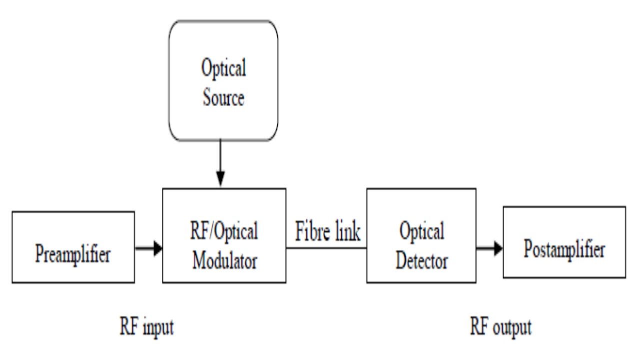

Fig. 1. Intensity modulation direct detection optical link

the modulation device and between the optical detector and the load output. It is also possible to employ a combination of both approaches. Noise within the fiber link can limit the transmission performance of the communication system, especially in distributed antenna applications.

In Intensity modulation direct detection (IM/DD) links, the main sources of noise include laser relative intensity noise (RIN), shot noise from the optical detection process, thermal noise of the radio frequency source, modulation device, optical detector and any interconnecting circuit between the radio frequency source and output load of the link. In general, laser RIN dominates over the shot noise and thermal noise processes [7], and can greatly degrade the link transmission performance. The advantage of this method is that it is simple. If low dispersion fiber is used together with a linear external modulator, the system becomes linear. Consequently, the optical fiber link acts only as an optical amplifier or attenuator and is therefore transparent to the modulation format of the radio frequency signal [8].

III. Theoretical Model Analysis

Considering a direct intensity modulation at the laser diode, the instantaneous optical power output P(t) from the laser in response to input electrical signal s(t), neglecting laser nonlinearity is generally given by [9]:

$$P(t) = [1 + m\,s(t)]P_0 \ , \tag{1}$$

Here, P_0 is the mean optical power, and m is the optical modulation index. The received optical signal at the receiver illuminates the photo detector, which produces a detected current i_D (t) =ρP(t) where ρ is the detector responsivity. Total detected current i_D (t) is the sum of the mean current I_D (t) and the ac component i_d (t). The losses in the laser modulator, fiber and optical receiver need to be added. The loss in the direct modulated laser transmitter comes from the modulation gain of the laser G_m in mW (optical power)/mA(injected current), which depends on the external and internal gains of the laser. With a resistive matching network that will provide maximum power transfer, the optical output power from the laser in dBm is [10]:

$$P_{opt,Laser} = P_{RF,Laser}/2 + 10\log\left(G_m\sqrt{1000/Z_{in}}\right) \ , \tag{2}$$

Where Z_{in} is the input impedance of the laser transmitter (50 Ω). The RF output power from the detector in dBm, again considering impedance mismatch is given by [10]:

$$P_{RF} = 10\log(\rho\, Z_{out}) + 2\,P_{opt,Laser} \ , \tag{3}$$

The factor 2 reflects the square law detection and Z_{out} is the output RF impedance of the O/E converter (50 Ω). By Substituting from Eq. (2) into Eq. (3), The total loss due to the ROF link with resistive matching at the O/E and E/O converters can be shown as the following equation [11]:

$$L_{op} = 20\log(G_m\,R/0.001) + 10\log(Z_{out}/Z_{in}) + 2\,OL \ , \tag{4}$$

Where OL is the optical losses including fiber attenuation and connector losses. The second term is zero when the input to the laser and the output of the optical receiver are matched to the same RF impedance (Z_{out} = Z_{in} = 50 Ω). In a point-to-point fiber link, OL = 2 L_C + α L_F where L_F is the fiber link length, L_C is the connector loss and α is the fiber attenuation in dB/km. Typical values for the prototype used are, G_m = 0.12 mW/mA and ρ= 0.75 mA/mW. This gives a 39 dB loss due to E/O and O/E conversion which should be added to OL to get L_{op}. The optical signal to noise ratio of the ROF link considering the dominant noise processes can be given [11]:

$$OSNR = \frac{m^2 I_D^2\, E\left[s^2(t)\right]10^{-L_{op}/10}}{\left\langle I_{shot}^2\right\rangle + \left\langle I_{th}^2\right\rangle + \left\langle I_{RIN}^2\right\rangle} \tag{5}$$

In Eq. 5, $\langle I_{shot}^2 \rangle$ = 2qρP_0B = 2q ⟨I_D (t)⟩ B is the shot noise variance after the ideal band pass filter (BPF). $\langle I_{th}^2 \rangle$= 4 F$K_B T_0$B/R_L is the thermal noise variance where, K_B is the Boltzmann's constant, F is the amplifier noise factor and T_0 is the absolute temperature and R_L is the load resistance. In Radio over fiber links, the resistance of the photodiode as well as that of the preamplifier add to thermal noise. The noise power due to RIN is given as $\langle I_{RIN}^2 \rangle$ = (RIN) I_D^2 B. Shot, RIN and thermal noises terms are involved in the optical signal to noise ratio (OSNR). Thermal noise has constant variance and white spectrum. The variance of the shot noise is linearly proportional to mean optical power in the fiber and has a Poisson distribution. Although the instantaneous optical power in the fiber fluctuates due to RF intensity modulation, if E[s(t)] =0, the mean optical power does not change unless the DC bias current is changed. If the thermal noise at the receiver optical amplifier is made negligible with an improved design then Eq. 5 becomes as the following expression [11]:

$$OSNR = \frac{m^2 I_D\, E\left[s^2(t)\right]10^{-\alpha_{op}/10}}{\left(2q + (RIN)I_D\right)B} \ , \tag{6}$$

When the RIN value is specified for a given laser diode in dB/Hz, Typically for value of -155 dB/Hz, the linear scale RIN(A^2/Hz) is obtained by the following expression:

$$RIN\left(A^2/Hz\right) = 10^{\frac{RIN(dB/hz)}{10}} \tag{7}$$

In the shot noise limited case, then from Eq. (6) can be deduced that:

$$OSNR = \frac{m^2 I_D\, E\left[s^2(t)\right]10^{-\alpha_{op}/10}}{2q\ B} \ , \tag{8}$$

That is the OSNR increases with mean detected current I_D linearly and with m in second order. Mean detected current is proportional to mean optical power P_0. However, note that typically larger P_0 means lower m again due to nonlinear effects. Nevertheless, the OSNR eventually would increase with m. In the RIN limited case, Eq. (6) can be deduced that gives the following expression:

$$OSNR \approx \frac{m^2\, E\left[s^2(t)\right]10^{-\alpha_{op}/10}}{(RIN)\ B} \ , \tag{9}$$

That is the OSNR is independent of mean optical power and increases with RF power. However, when the RF power is too large the OSNR would saturate due to large RIN as observed by [12]. The signal is weak at the optical receiver where n_{op} (t) is added. n_{op}(t) is amplified by optical post amplifier (G_{op}) along with the signal and then undergoes optical wired channel loss α_{wired}. Again at the portable optical receiver, n_{wired} (t) is added to the optical signal. Therefore, the cumulative noise n(t) consists of optical channel noise terms n_{op} (t) as well as wired optical channel noise n_{wired} (t).

$$n(t) = \frac{n_{op}(t)G_{op}}{\alpha_{wired}} + n_{wired}(t) \ , \tag{10}$$

The signal to noise ratio (SNR) can be expressed as a function of OSNR as the following [11]:

$$SNR = OSNR\left[\frac{1}{1+\left(\frac{\alpha_{wired}}{G_{op}}\right)^2}\right]. \quad (11)$$

Let us consider a general fiber link area in which the maximum power loss is specified as α in dB. α depends on the fiber link area and radio environment. At the maximum loss point in the fiber link, $\alpha_{worst} = 10^{\alpha/10}$. Hence, the worst case SNR is given as:

$$SNR_{worst} = OSNR\left[\frac{1}{1+\frac{10^{10/\alpha}}{G_{op}^2}}\right]. \quad (12)$$

From Eq. 12, the required optical receiver amplifier gain for different values of the maximum loss α in the fiber link area given the value for OSNR and worst case SNR at the portable. That is:

$$G_{op} = \sqrt{\frac{10^{\alpha/10}}{\frac{OSNR}{SNR_{worst}}-1}}\ , \quad (13)$$

Then from Eq. (13), the maximum loss, α and minimum required OSNR are related by:

$$\alpha = 10\ \log_{10}\left[(OSNR/SNR_{worst}-1)G_{op}^2\right]. \quad (14)$$

A. Attenuation analysis of optical link

Based on the models of Ref. [13], the silica-doped spectral losses are cast as:

$$\alpha = \alpha_I + \alpha_S + \alpha_{UV} + \alpha_{IR},\ \text{dB/km} \quad (15)$$

Where: $\alpha_I \equiv the\ \text{int}rinsic\ loss \cong 0.03$, dB/km, and (16)

$$\alpha_S \equiv Rayleigh\,scattering = \left(\frac{0.75+66\Delta}{\lambda^4}\right)\left(\frac{T}{T_0}\right)\ ,\ \text{dB/km} \quad (17)$$

