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Performance Enhancement of Radio Over Fiber Communication Systems With Wavelength Division Multiplexing and Modulation Techniques

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Abstract— 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. Radio over fiber link is a promising technology for short range transmission applications within multimode polymer optical fibers. Typically, the radio over fiber link employs a single mode fiber. But the signal power at the remote antenna is very small. The main reason is large power loss in the electrical to optical and optical to electrical converter. But the coupling efficiency of a electrical to optical converter can be improved with multimode fiber (MMF). so we have developed to use a ROF link with a vertical cavity surface emitting laser with a graded index MMF polymer optical fibers to transport optical signals. As well as we have developed ROF communication system within multimode polymer optical fibers for short transmission distances in wavelength division multiplexing (WDM) technique using pulse code modulation scheme and Soliton transmission technique.

Keywords— **Multi mode fiber, Radio over fiber, Modulation techniques, and Wavelength division multiplexing technique.**

I. INTRODUCTION

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 [1]. 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. To fulfill the requirement of low cost implementation, an inexpensive distributed-feedback laser diode, vertical cavity surface emitting lasers and multimode fiber (MMF) have been investigated [2, 3].

The low dispersion, low loss and lightweight capability of optical fiber compared with electrical media have made it an excellent choice for the transmission of RF signals into the millimeter wave region. As the fiber is a dielectric, it is free from the effects of electromagnetic interference (EMI), unaffected by large electromagnetic pulses and can be closely confined with negligible crosstalk. Fiber optic technology has recently seen a growth in applications utilizing analogue point-to-point links that distribute radio frequency (RF) signals in antenna, cellular communications and subcarrier cable television distribution networks. The demand for broadband access has also led to interest in distributing signals capable of supporting systems operating in the microwave bands used for provision of Hyper local area network services. In fact, a major current objective of the telecommunications industry, is not only to provide voice and data services but also provide video services where applicable using economically viable techniques. A high degree of flexibility and upgradeability must also be available so as to meet the high consumer demand for broadband access. This technological requirement has recently been met with the provision of high definition television (HDTV) by most of the cable television network operators [4, 5].

The demand for broadband services has driven research on millimeter (mm) wave frequency band communications for wireless access network due to its spectrum availability, and compact size of radio frequency devices [6, 7]. However, the mm wave signals suffer from severe loss along the transmission as well as atmospheric attenuation. In other words, upcoming wireless networks will use a combination of air interface methods in different channels and in different cells that can be changed dynamically to meet variations in traffic conditions. One of the solution to overcome these problem is by using low attenuation, electromagnetic interference-free optical fiber. Radio over Fiber (ROF) is integration of optical fiber for radio signal transmission within network infrastructures that is considered to be cost effective, practical and relatively flexible system configuration for long-haul transport of millimeter frequency band wireless signals. Fiber optic local area networks (LANs) will be carrying traffic at data rates of tens of gigabits per second in the near future, whereas data rates of tens of megabits per second are difficult to provide to mobile users [8-10]. In the present study, the model deeply investigated for ROF communication systems within multi mode polymer optical fibers for short transmission applications. Normally the MMF is used in short distance transmission applications within polymer optical fibers links. ROF systems have presented high transmission bit rates per transmitted channels in polymer fibers links.

II. MODELING 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 [11]:

$$P(t) = [1 + m\,s(t)]P_0 \ , \qquad (1)$$

Here, P_0 is the mean optical power, and m is the optical modulation index. The number of transmitted channels in the system N_{ch}. It comes from the relationship in the frequency domain between the total system bandwidth, the channel bandwidth and the guard bandwidth, and it is given by:

$$N_{ch} = \sqrt{\frac{B.W_{Total}}{B.W_{Up} + B.W_{Down} + 2\,B.W_{Guard}}} \quad , \qquad (2)$$

Where $B.W_{Up}$ is the bandwidth of the uplink, $B.W_{Down}$ is the bandwidth of the downlink, and $B.W_{Guard}$ is the bandwidth of the guard band. Assume that $B.W_{Up}$=$B.W_{Down}$, and then the desired user data rate can be expressed as:

$$BR_{User} = \frac{B.W_{Up} + B.W_{Down}}{2} \quad , \qquad (3)$$

The bandwidth of the guard band for audio signal can be, $B.W_{guard}$=1 KHz, and the bandwidth of the guard band for video signal can be, $B.W_{guard}$=100 KHz. To evaluate the performance of an optical link, the optical signal to noise ratio (OSNR) is needed. It is evaluated at the output of the optical receiver. The OSNR can be expressed as [12, 13]:

$$OSNR = \frac{0.5\,P_T}{f_{RF}\ h\ B.W_{Up=Down}} \quad , \qquad (4)$$

Where h is the Planck's constant (6.02 x10^{-34} J.sec), P_T is the transmitted signal power, and f_{RF} is the radio frequency in MHz. It is well known that the bandwidth can be maximized by optimizing the shape of the GI distribution of the fiber core. The signal to noise ratio (SNR) can be expressed as a function of OSNR as the following [11]:

$$SNR = OSNR\left[\frac{1}{1+\left(\frac{\alpha_{wired}}{G_{op}}\right)^2}\right]. \qquad (5)$$

Where G_{op} is the amplifier gain, and α_{wired} is the medium attenuation coefficient which will be listed in the following part. 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 [12]. 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 Polystyrene plastic fiber, it is shown that α_R is given [15], then the total losses of plastic material with curve fitting is given by:

$$\alpha_{wired} = 0.00554\exp\left(\frac{3.654\,T}{\lambda}\right) + 0.345\left(\frac{0.076\,T^2}{\lambda}\right)^2 , \text{dB/m} \qquad (6)$$

