

# Radio over Fiber Communication Systems over Multimode Polymer Optical Fibers for Short Transmission Distances under Modulation Technique

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## ABSTRACT

Radio over Fiber (ROF) technology was being explored and used because of its advantages. Radio over fiber means the optical signal is being modulated at radio frequencies and transmitted via the optical fiber. By using this technology, we can transport the radio frequency (RF) signal over few kilometers with minimal loss. ROF 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 coarse wavelength division multiplexing (CWDM) technique using pulse code modulation schemes.

**Keywords:** *ROF, Polymer wired transmission, Short distances, Multimode fibers, Optical signal to noise ratio.*

## I. INTRODUCTION

Next-generation networks, which are capable of simultaneously transmitting both wired data and wireless one, have been regarded as the most promising systems for the fulfillment of various services required by several customers. It becomes important what techniques can be focused on the implementation of this system depending on the IT (Information technology) environments of each country. Among these technologies, a radio over fiber has been considered as an attractive solution for effectively supporting the fixed and mobile services to various subscribers [1]. It is important for us to deal with the following technical issues in order to lead to the successful development of real networks. The simultaneous generation of both wired and wireless signal using simple and cost-effective methods should be implemented in a central station (CS). Secondly, a base station (BS) should be a simple and cost effective one because a conventional RoF system requires many BS to cover a number of cells. Finally, it can be very helpful that the architecture of a BS is implemented the same way of making an optical network unit in the conventional passive optical network (PON) because a RoF system is more likely to connect with a PON rather than to be operated independently. The cost of installing a BS can be also reduced considerably because the optical network unit (ONU) of a conventional PON system can play a role of a BS in a ROF system [2].

It has long been recognized that ROF links could play an important role in such systems when high frequency wireless signals need to be distributed over many 100's of meters. The use of ROF techniques can result in a simplified overall system design since both RF

carrier generation and data modulation can be done at a central base station [3]. For 60 GHz ROF systems to be feasible, cost will be a very important factor and the main issue for RoF solutions is the cost of modulating a laser at 60 GHz. An alternate solution would be the direct modulation of a laser [9] at 4 Gbit/sec for high speed data transmission over fiber but this would still require a 60 GHz local oscillator at the remote end for data up/down conversion using mixers which could increase the cost significantly. Traditionally, modulation at 60 GHz would be done with an expensive electro-optic modulator (EOM) [4] although more recently electro-absorption modulators have also been explored. Up to now, several EOM based methods for mm wave signal generation and data modulation using Mach Zehnder modulator (MZM) have been proposed [5]. Among these methods, double sideband (DSB) modulation schemes have a critical drawback caused by chromatic dispersion. Whereas single sideband (SSB) modulation schemes which overcome the dispersion issue tend to have low signal to noise (SNR) characteristics. Other possible schemes include optical carrier suppression and optical phase modulation with optical filtering. These have been applied to many ROF systems for better SNR characteristics of the generated mm-wave signals. Other techniques to generate mm-wave signals using semiconductor photonic devices have also been explored, some of the important ones are two mode locked Fabry-Perot (FP) slave lasers [6], dual parallel injection locked FP laser and an optical heterodyne technique using two single mode lasers. In the optical heterodyne technique, two single-mode lasers beat together to generate a mm-wave signal at their optical frequency difference in a fast photodiode (PD).

In the present study, we have deeply investigated ROF communication systems within multi mode polymer optical fibers for short transmission applications. Multimode polymer fibers have a larger core radius compared to single mode fibers. A larger core radius allows more optical power coupled into a fiber. The coupling efficiency can be reached to 90% and simplicity leads to reduction in cost of the link within multi mode fibers. 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 compared to traditional communication systems.

## II. SCHEMATIC VIEW OF RADIO OVER FIBER COMMUNICATION SYSTEM

Fig. 1 shows a general ROF communication system architecture. At a minimum, ROF link consists of all the hardware required to impose an RF signal on an optical carrier, the fiber-optic link, and the hardware required to recover the RF signal from the carrier.