Where T is ambient temperature, and T_0 is a room temperature (300 K), Δ and λ are the relative refractive index difference and optical wavelength respectively. The absorption losses α_{UV} and α_{IR} are given as [13]:

$$\alpha_{UV} = 1.1\times10^{-4}\,\omega_{ge}\%\ e^{4.9\lambda},\quad \text{dB/km} \quad (18)$$

$$\alpha_{IR} = \left(7\times10^{-5}\ e^{-24/\lambda}\right)^2,\quad \text{dB/km} \quad (19)$$

Where ω_{ge} % is the weight percentage of Ge, the correlated ω_{ge} % and the mole fraction x under the form:

$$\omega_{ge}\% = 213.27x - 594x^2 + 2400x^3 - 4695x^4 \quad (20)$$

Plastics, as all any organic materials, absorb light in the ultraviolet spectrum region. The absorption depends on the electronic transitions between energy levels in molecular bonds of the material. Generally the electronic transition absorption peaks appear at wavelengths in the ultraviolet region [14]. According to urbach's rule, the attenuation coefficient α_e due to electronic transitions in plastic optical fiber. In addition, there is another type of intrinsic loss, caused by fluctuations in the density, orientation, and composition of the material, which is known as Rayleigh scattering.. This phenomenon gives the rise to scattering coefficient α_R that is inversely proportional to the fourth power of the wavelength, i.e., the shorter is λ the higher the losses are. For a plastic fiber, it is shown that α_R is given [15], then the total losses of plastic material is given by:

$$\alpha = 1.10\times10^{-5}\exp\left(\frac{8}{\lambda}\right) + 13\left(\frac{0.633}{\lambda}\right)^4\ ,\ \text{dB/km} \quad (21)$$

B. Dispersion analysis of optical link

The standard single mode fiber cable is made of the silica-doped material which the investigation of the spectral variations of the waveguide refractive-index, n requires empirical equation under the form [16]:

$$n^2 = 1 + \frac{A_1\lambda^2}{\lambda^2 - A_2^2} + \frac{A_3\lambda^2}{\lambda^2 - A_4^2} + \frac{A_5\lambda^2}{\lambda^2 - A_6^2} \quad (22)$$

The empirical equation coefficients as a function of temperature and Germania mole fraction x can be expressed as the following formulas: A_{1S}=0.691663+0.1107001x, A_{2S}=(0.068043+0.00056306x)^2(T/T$_0$)^2, A_{3S}=0.4079426+0.31021588x, A_{4S}=(0.116414+0.0372465x)^2 (T/T$_0$)^2, A_{5S}=0.8974749-0.043311091x, A_{6S}=(9.896161+1.94577x)^2. Where T is ambient temperature in K, and T_0 is the room temperature and is considered as 300 K. Second differentiation of empirical equation w. r. t operating wavelength λ as in Ref. [4]. For the plastic fiber material, the coefficients of the Sellmeier equation and refractive-index variation with ambient temperature are given as: A_{1P}= 0.4963, A_{2P}= 0.6965 (T/T$_0$), A_{3P}= 0.3223, A_{4P}= 0.718 (T/T$_0$), A_{5P}= 0.1174, and A_{6P}= 9.237.

C. Transmission capacity analysis

The rise time of an optical fiber communication system $\Delta\tau_{system}$ is given by [18]:

$$\Delta\tau_{system} = \left[\sum_{i=1}^{N}\Delta\tau_i^2\right]^{1/2}\ , \quad (23)$$

Where $\Delta\tau_i$ is the rise time of each component in the system. The three components of the system that can contribute to the system rise time are as the following:

i) The rise time of the transmitting source $\Delta\tau_{source}$ (typically equal to value of 16 psec) .

ii) The rise time of the receiver $\Delta\tau_{receiver}$ (typically equal to value of 25 psec).

iii) The material dispersion time of the fiber $\Delta\tau_{mat}$ which is given by the following equation:

$$\Delta\tau_{mat.} = -\left(\frac{L.\Delta\lambda.\lambda}{c}\right).\left(\frac{d^2n}{d\lambda^2}\right)\ , \quad (24)$$

Then the total dispersion of the optical communication system can be expressed as:

$$\Delta\tau_{system} = \Delta\tau_{source} + \Delta\tau_{receiver} + \Delta\tau_{mat.}\ , \quad (25)$$

The bandwidth for standard single mode fibers for both materials based optical link length L_F is given by:

$$B.W_{sig.} = \frac{0.44}{\Delta\tau_{system}\ .\ L_F}\ , \quad (26)$$

The transmission data rate that the system can support NRZ coding as the following:

$$B_{R(NRZ)} = \frac{0.7}{\Delta\tau_{system}}\ , \quad (27)$$

Also the transmission data rate that the system can support RZ coding as the following [18]:

$$B_{R(RZ)} = \frac{0.35}{\Delta\tau_{system}}\ , \quad (28)$$

The maximum transmission bit rate or capacity according to modified Shannon technique is given by [19, 20]:

$$C = B.W_{sig.} \log_2 (1 + SNR) \quad , \tag{29}$$

Where $B.W_{sig.}$ is the actual bandwidth of the optical signal, and SNR is the signal to noise ratio in absolute value (i. e., not in dB). Where SNR can be expressed in dB unit as in the following formula:

$$SNR = 10 \log_{10} (SNR), \ dB \tag{30}$$

The bandwidth-distance product can be expressed as the following expression:

$$Bandwidth - distance\ product (P) = B_R . L_F \tag{31}$$

Where B_R is the transmitted bit rate per channel, and L_F is the fiber link length in km. Where the Shannon bandwidth-distance product can be given by [21]:

$$P_{sh} = C . L_F \ , \tag{32}$$

The bit error rate (BER) essentially specifies the average probability of incorrect bit identification. In general. The higher the received SNR, the lower the BER probability will be. For most PIN receivers, the noise is generally thermally limited, which independent of signal current. The bit error rate (BER) is related to the signal to noise ratio (SNR) as [22]:

$$BER = 0.5 \left[1 - erf \left(0.3535 \, (SNR)^{1/2} \right) \right] \quad , \tag{33}$$

IV. Simulation Results and Discussions

We have investigated the high performance of ROF systems over traditional optical fiber communication systems within modified Shannon technique using different coding formats under the set of the wide range of the affecting and operating parameters as shown in Table 1:

Table 1: Proposed operating parameters for our suggested ROF transmission systems

Operating Parameter	Definition	Value and unit
T	Ambient temperature	300 K ≤ T ≤ 340 K
L_F	Fiber link length	40 km ≤ L_F ≤ 320 km
$\Delta\tau_{source}$	Rise time of the transmitter	16 psec
$\Delta\tau_{receiver}$	Rise time of the receiver	25 psec
x	Mole fraction of germanium	0.0 ≤ x ≤ 0.3
T_0	Reference temperature	300 K
RIN	Relative intensity noise	-155 dB/Hz
$\Delta\lambda$	Spectral line width of the optical source	0.1 nm
λ	RF signal operating wavelength	1 mm ≤ λ_s ≤ 1.5 mm
P_0	Mean optical power	0.2 Watt ≤ P_0 ≤ 0.597 Watt
Z_{in}	Input impedance of the laser transmitter	50 Ω
Z_{out}	Output RF impedance of the receiver	50 Ω
m	Optical modulation index	0.1 ≤ m ≤ 0.9
L_C	Connector loss	0.1 dB/km
SNR	Signal to noise ratio	5 dB ≤ Optical loss≤ 65 dB
ρ	Detector responsivity	0.75 mA/mW
G_m	Modulation gain of the laser	0.12 mW/mA
OSNR	Optical signal to noise ratio	5 ≤ OSNR ≤ 25
F	Amplifier figure noise	5 dB

Based on the model equations analysis, assumed set of the operating parameters as listed in the Table 1 above, and based on the series of the figs. (2-26), the following facts are assured:

i) Fig. 2 has demonstrated that as fiber link length increases, these results in increasing of optical loss for both silica-doped and plastic materials based optical link. As well as plastic material presents higher optical loss than silica-doped material. Also as germanium percentage amount increases this result in increasing optical loss.

ii) As shown in Figs. (3-6) have assured that as optical modulation index increases, this leads to increase in required signal to noise ratio at constant of both optical signal to noise ratio and optical amplifier gain. As well as both optical signal to noise ratio and optical amplifier gain increases, this results in increasing required signal to noise ratio at constant optical modulation index. Silica-doped material based optical link has presented higher SNR than plastic material based optical link.

iii) As shown in Figs. (7-10) have assured that as optical modulation index increases, this leads to decrease in BER at constant of both optical signal to noise ratio and optical amplifier gain. Moreover as both optical signal to noise ratio and optical amplifier gain increases, this results in decreasing BER at constant optical modulation index. Silica-doped material based optical link has presented lower BER than plastic material based optical link.

iv) As shown in Figs. (11, 12) have proved that ambient temperature increases, transmission bit rates for both silica-doped at different level of doping of germanium and plastic materials decrease for different RZ, and NRZ coding formats.

v) Figs. (13-16) have assured that as ambient temperature increases, signal bandwidth decreases for both silica-doped at different level of doping of germanium and plastic materials at constant fiber link length. Also as fiber link length increases, signal bandwidth decreases at constant ambient temperature.

vi) As shown in Figs. (17, 18) have proved that fiber link length increases, bandwidth-distance product also increases for both silica-doped at different level of doping of germanium and plastic materials for different RZ, and NRZ coding formats.

vii) Figs. (19-22) have demonstrated that signal bandwidth increases for both silica-doped at different level of doping of germanium and plastic materials, Shannon transmission capacity also increases at constant signal to noise ratio. Moreover as signal to noise ratio increases, Shannon transmission capacity also increases at constant signal bandwidth.