Ref. [14] derived the optimum index profile which is expressed as the following formula:

$$g_{opt} = 2 + \varepsilon - \frac{(4+\varepsilon)\,(3+\varepsilon)\Delta n}{5+2\varepsilon} \quad , \qquad (7)$$

The parameters to characterize the temperature and operating signal wavelength dependence of the refractive-index from empirical equation is given as by [15]:

$$n = \sqrt{1 + \frac{S_1\lambda^2}{\lambda^2 - S_2^2} + \frac{S_3\lambda^2}{\lambda^2 - S_4^2} + \frac{S_5\lambda^2}{\lambda^2 - S_6^2}} \quad , \qquad (8)$$

Where the first and second differentiation with respect to operating signal wavelength λ as discussed in Ref. [15]. Where the coefficients of the polystyrene (PS) given as follows: S_1=1.043x10^{-3}, S_2=10.543 $(T/T_0)^2$, S_3= 8.543, S_4=0.0754 $(T/T_0)^2$, S_5=0.008765, S_6= 2.453x10^{-5} $(T/T_0)^2$. Where T and T_0 are the ambient temperature and room temperature along polymer optical fiber link and measured both in K. The output pulse width from the GI-POF was calculated by the solution of WKB method in which both modal and material dispersions were taken into account as shown in the following expressions [15]:

$$\sigma_{modal} = \frac{LN_1\Delta n}{2c} A_1 A_2 \left(C_1^2 + A_3 + A_4\right)^{0.5} , \qquad (9)$$

With A_1=g/g+1, A_2=$(g+2/3g+2)^{0.5}$, A_3=$4C_1C_2\Delta n(g+1)/2g+1$, and A_4=$4\Delta n^2C_2(2g+2)^2/(5g+2)(3g+2)$.

$$\sigma_{chromatic} = \frac{\sigma_s L}{\lambda}\left(A_5^2 + A_6A_7 + A_8A_9\right) \quad , \qquad (10)$$

With A_5=$-\lambda^2 d^2 n_{core}/d\lambda^2$, A_6=-2 $\lambda^2 d^2 n_{core}/d\lambda^2 (N_1\Delta n)$, A_7=$C_1(g/g+1)$, A_8=$(N_1\Delta n)^2(g-2-\varepsilon)/g+2$, and A_9=2g/3g+2. Where σ_s is the root mean square spectral width of the light source in nm, L is the polymer fiber link length in m, N_1, ε are the group refractive index [16], profile dispersion parameter and can be expressed as follows:

$$N_1 = n - \lambda\frac{dn}{d\lambda} , \qquad (11)$$

$$\varepsilon = \frac{-2n}{N_1}\frac{\lambda}{\Delta n}\frac{d\Delta n}{d\lambda} , \qquad (12)$$

With the constants C_1=g-2-ε/g+2, and C_2=3g-2-2ε/2(g+2). Then the total root mean square pulse width can be:

$$\sigma_{total} = \sigma_{modal} + \sigma_{chromatic} \quad , \qquad (13)$$

The power penalty of the receiver reaches one decibel when the pulse width exceeds one tenth of the bit period and therefore the possible transmission bit rate with soliton transmission technique can be expressed as [17, 18]:

$$B_{R(Soliton)} = \frac{1}{10\,\sigma_{total}} \quad , \qquad (14)$$

The total system capacity or total bit rate within pulse code modulation scheme with carrier radio frequency can be expressed as follows [19]:

$$B_{R(PCM)} = 2\gamma\,(f_m + f_{RF}) = 2\,(f_m + f_{RF})\log_2 Q \ , \qquad (15)$$

Where γ is the number of bits per sample, Q is the number of quantization levels, f_m is the modulating frequency which can be ranged from 3.4 KHz–4 KHz for audio signal, and can be ranged from 6.8 MHz–8 MHz for video signal. Therefore the total system transmission capacity can be expressed as follows [20]:

$$System\ Capacity(SC) = B_R\ L \ , \qquad (16)$$

Where L is the polymer fiber link length in meters.

III. SIMULATION RESULTS AND DISCUSSIONS

Based on the modeling equations analysis and the assumed set of the operating system parameters as the following: operating optical wavelength λ=1.3-1.65 μm, root mean square spectral linewidth of the optical source σ_s=0.1 nm, ambient temperature T=300-330 K, room temperature T_0=300 K, G_{op}=20 dB, Total bandwidth user data rate BR_{user}=20 Gbit/sec, Transmitted signal power P_T=0.1 Watt–0.6 Watt, , polymer fiber link length L=100 m–1000 m, radio frequency f_{RF}=500 MHz–1500 MHz, number of transmitted channels N_{ch}=20-100, number of quantization levels Q=4–128 relative refractive index difference

Δn=0.01-0.03, and index exponent g=2.5. Based on specially designed software, and the assumed set of the series of the above operating parameters, the following facts as shown in the series of Figs. (1-15) are assured the clarified results:

i) As shown in Fig. 1 has assured that as total transmitted signal power increases, this leads to increase in optical signal to noise ratio. As well as radio frequency decreases, this results in increasing of optical signal to noise ratio.

ii)Fig. 2 has indicated that signal to noise ratio degraded with increasing both operating signal radio frequency and ambient temperature at the operating in second optical transmission window.

iii) Figs. (3-5) have assured that signal to noise ratio increases with increasing optical carrier wavelength and decreasing both operating signal radio frequency and high ambient temperatures.

iv) As shown in the series of Figs. (6, 7) have proved that as number of transmitted channels increases and radio frequency decreases, this leads to increase of total signal bandwidth for audio and video signals. We have observed that the video signals occupy large bandwidth than audio signals.