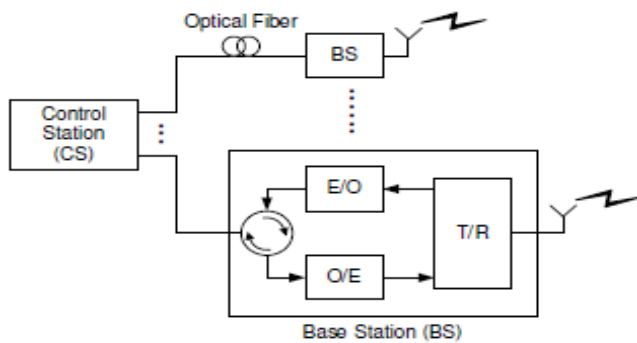


Fig. 1: ROF communication system architecture.

The optical carrier's wavelength is usually selected to coincide with either the 1.3  $\mu\text{m}$  window [7], at which standard single-mode fiber has minimum dispersion, or the 1.55  $\mu\text{m}$  window, at which its attenuation is minimum. Where the E/O is the electrical to optical conversion, O/E is the optical to electrical conversion [8], and T/R is the route from transmitter to receiver. By using these large low attenuation areas for data transmission, the signal loss for a set of one or more wavelengths can be made very small, thus reducing the number of amplifiers and repeaters actually needed. In single channel long-distance experiments, optical signals have been sent over hundreds of kilometers without amplification. Besides its enormous bandwidth and low attenuation, fiber also offers low error rates. Communication systems using an optical fiber typically operate at BER's of less than  $10^{-11}$ . The small size and thickness of fiber allows more fiber to occupy the same physical space as copper, a property that is desirable when installing local networks in buildings. Fiber is flexible, reliable in corrosive environments, and deployable at short notice. Also, fiber transmission is immune to

electromagnetic interference and does not cause interference [9].

## III. MODELING ANALYSIS

The optical channel of the ROF link that use a multimode fiber that consists of an optical source, a fiber, and a photodetector. The signal is directly modulated onto a laser and biased to minimize nonlinearity and clipping distortion. The signal  $s(t)$  after biased is given as [10]:

$$S_{bias}(t) = [1 + m s(t)], \quad (1)$$

Where  $m$  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 [11]:

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

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:

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

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 follows [12, 13]:

$$OSNR = \frac{\lambda_s P_T}{2h c B.W_{Up=Down}} = \frac{0.5 P_T}{f_{RF} h B.W_{Up=Down}}, \quad (4)$$

Where  $h$  is the Planck's constant ( $6.02 \times 10^{-34}$  J.sec),  $c$  is the speed of light ( $3 \times 10^8$  m/sec),  $\lambda_s$  is the operating optical signal wavelength in mm,  $f_{RF}$  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 index distribution is expressed by a power law of the form [14]:

$$n(r) = n \left( 1 - \left( \frac{r}{R_p} \right)^g \Delta n \right), \quad (5)$$

Where  $n(r)$  is the refractive index at radial distance  $r$ ,  $R_p$  is the polymer radius of the core in  $\mu\text{m}$ ,  $\Delta n$

is a parameter that can be used to measure the relative refractive-index difference, and parameter  $g$  is the exponent of the power law. Ref. [14] derived the optimum index profile as a function of  $g$ , which is expressed as follows:

$$g_{opt} = 2 + \varepsilon - \frac{(4 + \varepsilon)(3 + \varepsilon)\Delta n}{5 + 2\varepsilon}, \quad (6)$$

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

$$n = \sqrt{1 + \frac{S_1\lambda^2}{\lambda^2 - S_2} + \frac{S_3\lambda^2}{\lambda^2 - S_4} + \frac{S_5\lambda^2}{\lambda^2 - S_6}}, \quad (7)$$

Where the first and second differentiation with respect to operating signal wavelength  $\lambda$  as discussed in Ref. [15]. Where the coefficients of the benzyl benzoate for PMMA (PMMA-BEN) given as follows:  $S_1=0.4855$ ,  $S_2=0.1043$  (T/T<sub>0</sub>),  $S_3=0.7555$ ,  $S_4=0.1147$  (T/T<sub>0</sub>),  $S_5=0.4252$ ,  $S_6=49.34$  (T/T<sub>0</sub>). Where T and T<sub>0</sub> 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]:

$$\sigma_{modal} = \frac{LN_1\Delta n}{2c} A_1 A_2 (C_1^2 + A_3 + A_4)^{0.5}, \quad (8)$$

With  $A_1=g/g+1$ ,

$$A_2=(g+2/3g+2)^{0.5},$$

$$A_3=4C_1C_2\Delta n(g+1)/2g+1, \text{ and}$$

$$A_4=4\Delta n^2C_2(2g+2)^2/(5g+2)(3g+2).$$

$$\sigma_{chromatic} = \frac{\sigma_s L}{\lambda} (A_5^2 + A_6 A_7 + A_8 A_9), \quad (9)$$