Figs. (23-26) have demonstrated that transmission capacity increases for both silica-doped at different level of doping of germanium and plastic materials, Shannon product also increases at constant fiber link length. Moreover as fiber link length increases, Shannon product also increases at constant transmission capacity.

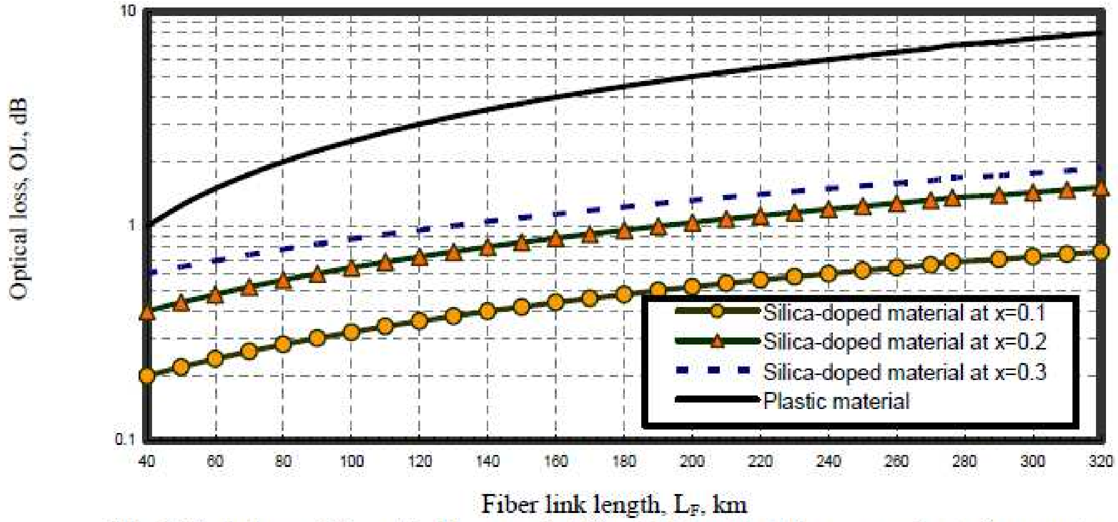

Fig. 2. Variations of the optical loss against fiber link length at the assumed set of parameters.

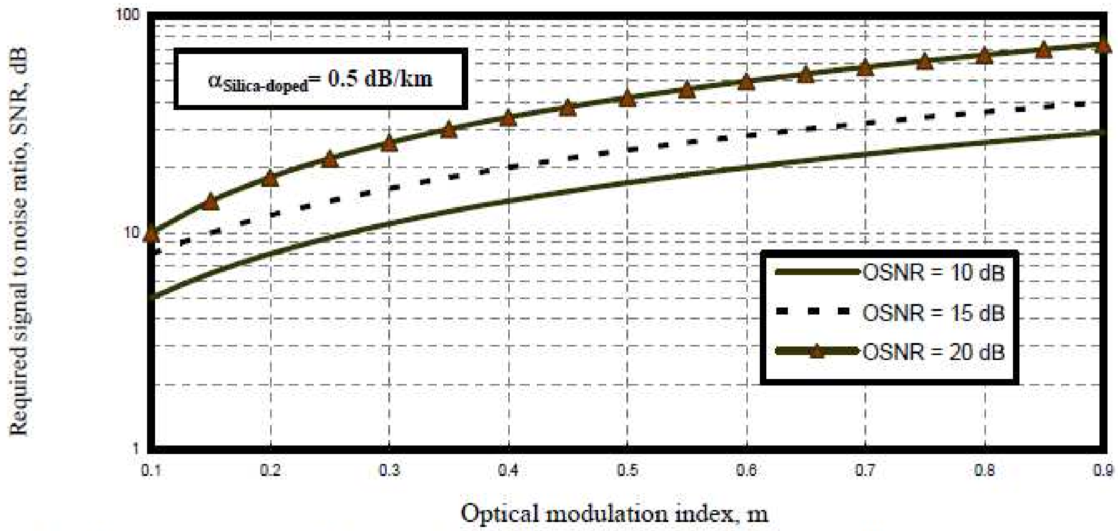

Fig. 3. Variations of signal to noise ratio against optical modulation index at the assumed set of parameters.

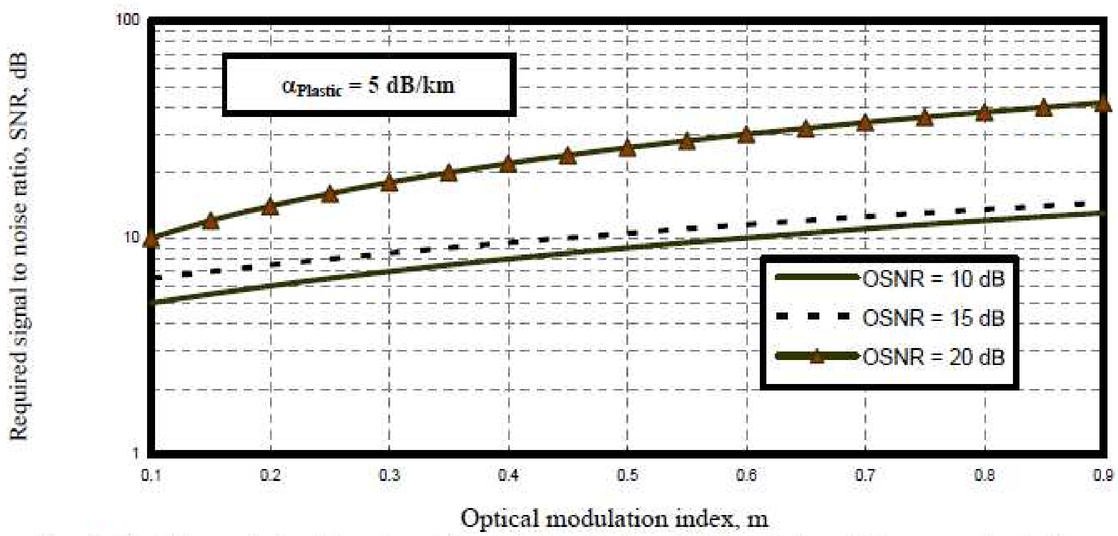

Fig. 4. Variations of signal to noise ratio against optical modulation index at the assumed set of parameters.

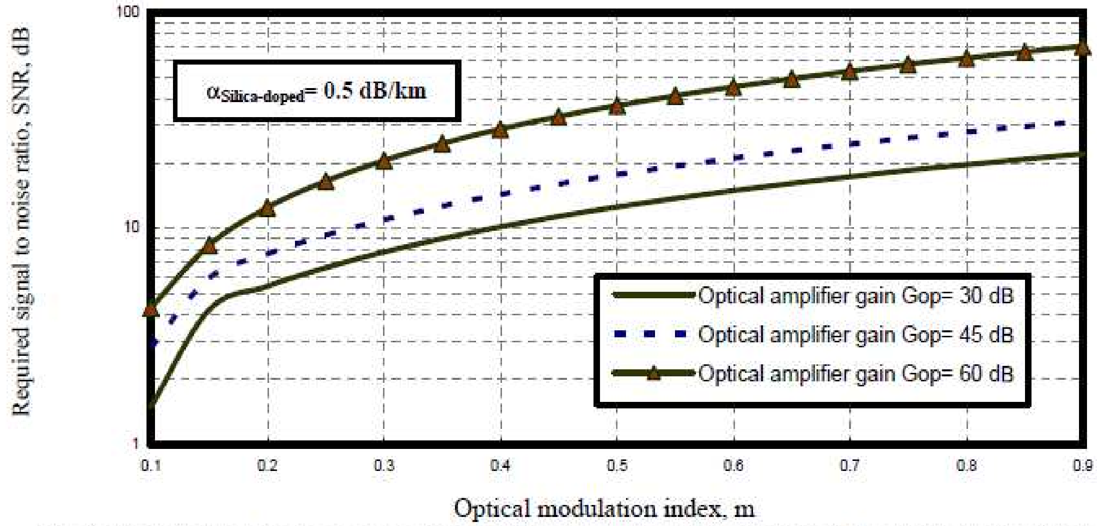

Fig. 5. Variations of signal to noise ratio against optical modulation index at the assumed set of parameters.