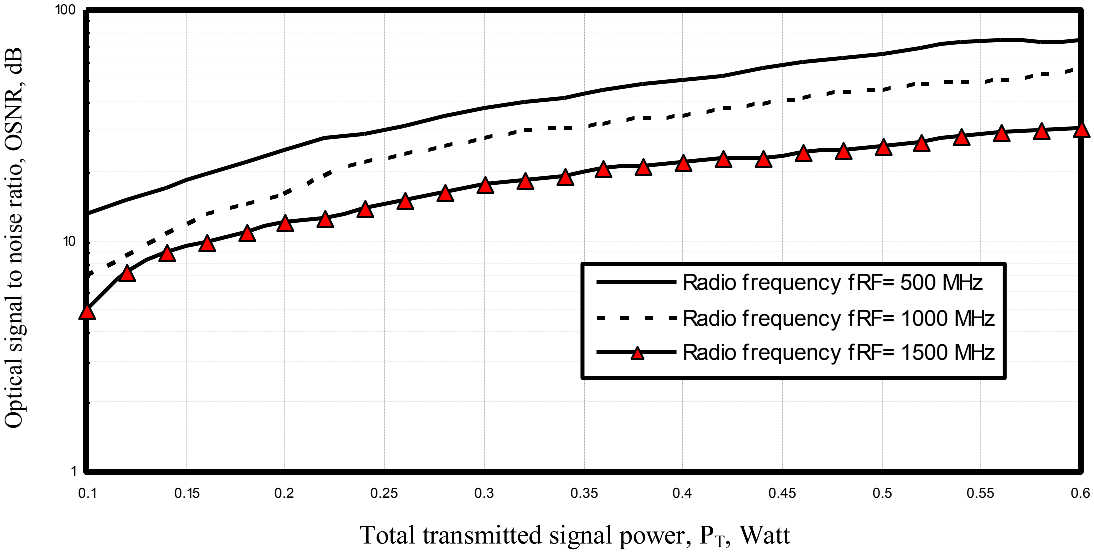

Fig. 1. Variations of the optical signal to noise ratio against total transmitted signal power at the assumed set of the parameters.

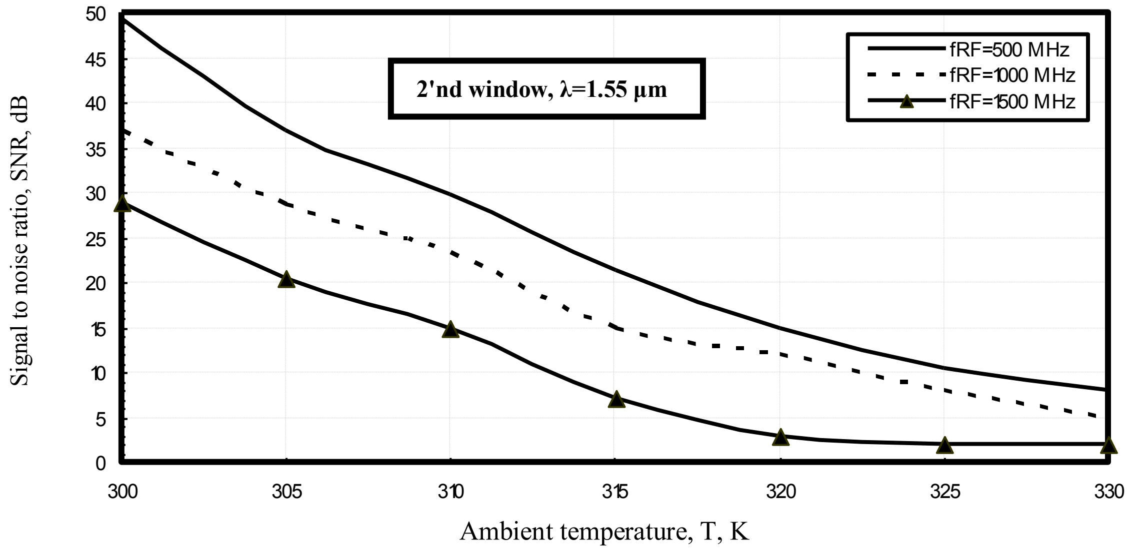

Fig. 2. Signal to noise ratio in relation to ambient temperature and operating signal radio frequency at the assumed set of the operating parameters.