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  $\sigma_s$  is the root mean square spectral width of the light source in nm, L is the polymer fiber link length in m,  $N_1$ ,  $\varepsilon$  are the group refractive index [16], profile dispersion parameter and can be expressed as follows:

$$N_1 = n - \lambda \frac{dn}{d\lambda}, \quad (10)$$

$$\varepsilon = \frac{-2n}{N_1} \frac{\lambda}{\Delta n} \frac{d\Delta n}{d\lambda}, \quad (11)$$

With the constants  $C_1=g-2-\varepsilon/g+2$ , and  $C_2=3g-2-2\varepsilon/2(g+2)$ .

Then the total root mean square pulse width can be:

$$\sigma_{total} = \sigma_{modal} + \sigma_{chromatic}, \quad (12)$$

The power penalty of the receiver reaches one decibel when the pulse width exceeds one fourth of the bit period and therefore the possible transmission bit rate with maximum time division multiplexing can be expressed as [17, 18]:

$$B_R(MTDM) = \frac{1}{4\sigma_{total}}, \quad (13)$$

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

$$B_R(PCM) = 2\gamma (f_m + f_{RF}) = 2 (f_m + f_{RF}) \log_2 Q, \quad (14)$$

Where  $\gamma$  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]:

$$\text{System Capacity}(SC) = B_R L, \quad (15)$$

Where L is the polymer fiber link length in meters.

## IV. SIMULATION RESULTS AND PERFORMANCE ANALYSIS

Based on the modeling equations analysis and the assumed set of the operating system parameters as follows: , root mean square spectral linewidth of the optical source  $\sigma_s=0.1$  nm, ambient temperature T=300-330 K, room temperature T<sub>0</sub>=300 K, polymer fiber radius R<sub>p</sub>=500  $\mu$ m, Transmitted signal power P<sub>t</sub>=0.1 Watt–0.6 Watt, OSNR=50 dB, polymer fiber link length L=100 m–1000 m, radio frequency f<sub>RF</sub>=900 MHz–1800 MHz, number of transmitted channels N<sub>ch</sub>=4–20, relative refractive index difference number of quantization levels Q=4–128,  $\Delta n=0.01-0.03$ , 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. (2-13) are assured the clarified results:

As shown in Fig. 2 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.

i) Fig. 3 has total transmitted signal power increases and radio frequency decreases, these results in increasing of user data rate in the uplink and downlink systems.

- ii) As shown in the series of Figs. (4, 5) 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.
- iii) Figs. (6, 7) 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 MTDM transmission technique.
- iv) As shown in Figs. (8, 9) 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 MTDM transmission technique at the lowest operating radio frequency.
- v) Figs. (10, 11) 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.
- vi) As shown in Figs. (12, 13) 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.

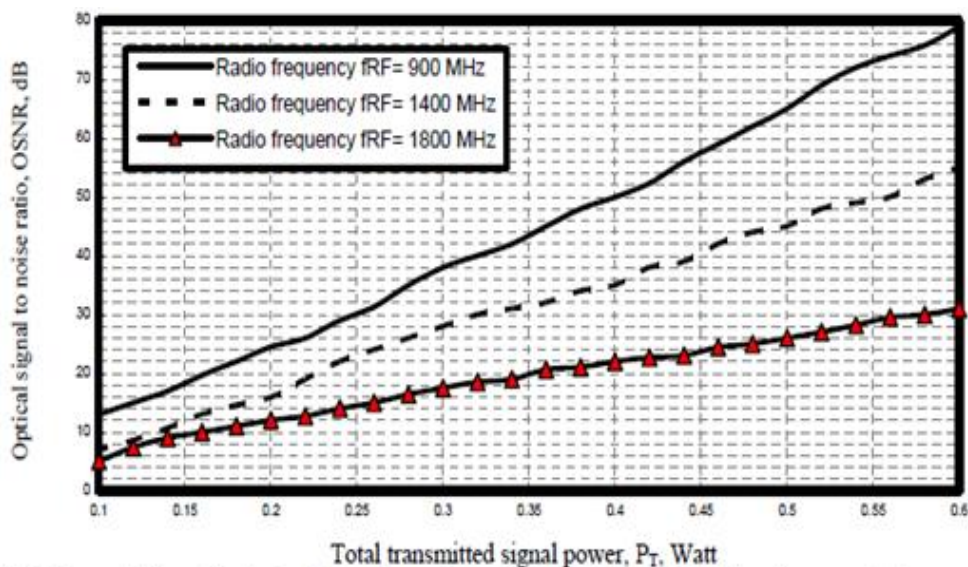


Fig. 2. Variations of the optical signal to noise ratio against total transmitted signal power at the assumed set of the parameters.

