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High Speed Performance of Electrooptic Polymer Modulator Devices in Advanced Optical Communication Systems

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***Abstract*— Electrooptic polymer modulator devices have been extensively studied and explored during the last few years. They have intrinsic advantages over conventional materials such as high-speed operation, compatibility with other materials and substrates, and the ability to make complex configurations and arrays. On the other hand, there have been problems with thermal stability, power handling, and drift. These problems are currently the subject of intense research and must be solved before commercial devices become available. This paper has been deeply investigated the high speed performance of polymer electrooptic modulator devices in advanced optical communication systems over wide range of the affecting parameters. We have taken in to account the study of modulator signal quality, sensitivity bandwidth product, switching voltage, transmitted signal bandwidth, device sensitivity, transmission bit rates under the effect of operating optical signal wavelength, modulator dimensions (i. e, modulator length, width and thickness), ambient temperature, and effective relative refractive index difference as a measurement of high speed performance operation.**

***Index Terms*— Optical Polymers, Integrated Optics Devices, High Speed Performance, Communication Systems and Modulator Sensitivity**

I. INTRODCTION

THE development of low loss, highly linear, and low-dispersion optical links coupled with the linear response of optical detectors to the intensity of incident light stream would make optical links an attractive alternative to microwave/millimeter links. Important applications include: 1) satellite receiver systems for distributed RF signals over long distances with high signal quality; 2) remote antenna and active phased array by means of high quality, low loss RF photonics without complicated digital processing equipment; and 3) local area networks (LANs) for low distortion distribution of RF signals in large building complexes, aircrafts, and television network systems [1, 2]. In these fields, highly efficient and linearized conversion from RF carrier based signals to optical carrier-based signals is of paramount importance.

A substantial research work performed over the past years has resulted in a number of linearization techniques, which can be subdivided into two categories, namely, electronic compensation and optical techniques of linearization. Electronic compensation includes pre-distortion compensation [3] and feed forward compensation [4]. Yet these techniques require expensive high-speed optoelectronic components, and have maximum bandwidth of only a few gigahertz. Optical techniques based on cascaded Mach Zehnder (MZ) modulator [5], dual wavelength MZ modulation [6], or ring resonator assisted MZ modulator [7] can achieve high bandwidth linearization, however, with a common shortcoming of complex device structure. In addition, these complex devices require high thermal stability and precise bias voltage, which substantially limit its use in practical applications [8].

In the present study, we have deeply investigated electrooptic polymer modulator device to estimate rise time, transmitted signal bandwidth, transmitted data rats and transmission bit rate length product, and switching voltage with using pulse code modulation scheme. The reliability of high speed electrooptic polymer modulators is the most critical milestone for the use of these materials in commercial applications.

II. MODEL ANALYSIS

The effective refractive index, n_e of polymer material based electrooptic modulator device can be given as [9]:

$$n_e^2 = \frac{B_1\lambda^2}{\lambda^2 - B_2^2} + \frac{B_3\lambda^2}{\lambda^2 - B_4^2} + \frac{B_5\lambda^2}{\lambda^2 - B_6^2} \quad , \tag{1}$$

The set of parameters of empirical equation coefficients of polymer material are recast as the following: B_1=0.4963, B_2= 0.0718$(T/T_0)^2$, B_3=0.6965, B_4=0.1174 $(T/T_0)^2$, B_5=0.3223, and B_6=9.237 $(T/T_0)^2$. Where T is the ambient temperature, and T_0 is the room temperature. Then the first and second differentiation of empirical equation with respect to operating wavelength λ yields as mentioned in Ref. [10]. The switching voltage V_π or the voltage required to change the output light intensity from its maximum value to its minimum value can be expressed as the following [11]:

$$V_\pi = \frac{\lambda\, d}{2\,\Gamma\, n_e^3\, r_{33}\, L_m} \quad , \tag{2}$$

Where d is the modulator thickness, λ is the operating optical signal wavelength, Γ is the confinement factor, L_m is the modulator length, and r_{33} is the electrooptic coefficient. If a modulating voltage V_m in z-direction is applied, the change in index for the transverse magnetic (TM) polarization is:

$$\Delta n_e = \frac{0.5 V_m\, n_e^3\, r_{33}}{L_m} \quad , \tag{3}$$

The sensitivity (S) of the EO polymer modulator can be written as [12]:

$$S = \frac{0.65\, Q\, \Gamma\, r_{33}\, n_e^2}{d} \quad , \tag{4}$$

Where Q is the quality factor of the EO polymer modulator device. The higher Q device will have higher sensitivity, as expected. The bandwidth of the modulator is inversely proportional to the Q. However, the product of the sensitivity and the bandwidth is not related to the Q and is given by [13-15]:

$$SBP = \frac{0.65\, n_e^2\, \Gamma\, r_{33}\, c}{d\, \lambda} \quad , \tag{5}$$

The quality factor of the EO polymer modulator device Q can be expressed as the following [16, 17]:

$$Q = \sqrt{m_1} - \sqrt{m_0} \quad , \tag{6}$$

Where $m_0=m_{b0}+m_d$ is the average number of electrons representing the 'zero' symbol, $m_1=m_{b1}+m_d$ is the average number of electrons representing the 'one' symbol, $m_d=i_d T_s/q$ is the average number of electrons correspond the dark current i_d during the switching time T_s. Where $m_{b0}=\lambda\eta P_0 T_s/hc$, $m_{b1}=\lambda\eta P_1 T_s/hc$. Where η is the efficiency of EO polymer modulator device, h is the Plank's constant ($6.625\text{x}10^{-34}$ J.Sec), q is the electron charge ($1.602\text{x}10^{-19}$ C), P_0 is the optical power representing the 'zero' symbol, and P_1 is the optical power representing the 'one' symbol. The transmitted signal bandwidth for standard single mode for polymer material based electrooptic modulator length L_m is given by [18]:

$$B.W_{sig.} = \frac{0.44}{\Delta\tau\ .\ L_m} \quad , \tag{7}$$

Where Δτ is the total pulse broadening due to total dispersion coefficient in system based EO modulator:

$$\Delta\tau = D_t\, \Delta\lambda\, L_m \quad , \ n\sec/nm.cm \tag{8}$$

Where the total dispersion coefficient in system based EO modulator device is given by:

$$D_t = \left(M_{md} + P\right) \quad , \tag{9}$$

In which both material and profile dispersions were taken into account as M_{md} and P respectively [19, 10]:

$$M_{md} = \left(-\frac{\lambda^3}{c}\left(\frac{dn_e}{d\lambda}\right)^2 - \frac{2\lambda}{c}\left(\frac{d^2 n_e}{d\lambda^2}\right)\left(N_1 \Delta n_e\right) C_1 \left(\frac{2\alpha}{\alpha+2}\right)\right)^{0.5} \tag{10}$$

$$P = \left(\left(\frac{N_1 \Delta n_e}{c\lambda}\right)^2 \left(\frac{\alpha - 2 - \varepsilon}{\alpha + 2}\right)^2 \times \frac{2\alpha}{3\alpha + 2}\right)^{1/2} \tag{11}$$

Where N_1 is the group index for the mode which is given by:

$$N_1 = n_e - \lambda \frac{dn_e}{d\lambda} \quad , \tag{12}$$

Where C_1 is a constant related to index exponent and profile dispersion and is given by:

$$C_1 = \frac{\alpha - 2 - \varepsilon}{\alpha + 2} \quad , \tag{13}$$

Where α is the index exponent, and ε is the profile dispersion parameter, and is given by:

$$\varepsilon = -\frac{2n_e}{N_1} \frac{\lambda}{\Delta n_e} \quad , \tag{14}$$

In the pulse code modulation scheme, total transmitted bit rate within EO polymer modulator device can be expressed in terms of transmitted signal bandwidth, and number of quantization levels, M as the following formula [20]:

$$R_{T(PCM)} = 2\, B.W_{sig.} \log_2 M \quad , \tag{15}$$

III. SIMULATION RESULTS AND DISCUSSIONS

We have been investigated the high speed performance operation of electrooptic polymer modulator in high speed optical communication over wide range of the affecting operating parameters as shown listed as follows: 1.3 μm ≤ λ, optical signal wavelength ≤ 1.55 μm, Spectral line width of the optical source, Δλ= 0.1 nm, 300 K ≤ T, ambient temperature ≤ 330 K, room temperature, T_0=300 K, 0.2 μm ≤ L_m, modulator length ≤ 1 μm, speed of light, c=3 $\text{x}10^{10}$ cm/sec, 0.5 msec ≤ switching time, T_s (on state) ≤ 1 msec, 0.1 msec ≤ switching time, T_s (off state) ≤ 0.4 msec, 0.1 μA ≤ dark current, i_d ≤ 1 μA, electro-optic coefficient, r_{33}=300 pm/Volt, 0.8 ≤ confinement factor, Γ≤ 0.95, 0.01≤ relative refractive index difference, Δn_e ≤ 0.05, 0.1 Watt ≤ optical power, P_0=P_1 ≤ 0.6 Watt, quantum Efficiency, η=90 %, index exponent, α=2, 16 ≤ number of quantization levels, M ≤ 128.

Based on the model equations analysis, assumed set of the operating parameters, and the set of the Figs. (1-12), the following facts are assured as the following results:

i) As shown in Figs. (1, 2) have assured that as both modulator length and ambient temperature increase, this results in decreasing of both transmitted signal bandwidth and transmission bit rate.

ii) Figs. (3, 4) have demonstrated that as both ambient temperature and operation optical signal wavelength increase, this leads to decrease in both transmitted signal bandwidth and transmission bit rate.

iii) As shown in Figs. (5, 6) have indicated that as both relative refractive index difference and operation optical signal wavelength increase, this leads to decrease in both transmitted signal bandwidth and transmission bit rate.

iv) Fig. 7 has assured that as number of quantization levels increases and operating optical signal wavelength deceases, these results in increasing of transmission bit rate.

v) Figs. (8, 9) have indicated that as modulator length increases, and both relative refractive index difference and operating signal wavelength increase, this leads to increase in both modulating and switching voltages.

vi) Fig. 10 has demonstrated that as optical signal wavelength decreases and dark current increases, these results in decreasing of modulator signal quality factor.

vii) As shown in Fig. 11 has indicated that as confinement factor increases, and modulator thickness decreases, these results in increasing of modulator device sensitivity.

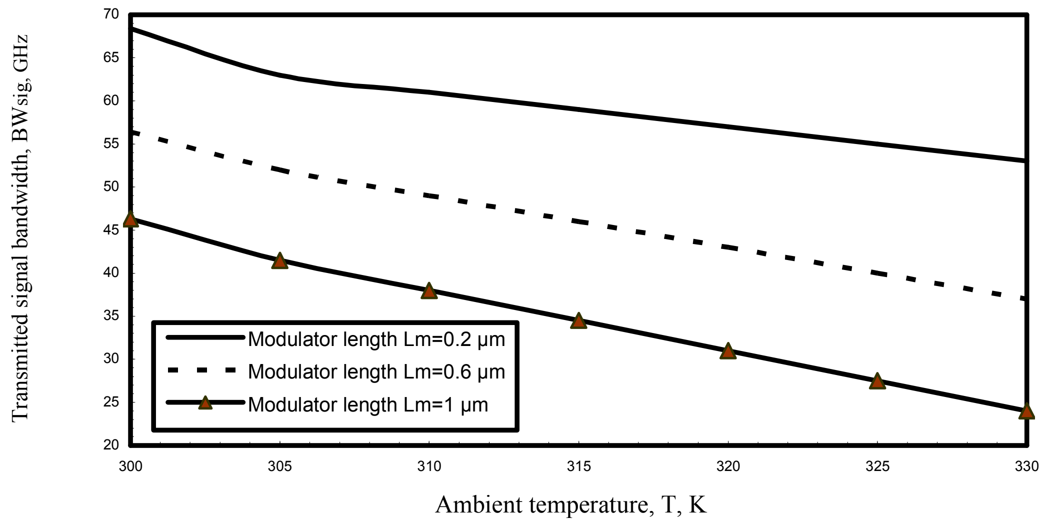

Fig. 1. Variations of signal bandwidth against ambient temperature at the assumed set of parameters.