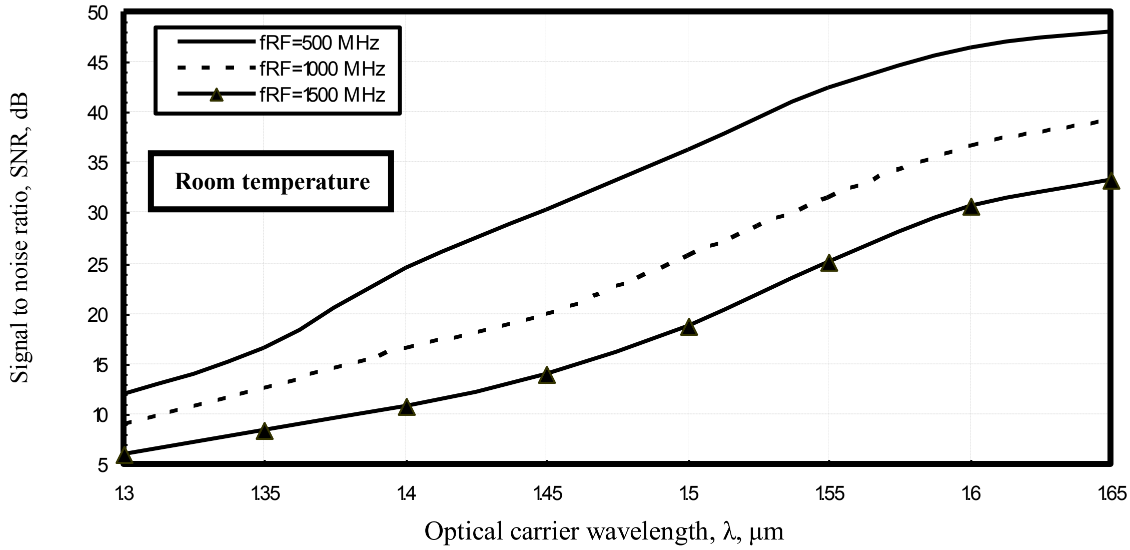

Fig. 3. Signal to noise ratio in relation to optical carrier wavelength with room temperature and operating signal radio frequency at the assumed set of the operating parameters.

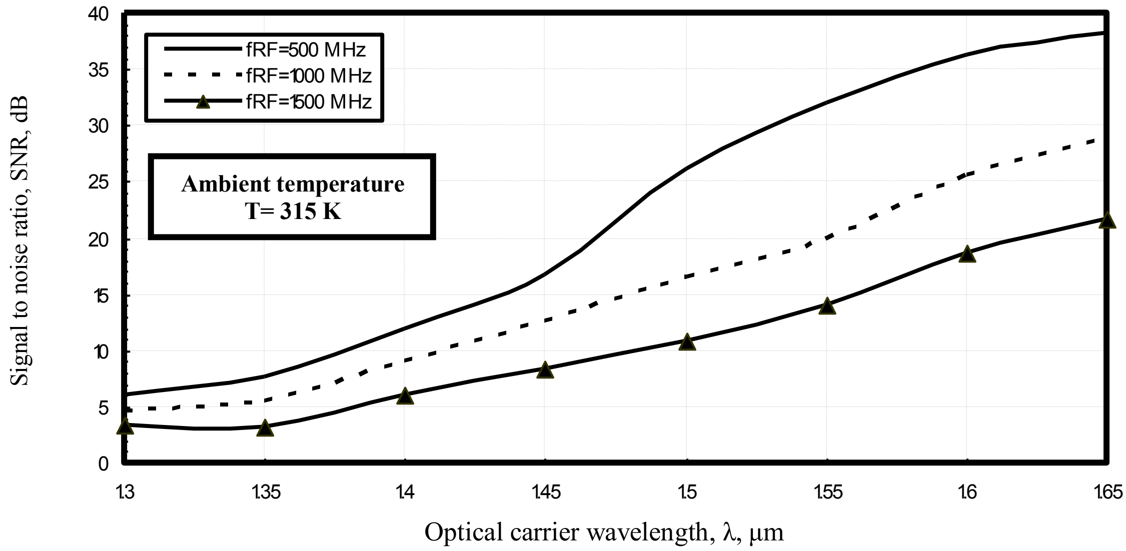

Fig. 4. Signal to noise ratio in relation to optical carrier wavelength (with T=315 K) and operating signal radio frequency at the assumed set of the operating parameters.

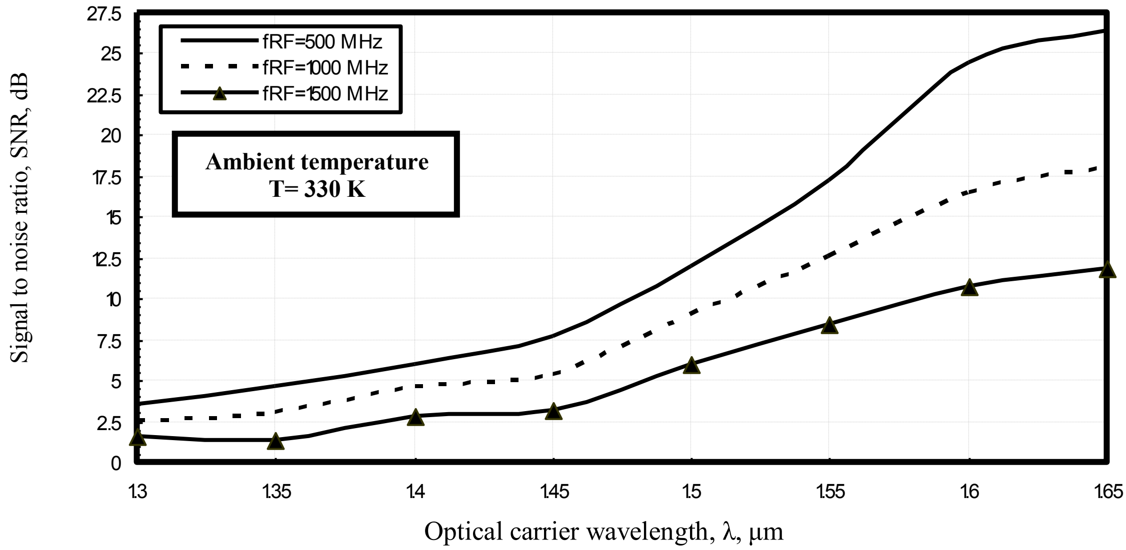

Fig. 5. Signal to noise ratio in relation to optical carrier wavelength (with T=315 K) and operating signal radio frequency at the assumed set of the operating parameters.