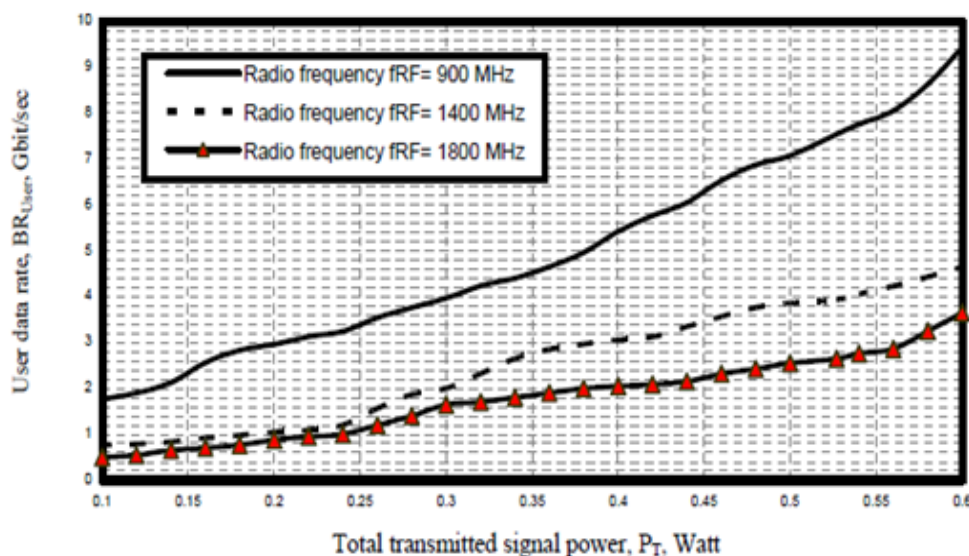


Fig. 3. Variations of the user transmission data rate against total transmitted signal power at the assumed set of the parameters.

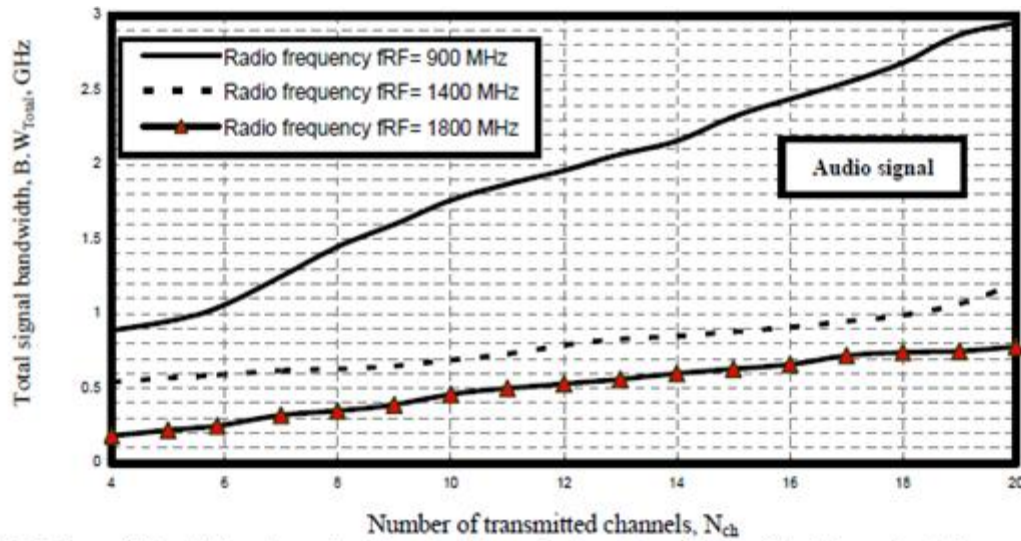


Fig. 4. Variations of the total system signal bandwidth against number of transmitted channels at the assumed set of the parameters.