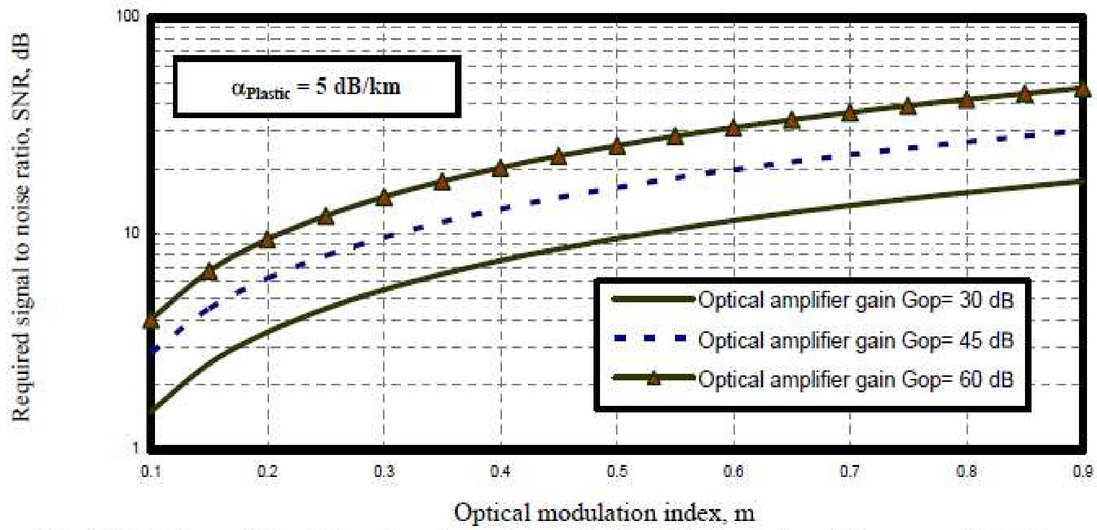

Fig. 6. Variations of signal to noise ratio against optical modulation index at the assumed set of parameters.

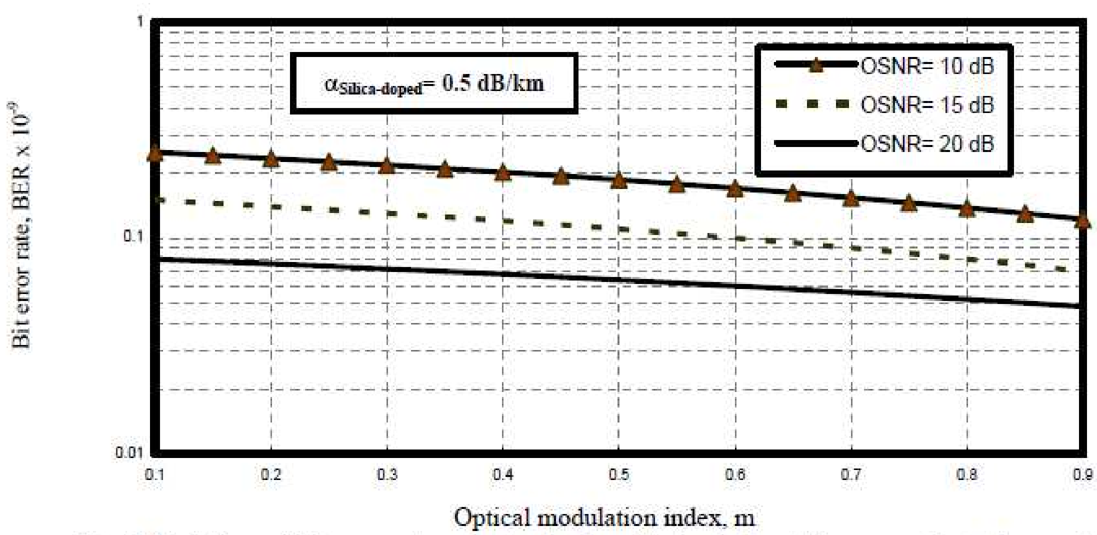

Fig. 7. Variations of bit error rate against optical modulation index at the assumed set of parameters.

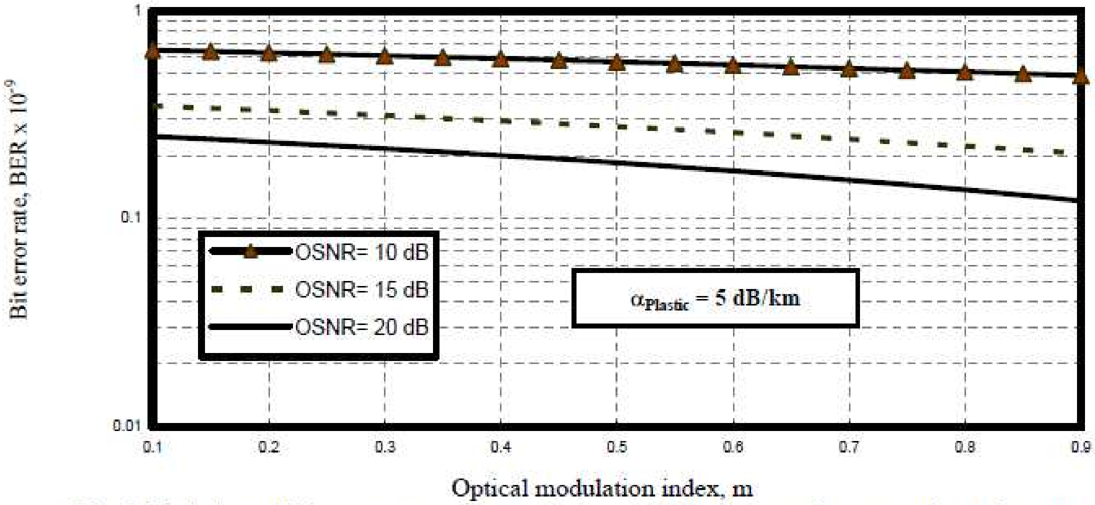

Fig. 8. Variations of bit error rate against optical modulation index at the assumed set of parameters.

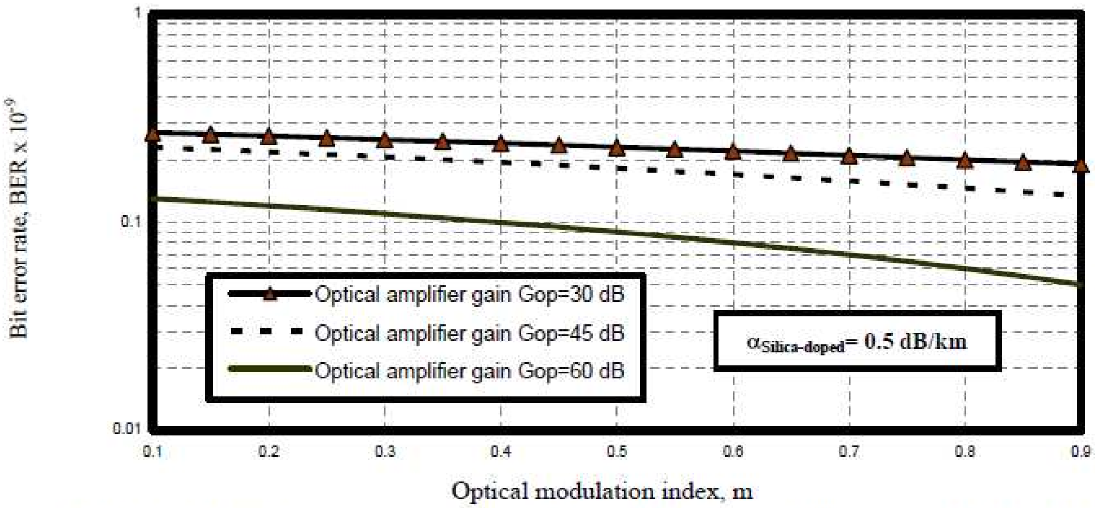

Fig. 9. Variations of bit error rate against optical modulation index at the assumed set of parameters.