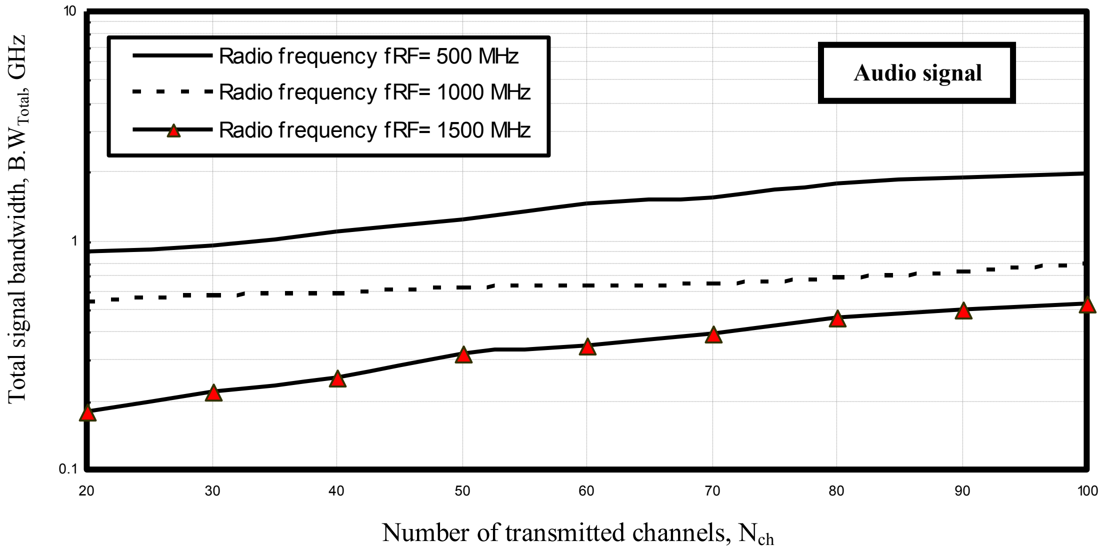

Fig. 6. Variations of the total system signal bandwidth against number of transmitted channels at the assumed set of the parameters.

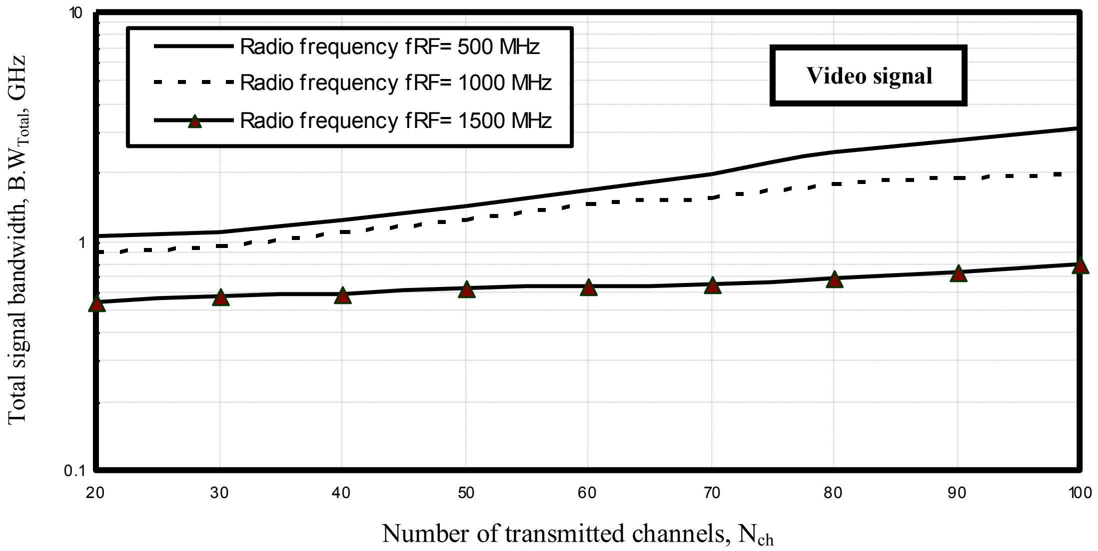

Fig. 7. Variations of the total system signal bandwidth against number of transmitted channels at the assumed set of the parameters.

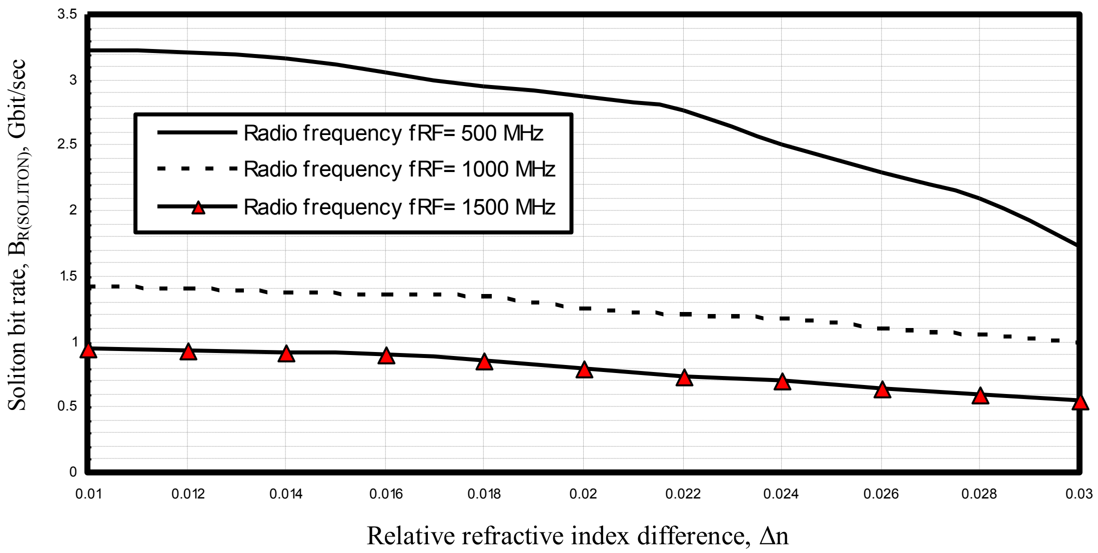

Fig. 8. Variations of the Soliton transmission bit rate against relative refractive index difference at the assumed set of the parameters.