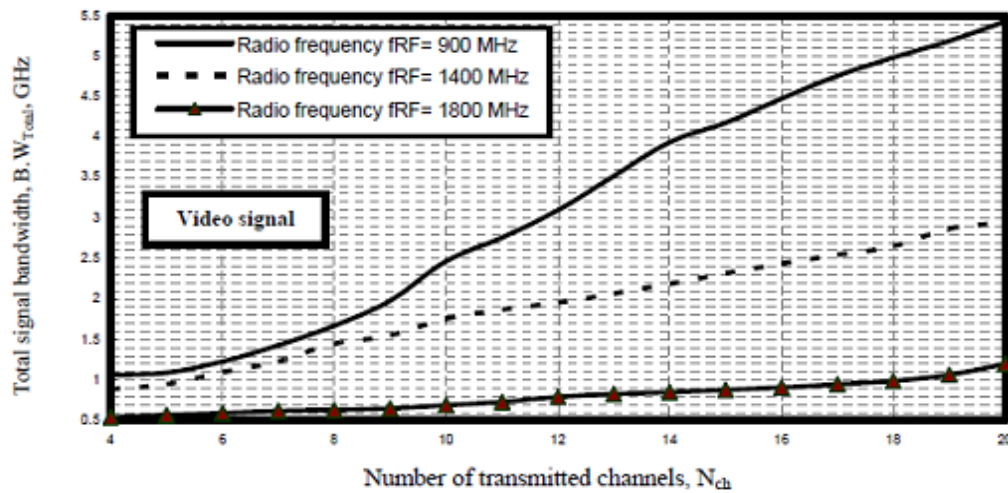


Fig. 5. Variations of the total system signal bandwidth against number of transmitted channels at the assumed set of the parameters.

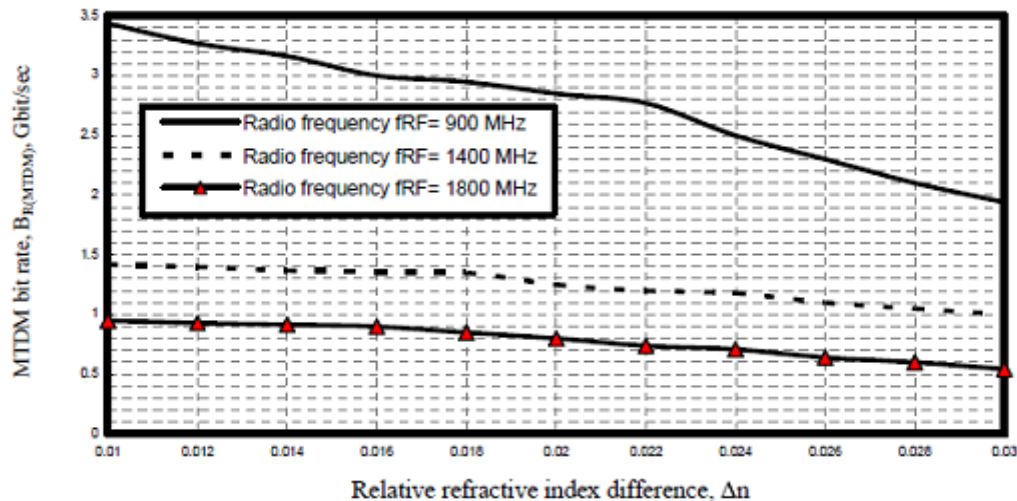


Fig. 6. Variations of the MTDM transmission bit rate against relative refractive index difference at the assumed set of the parameters.