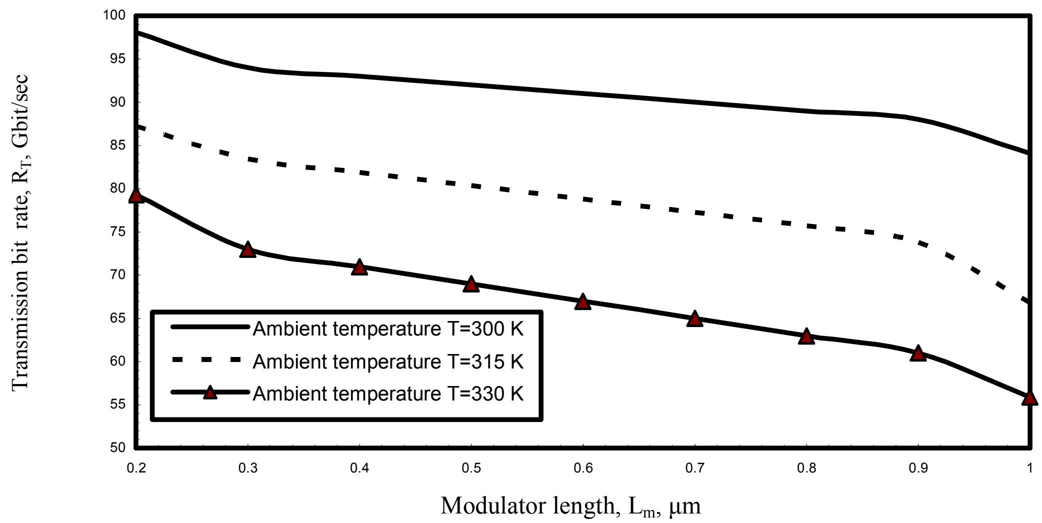

Fig. 2. Variations of the transmission bit rate against modulator length at the assumed set of parameters.

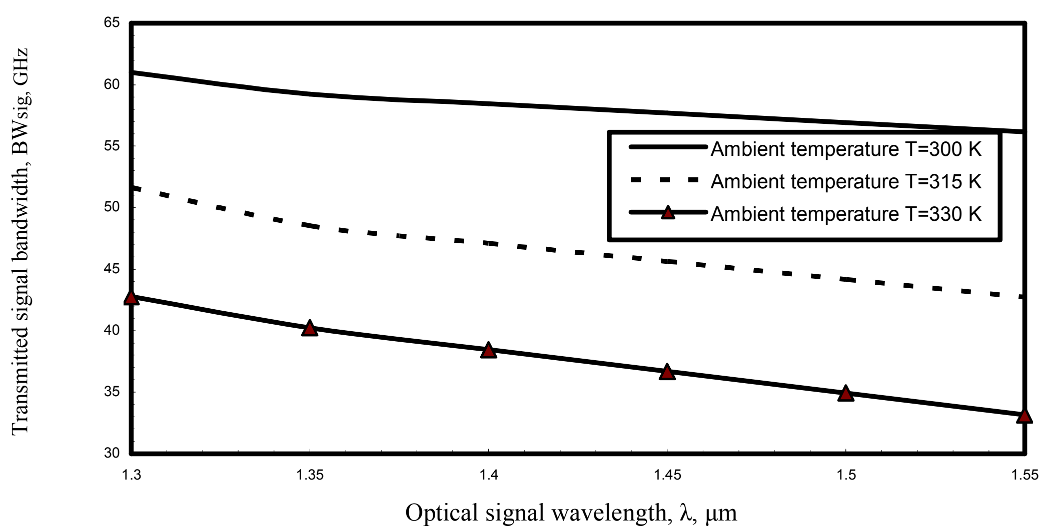

Fig. 3. Variations of transmitted signal bandwidth against optical signal wavelength at the assumed set of parameters.