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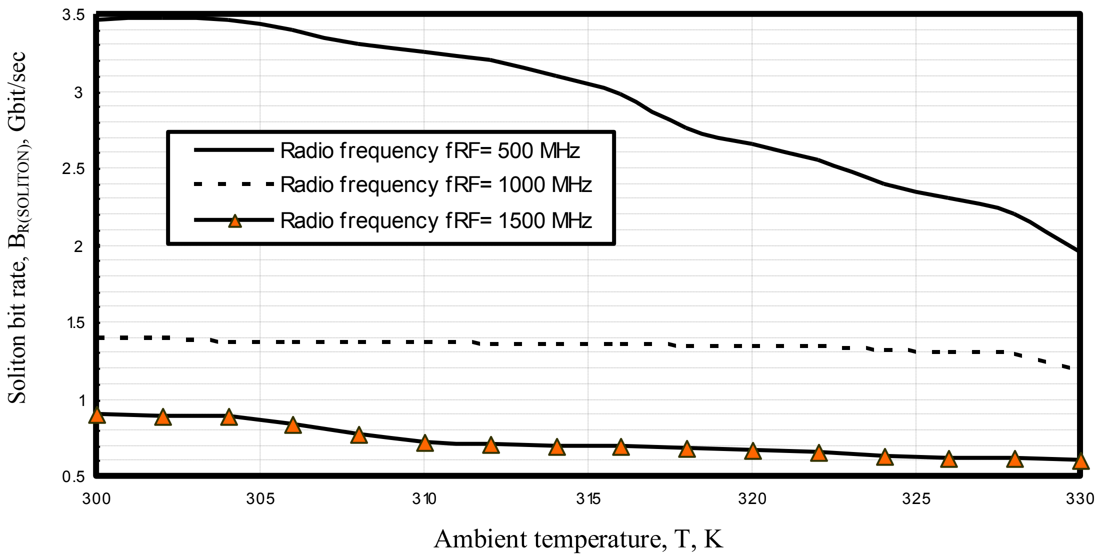

Fig. 9. Variations of the Soliton transmission bit rate against ambient temperature at the assumed set of the parameters.

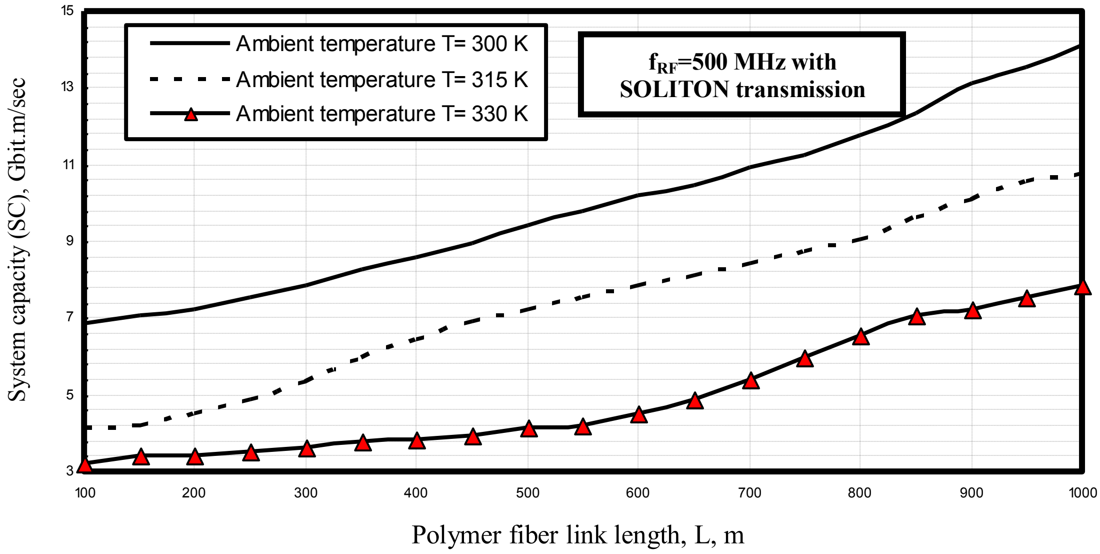

Fig. 10. Variations of the system transmission capacity against polymer fiber link length at the assumed set of the parameters.