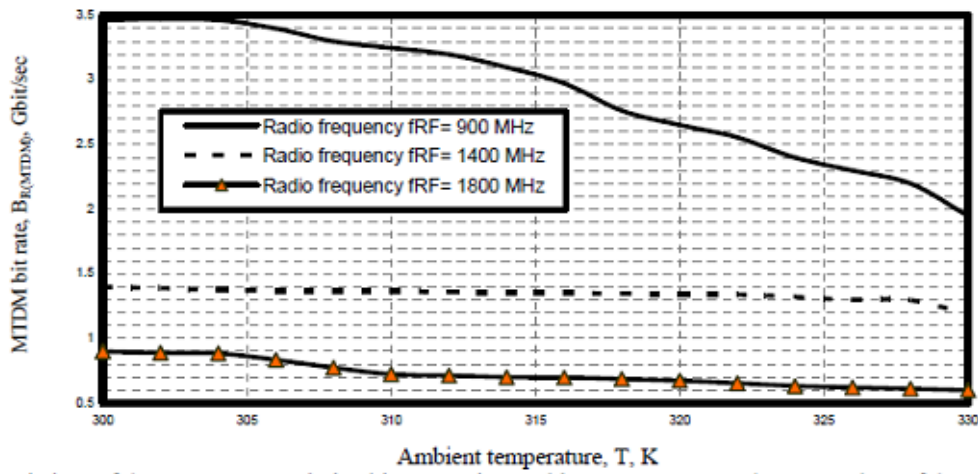


Fig. 7. Variations of the MTDM transmission bit rate against ambient temperature at the assumed set of the parameters.

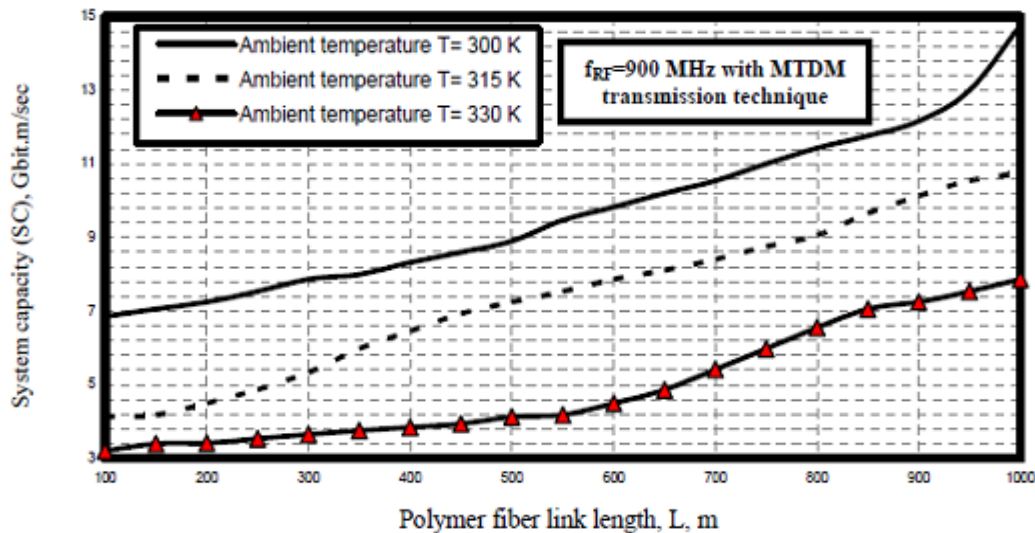


Fig. 8. Variations of the system transmission capacity against polymer fiber link length at the assumed set of the parameters.

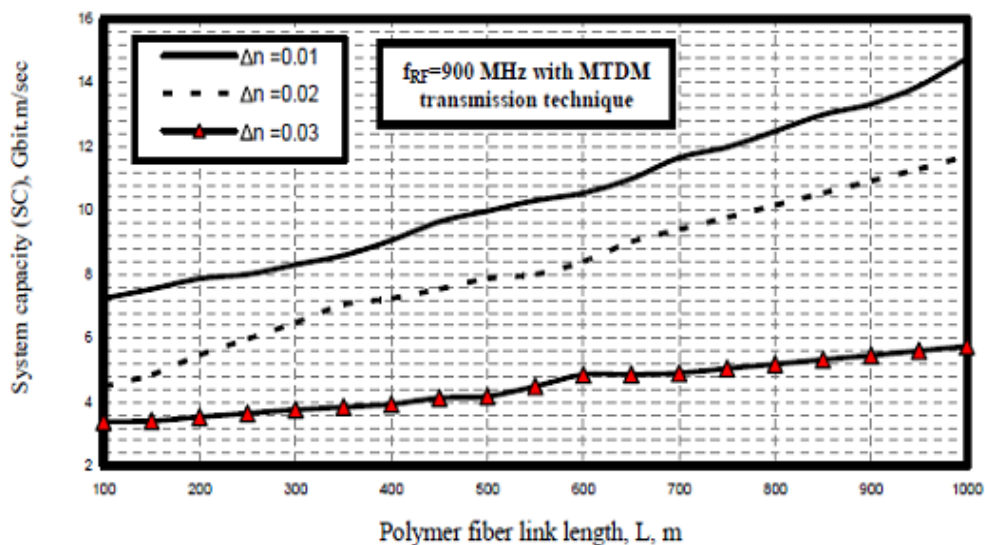


Fig. 9. Variations of the system transmission capacity against polymer fiber link length at the assumed set of the parameters.