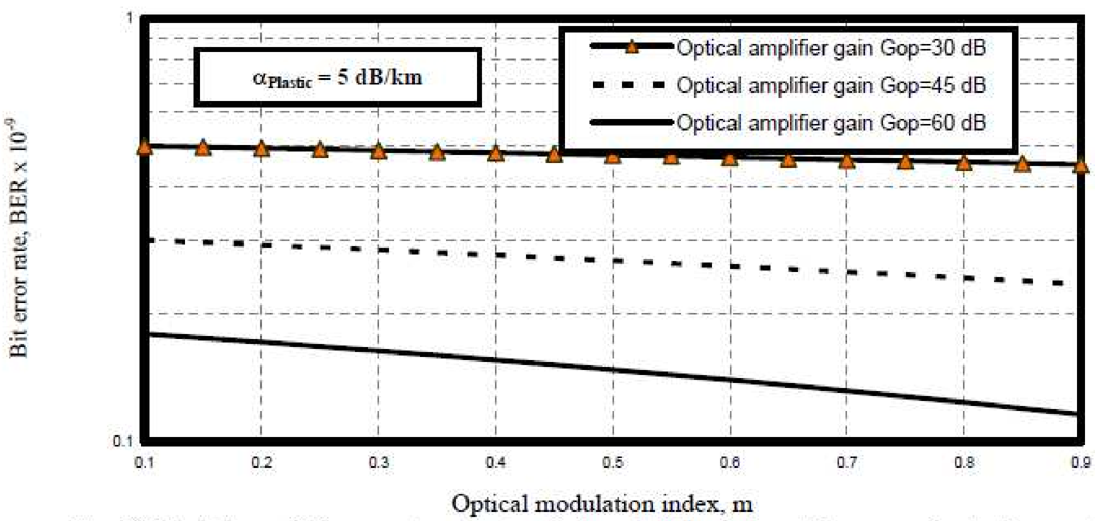

Fig. 10. Variations of bit error rate against optical modulation index at the assumed set of parameters.

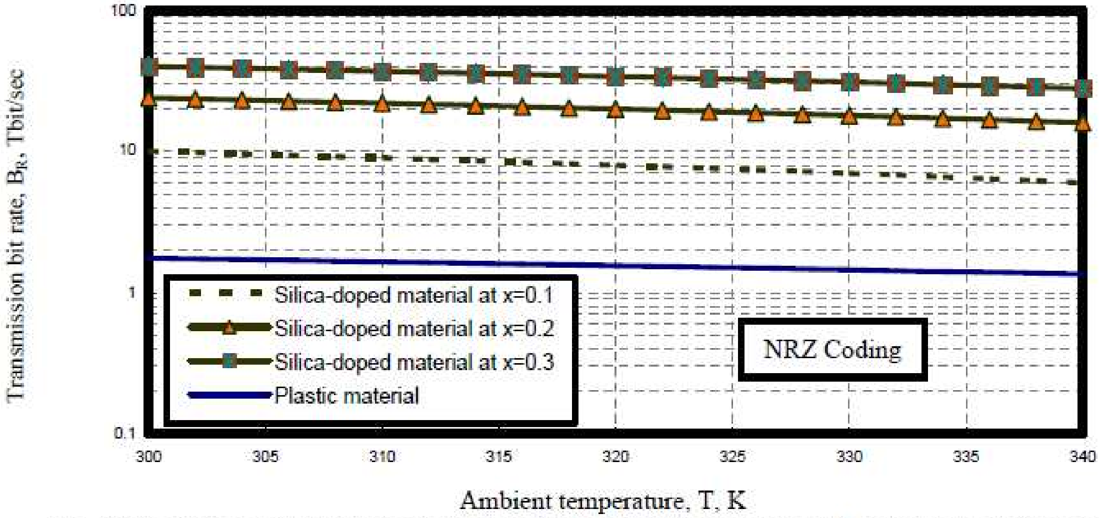

Fig. 11. Variations of transmission bit rate against ambient temperature at the assumed set of parameters.

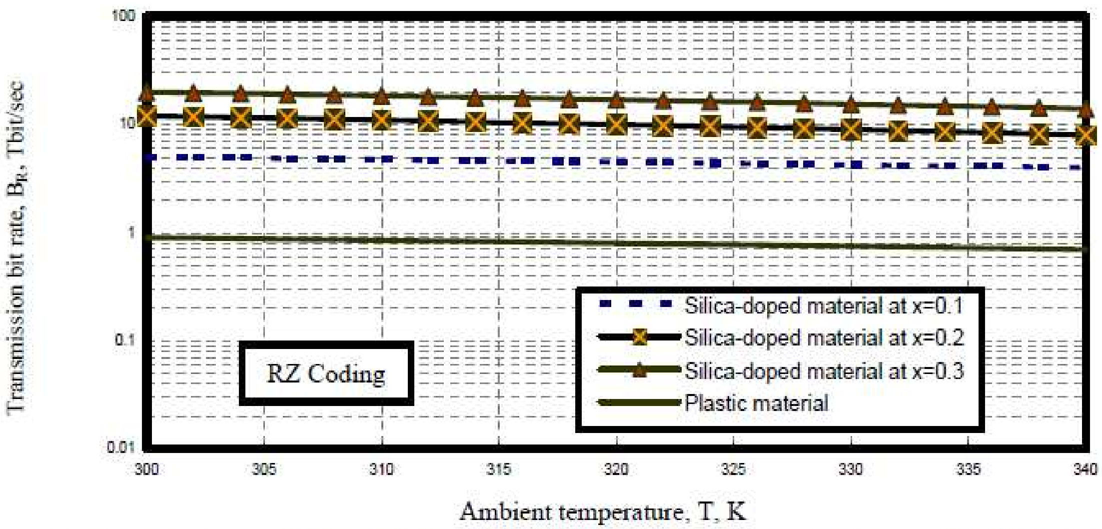

Fig. 12. Variations of transmission bit rate against ambient temperature at the assumed set of parameters.

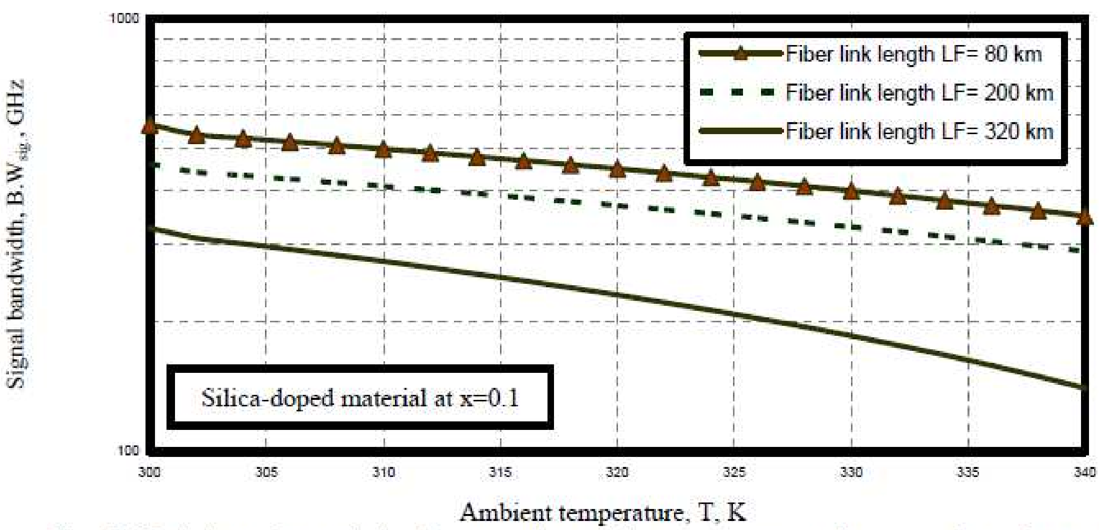

Fig. 13. Variations of transmission bit rate against ambient temperature at the assumed set of parameters.

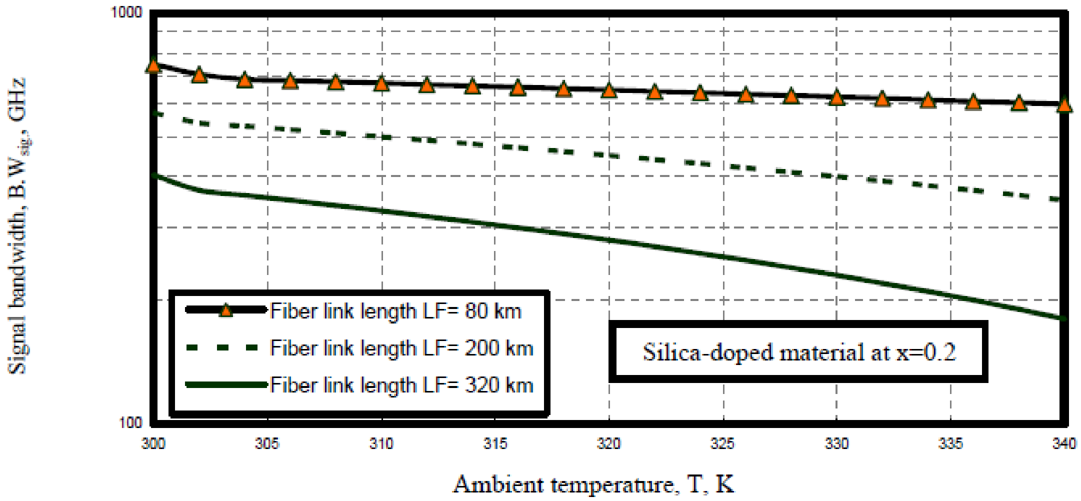

Fig. 14. Variations of transmission bit rate against ambient temperature at the assumed set of parameters.