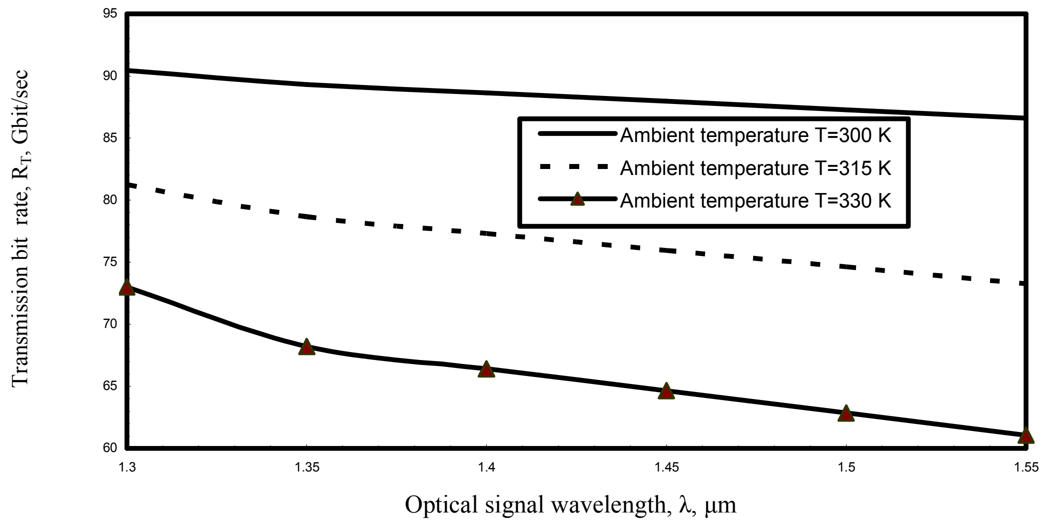

Fig. 4. Variations of transmission bit rate against optical signal wavelength at the assumed set of parameters.

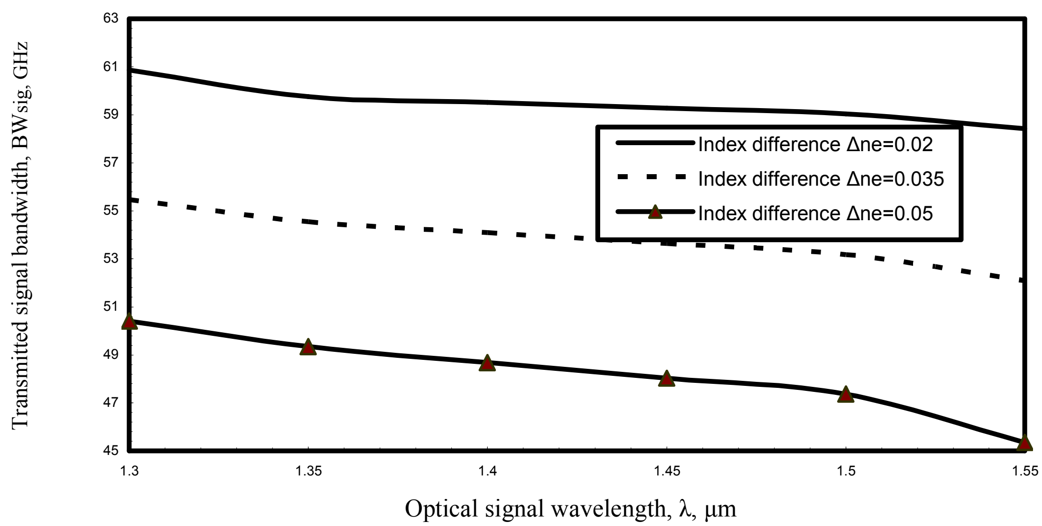

Fig. 5. Variations of transmitted signal bandwidth against optical signal wavelength at the assumed set of parameters.