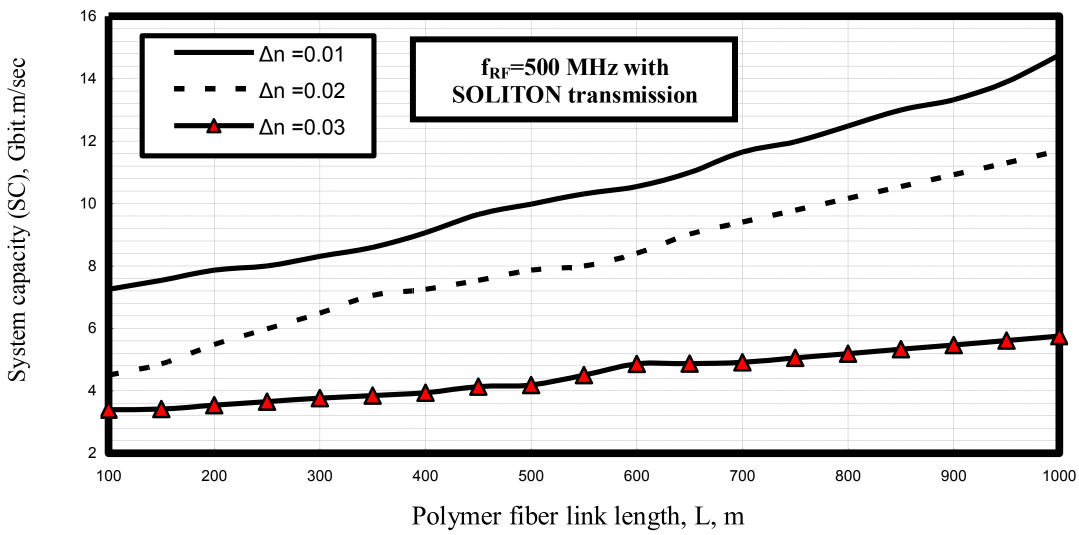

Fig. 11. Variations of the system transmission capacity against polymer fiber link length at the assumed set of the parameters.

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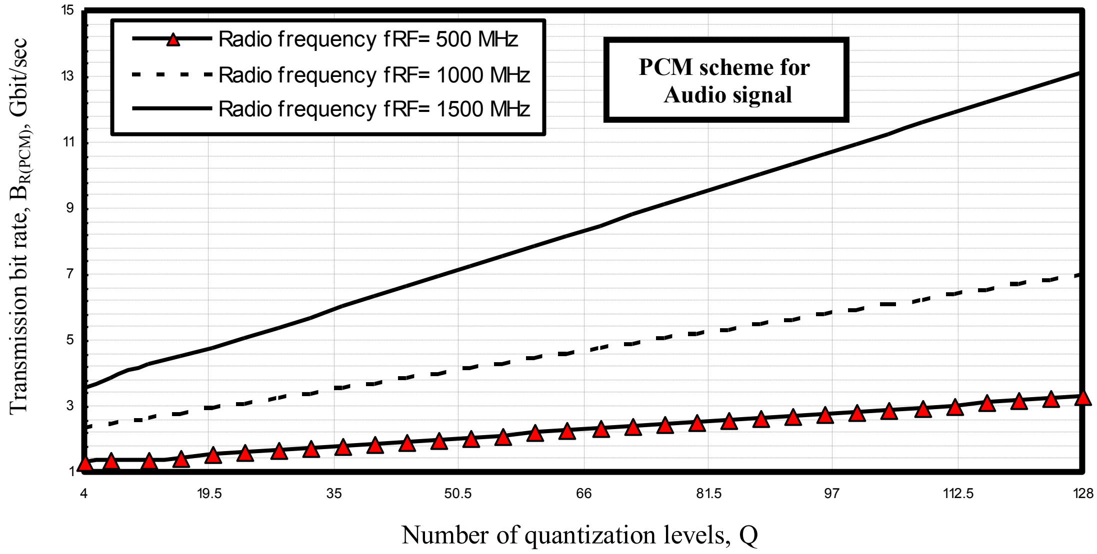

Fig. 12. Variations of the transmission bit rate against number of quantization levels at the assumed set of the parameters.

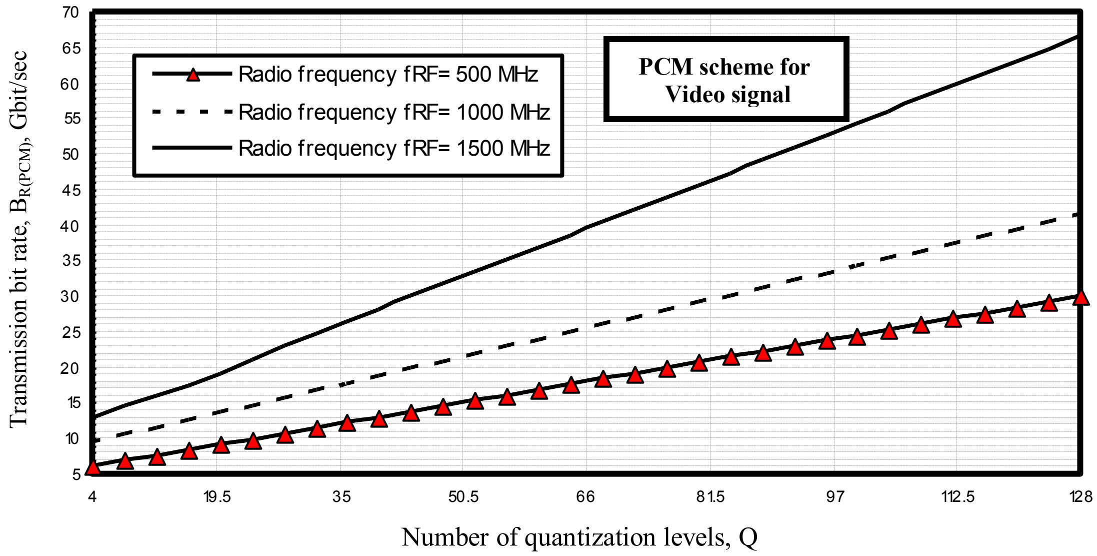

Fig. 13. Variations of the transmission bit rate against number of quantization levels at the assumed set of the parameters.