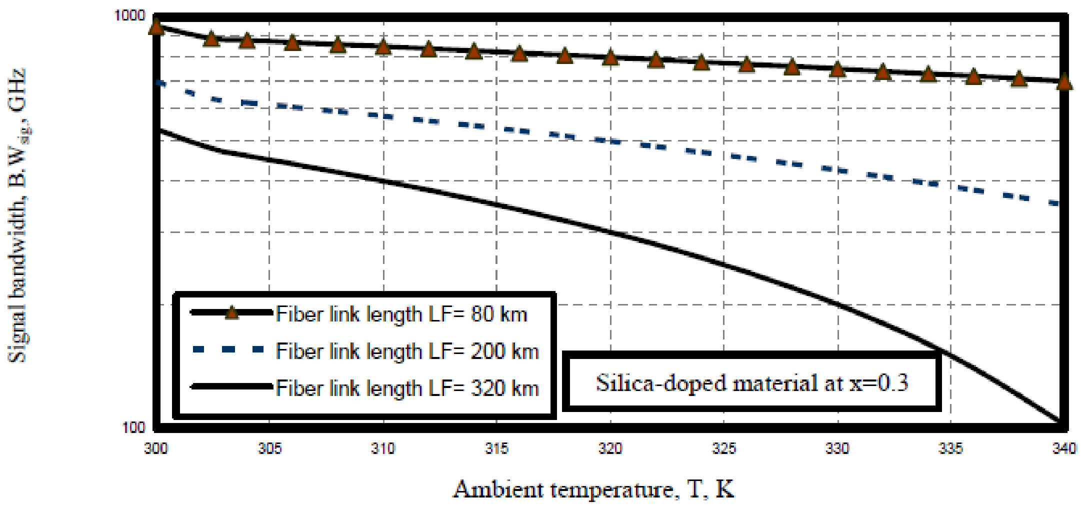

Fig. 15. Variations of transmission bit rate against ambient temperature at the assumed set of parameters.

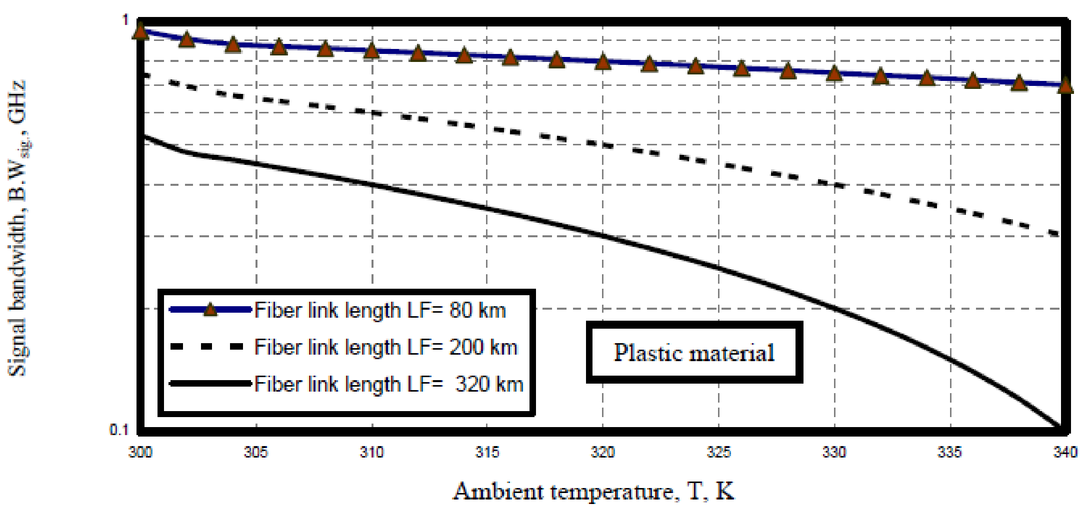

Fig. 16. Variations of transmission bit rate against ambient temperature at the assumed set of parameters.

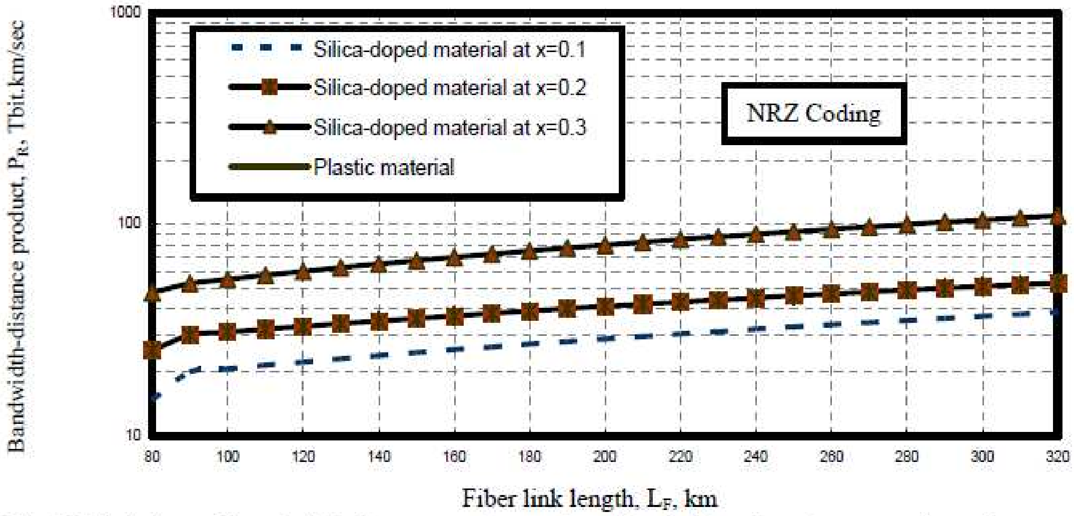

Fig. 17. Variations of bandwidth-distance product against fiber link length at the assumed set of parameters.

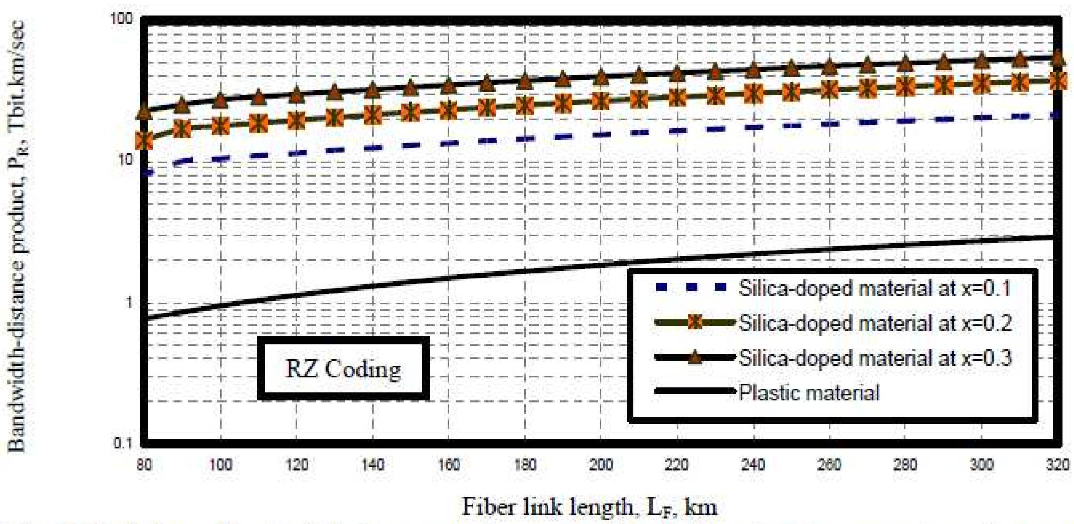

Fig. 18. Variations of bandwidth-distance product against fiber link length at the assumed set of parameters.

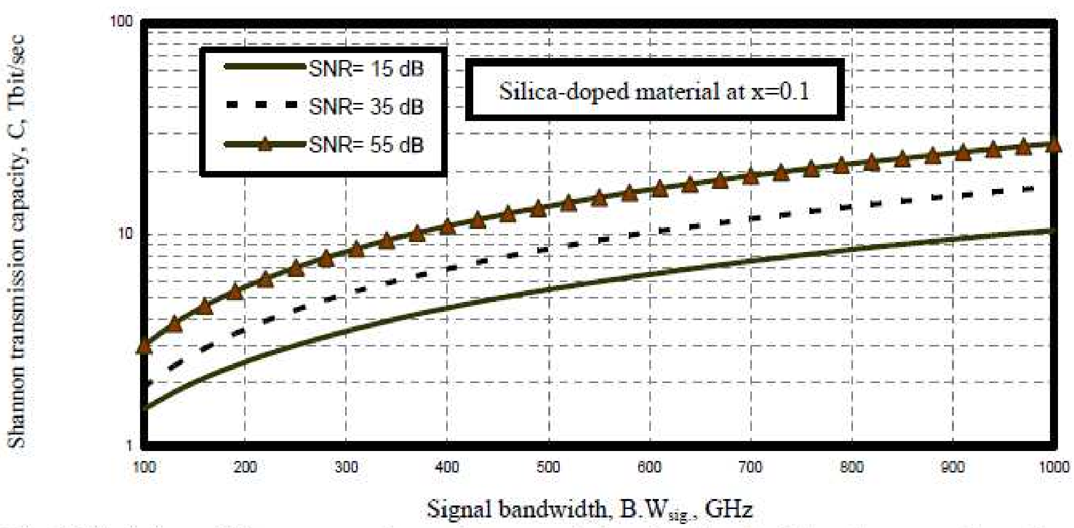

Fig. 19. Variations of Shannon capacity against transmission signal bandwidth at the assumed set of parameters.