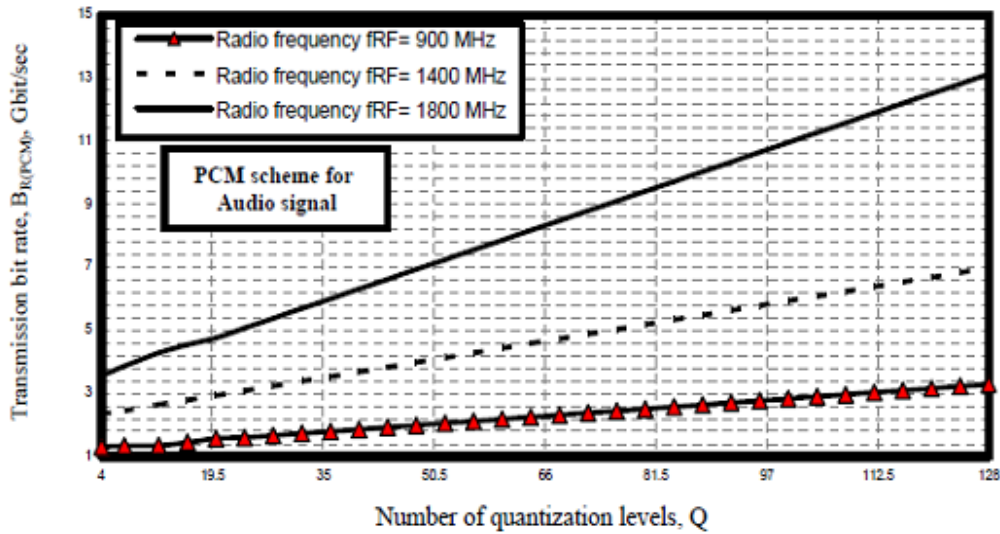


Fig. 10. Variations of the transmission bit rate against number of quantization levels at the assumed set of the parameters.

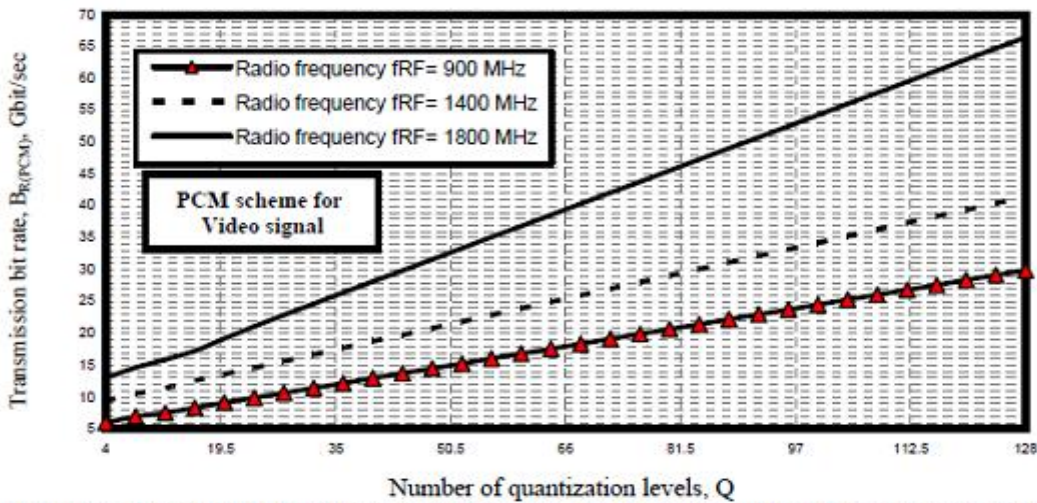


Fig. 11. Variations of the transmission bit rate against number of quantization levels at the assumed set of the parameters.