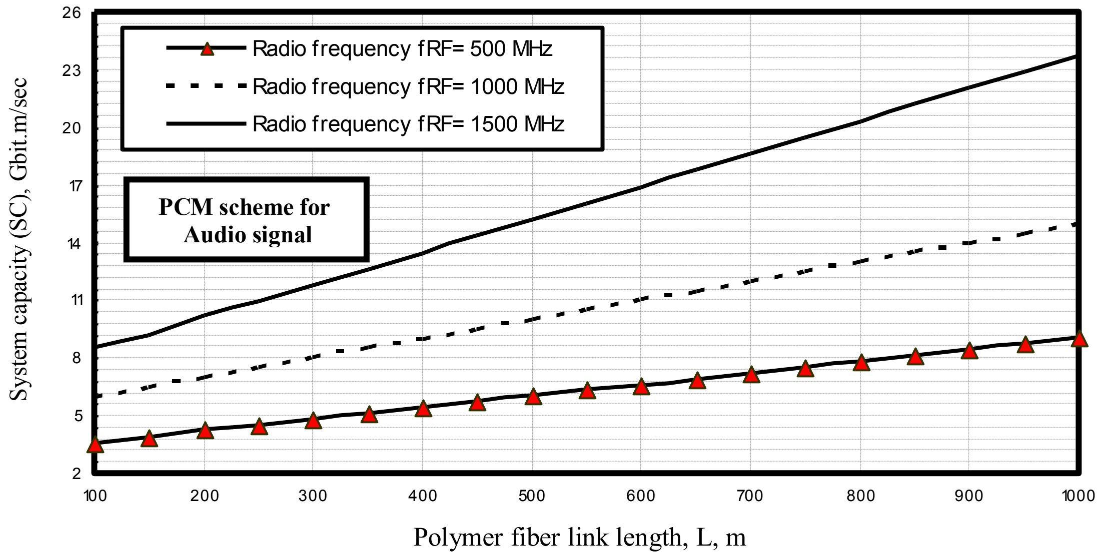

Fig. 14. Variations of the system transmission capacity against polymer fiber link length at the assumed set of the parameters.

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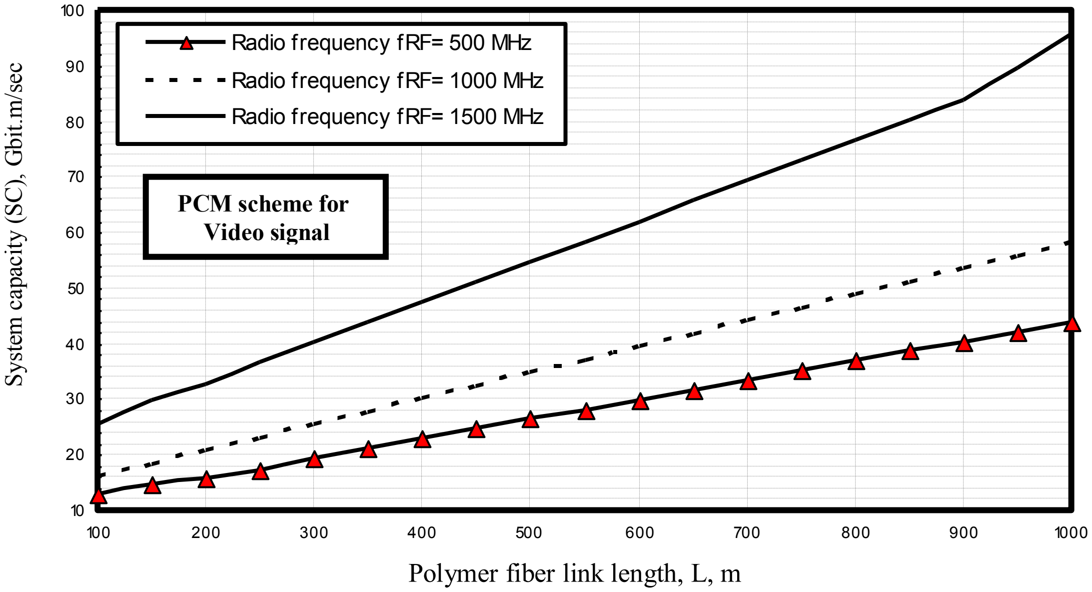

Fig. 15. Variations of the system transmission capacity against polymer fiber link length at the assumed set of the parameters.

v) Figs. (8, 9) have indicated that as both relative refractive index difference and ambient temperature decrease, and radio frequency decreases, this leads to increase of transmission bit rates with using SOLITON transmission technique.

vi) As shown in Figs. (10, 11) have assured that as polymer fiber link length increases, and both ambient temperature and relative refractive index difference decrease, this leads to increase of total system capacity with using SOLITON transmission technique at the lowest operating radio frequency.

vii) Figs. (12, 13) have demonstrated that as both number of quantization levels and radio frequency increase, this results in increasing transmission bit rates with using PCM scheme for audio and video signals. We have found that the video signals occupy large bandwidth than audio signals.

viii) As shown in Figs. (14, 15) have assured that as both polymer fiber link length and radio frequency increase, this results in increasing of total system capacity with using PCM scheme for both audio and video signals. We have theoretically found that the video signals have presented large transmission capacity compared to audio signals.

IV. CONCLUSIONS

In a summary, we have developed ROF communication systems within multimode polymer optical fibers with using pulse coding modulation scheme, maximum time division multiplexing transmission technique, and wavelength division multiplexing technique. It is observed that the increased transmitted signal power and the decreased radio frequency, this leads to the increased optical signal to noise ratio. Pulse code modulation scheme and wavelength division and time division multiplexing techniques have presented the highest transmission bit rates and systems capacity products through radio over fiber communication systems. As well as it is theoretically found that the dramatic effects of high ambient temperatures and the increased signal radio frequencies on the system signal to noise ratio.

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