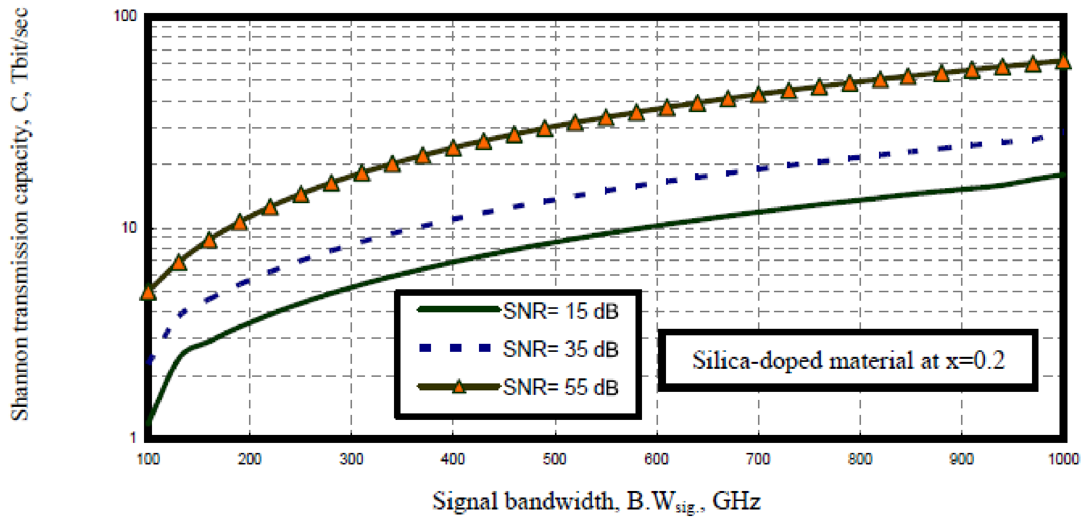

Fig. 20. Variations of Shannon capacity against transmission signal bandwidth at the assumed set of parameters.

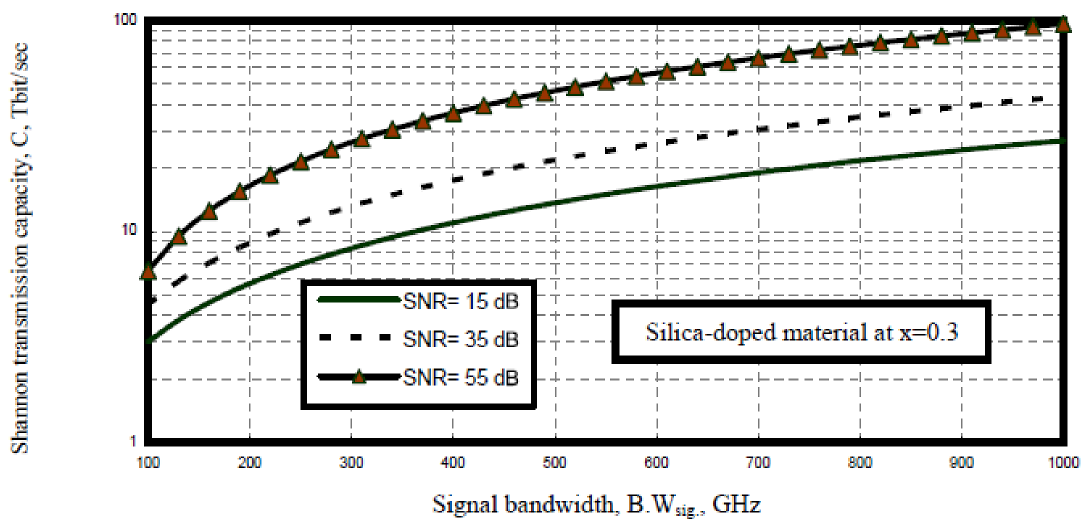

Fig. 21. Variations of Shannon capacity against transmission signal bandwidth at the assumed set of parameters.

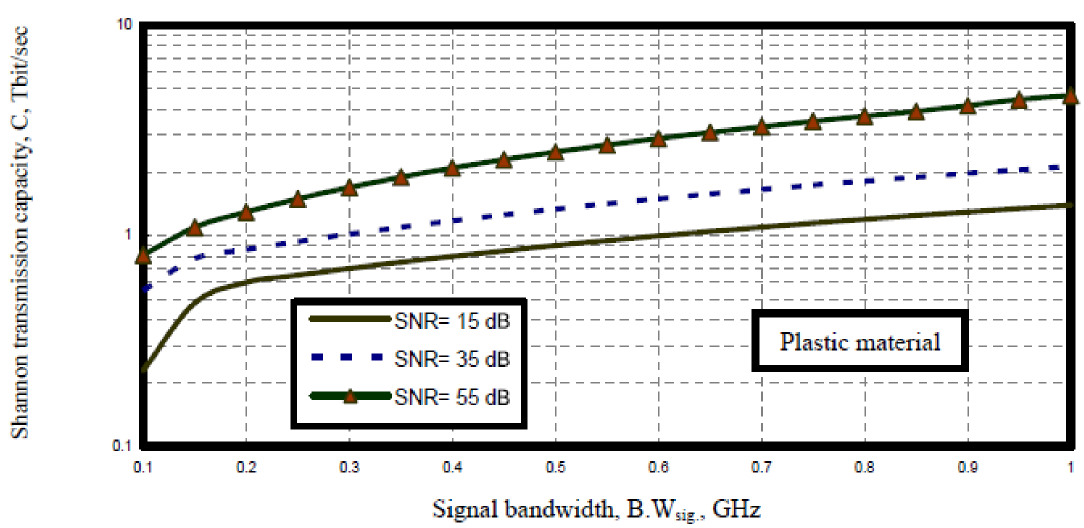

Fig. 22. Variations of Shannon capacity against transmission signal bandwidth at the assumed set of parameters.

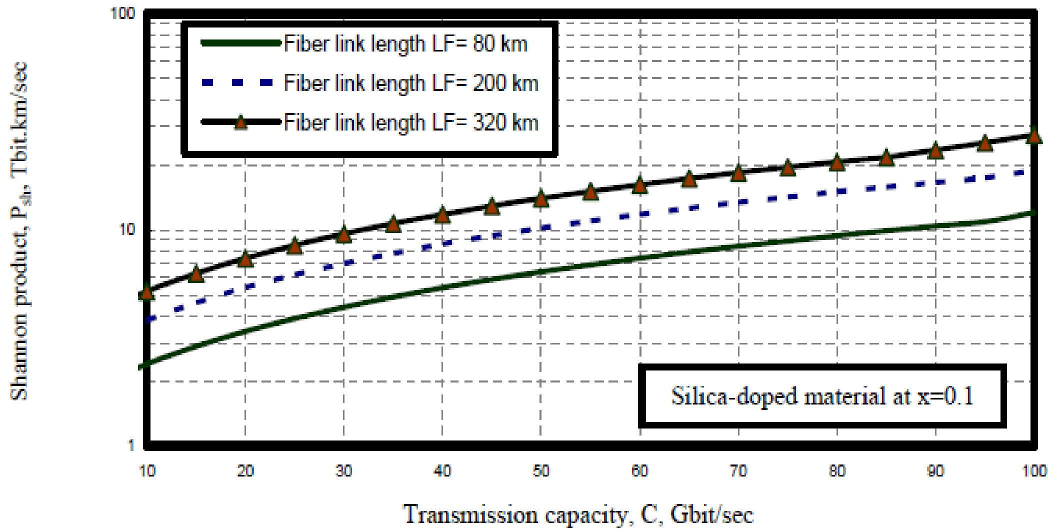

Fig. 23. Variations of Shannon product against transmission capacity at the assumed set of parameters.