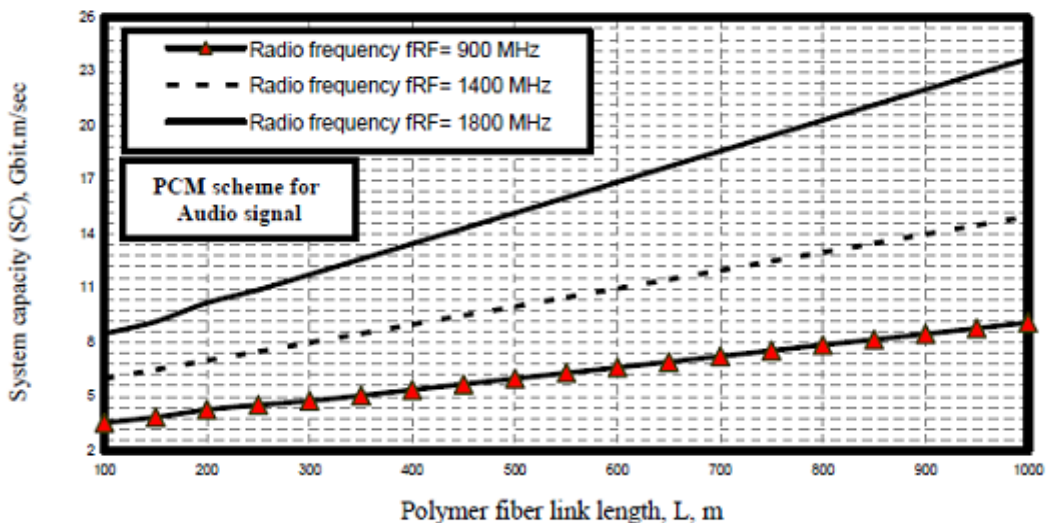


Fig. 12. Variations of the system transmission capacity against polymer fiber link length at the assumed set of the parameters.

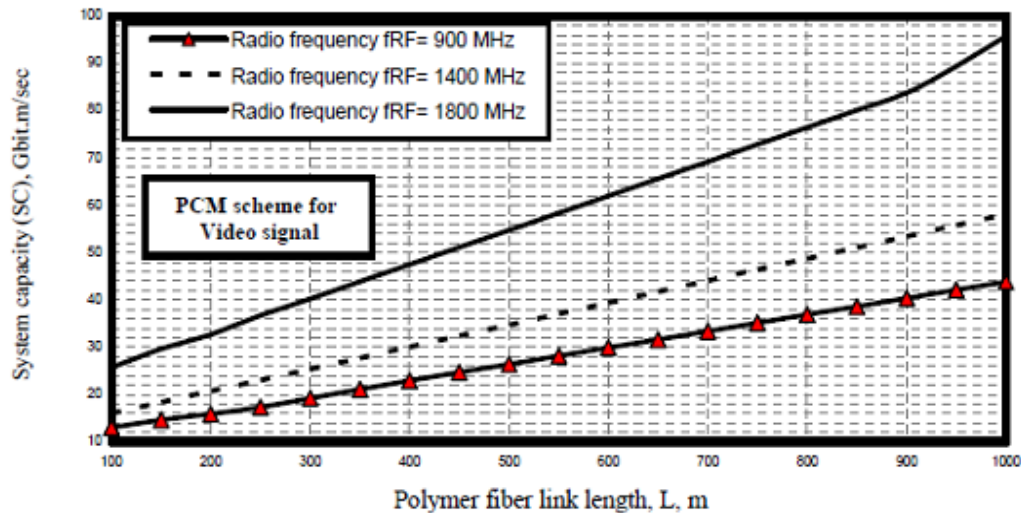


Fig. 13. Variations of the system transmission capacity against polymer fiber link length at the assumed set of the parameters.

## V. 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 coarse wavelength division multiplexing technique. It is theoretically found that the increased of total transmitted signal power and the decreased of operating radio frequencies, the increased of both OSNR and user data transmission bit rates. As well as we have indicated that the increased number of transmitted channels, and the decreased operating radio frequencies, this results in increasing of total signal bandwidth for both audio and video signals. Moreover we have demonstrated that the decreased of both ambient temperature and relative refractive index difference, and the decreased operating radio frequencies, this leads to increase of transmission bit rates with MTDM transmission technique. It is also theoretically found that the decreased of both ambient temperature and  $\Delta n$ , and the increased polymer fiber link length, this results in increasing of total system capacity with using MTDM transmission technique at the highest operating radio frequencies. It is observed that the increased number of quantization levels, polymer fiber link length and operating radio frequencies, this leads to increase of transmission bit rates and total system capacity with using PCM scheme for both audio and video signals. We have observed that the video signals have presented larger total signal bandwidth and total system capacity compared to audio signals.

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