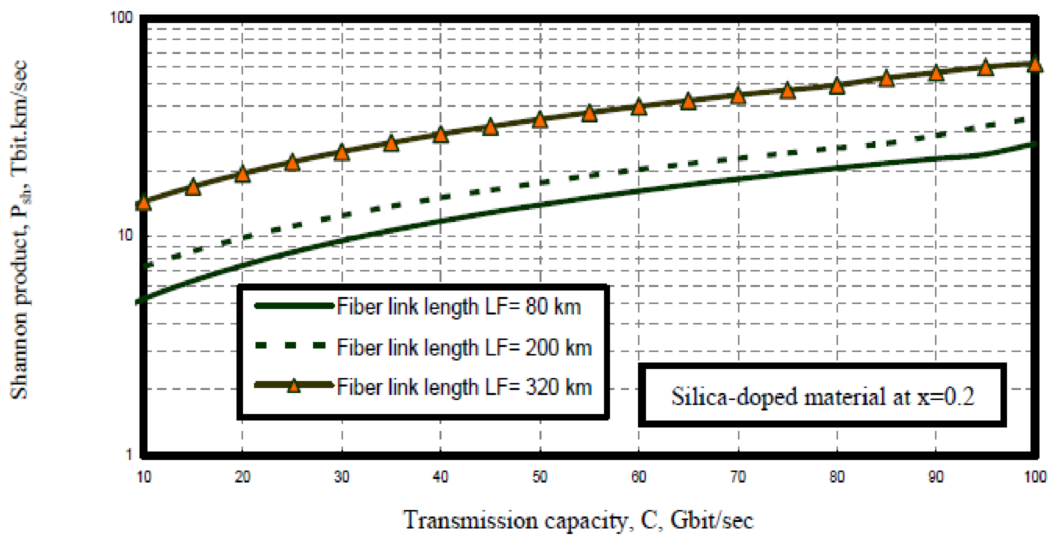

Fig. 24. Variations of Shannon product against transmission capacity at the assumed set of parameters.

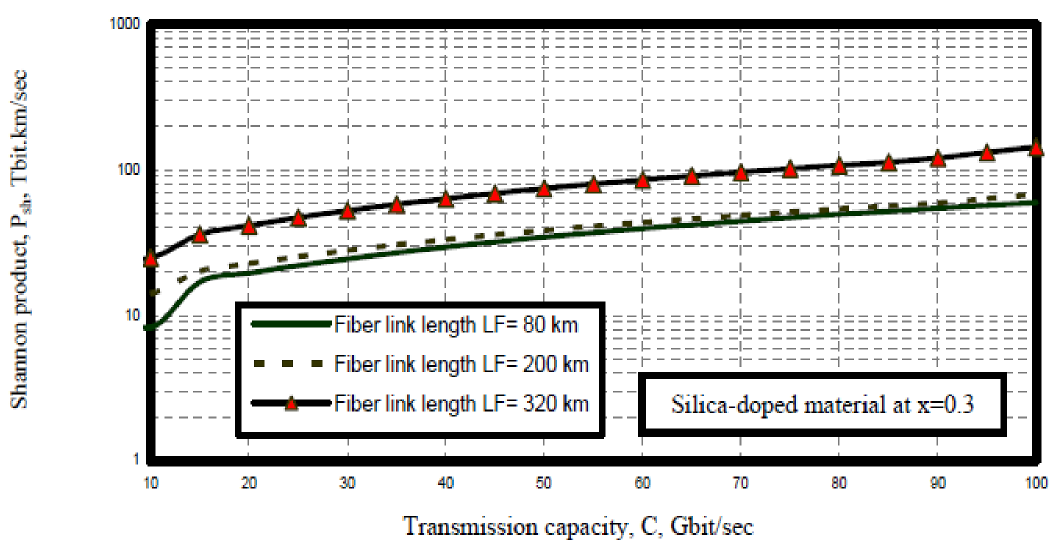

Fig. 25. Variations of Shannon product against transmission capacity at the assumed set of parameters.

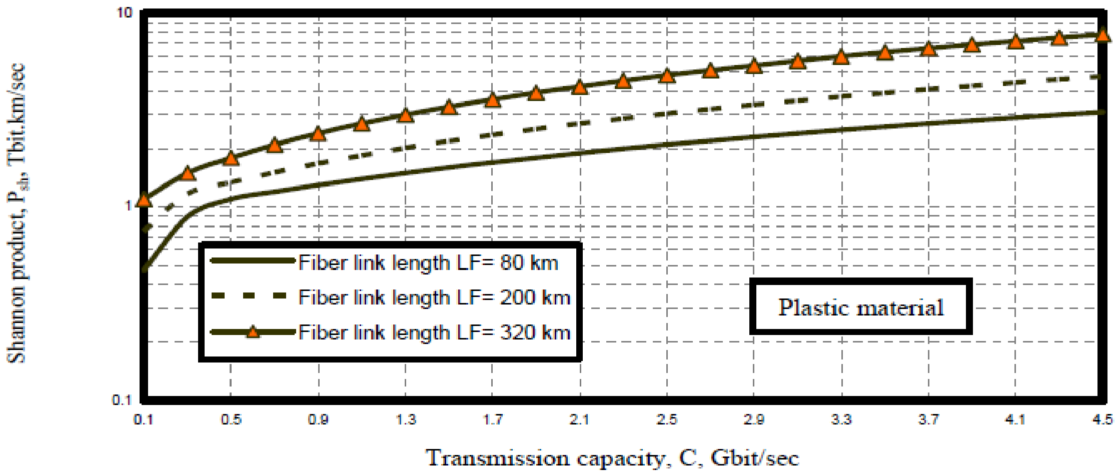

Fig. 26. Variations of Shannon product against transmission capacity at the assumed set of parameters.

Table 2: Comparison ROF transmission system with Simulation results as in Refs. [20, 21]

	Transmission bit rates and products with ROF transmission systems		Simulation results for transmission bit rates and products for traditional communication systems as in Refs. [17, 19, 20]
	Same conditions of operation		
	- Ambient temperature T= 300 K-340 K, Fiber link length= 80 km-320 km, - Optical amplifier gain= 30 dB.		
Transmission Techniques	ROF system with amplification		Bit rates and products with multi pumped Raman amplification
	Silica-doped based optical link	Plastic material based optical link	
Shannon bit rate (C)	95 Tbit/sec	4.7 Tbit/sec	60 Tbit/sec
Shannon product (P_{sh})	145 Tbit.km/sec	7.8 Tbit.km/sec	120 Tbit.km/sec
Signal bandwidth ($B.W_{sig.}$)	950 GHz	0.95 GHz	400 GHz
Signal to noise ratio (SNR)	Reach ed to 75 dB	Reach ed to 45 dB	Reach ed to 55 dB
Bit error rate (BER)	10^{-10}	10^{-9}	10^{-8}—10^{-9}

V. Conclusions

This paper have demonstrated that the highest performance and the largest potential with transmission bit rate capacity, product, signal bandwidth, signal to noise ratio and the lowest BER of Radio over fiber systems over traditional optical fiber communication systems for long haul transmission applications. The increased of optical modulation index, optical amplifier gain, and optical signal to noise ratio, the increased required signal to noise ratio, and the decreased BER. The increased of both ambient temperature and fiber link length, the decreased transmission bit rates and products using modified Shannon technique for RZ and NRZ coding formats. It is evident that NRZ coding present higher transmission bit rates and products than RZ coding Within Shannon Technique.

Moreover we have assured that the silica-doped material with different doping of germanium level based optical link presents higher transmission bit rates and products than plastic material based optical link. We have make a complete comparison to show the high efficiency, best performance of ROF transmission systems over traditional optical fiber communication systems with our simulation results as mentioned in Refs. [20, 21] as shown in Table 2.

It is very clear that from the above comparison, ROF systems have presented the highest transmission bit rates, products, signal bandwidth, and signal to noise ratio and the lowest BER within silica-doped based optical link than traditional optical fiber communication systems with multi-pumped Raman amplification technique.

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Dr. Ahmed Nabih Zaki Rashed

was born in Menouf city, Menoufia State, Egypt country in 23 July, 1976. Received the B.Sc., M.Sc., and Ph.D. scientific degrees in the Electronics and Electrical Communications Engineering Department from Faculty of Electronic Engineering, Menoufia University in 1999, 2005, and 2010 respectively. Currently, his job carrier is a scientific lecturer in Electronics and Electrical Communications Engineering Department, Faculty of Electronic Engineering, Menoufia University, Menouf, postal Menouf city code: 32951, Egypt.

His scientific master science thesis has focused on polymer fibers in optical access communication systems. Moreover his scientific Ph. D. thesis has focused on recent applications in linear or nonlinear passive or active in optical networks. His interesting research mainly focuses on transmission capacity, a data rate product and long transmission distances of passive and active optical communication networks, wireless communication, radio over fiber communication systems, and optical network security and management. He has published many high scientific research papers in high quality and technical international journals in the field of advanced communication systems, optoelectronic devices, and passive optical access communication networks. His areas of interest and experience in optical communication systems, advanced optical communication networks, wireless optical access networks, analog communication systems, optical filters and Sensors, digital communication systems, optoelectronics devices, and advanced material science, network management systems, multimedia data base, network security, encryption and optical access computing systems. He is a reviewer member in high quality scientific research international journals in the field of Electronics, Electrical communication and advanced optical communication systems and networks. His personal electronic mail ID is (ahmed_733@yahoo.com).