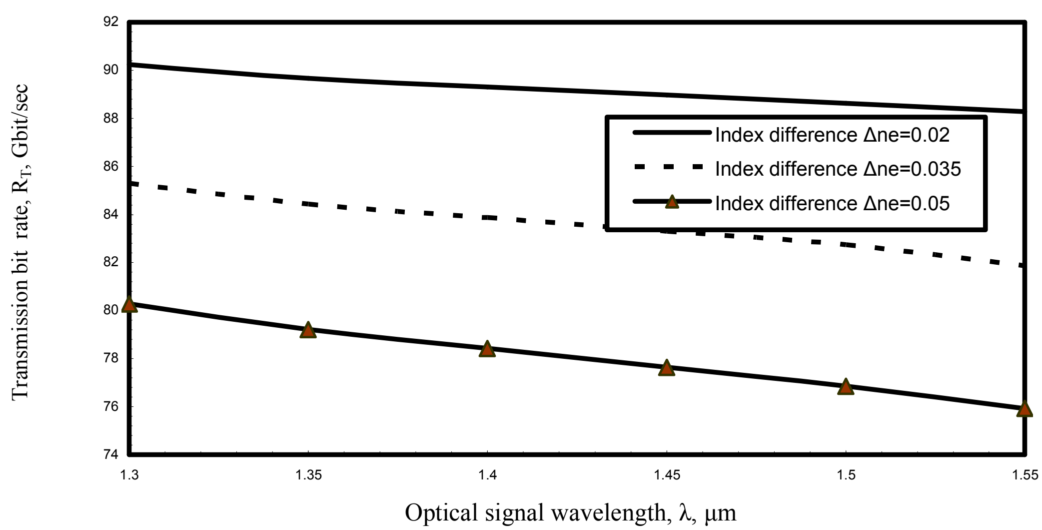

Fig. 6. Variations of transmission bit rate against optical signal wavelength at the assumed set of parameters.

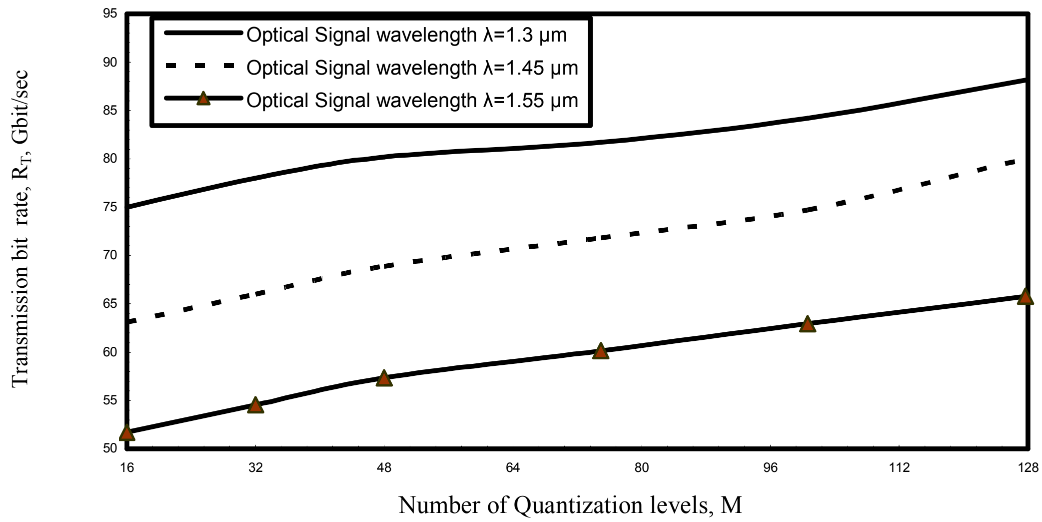

Fig. 7. Variations of transmission bit rate against number of quantization levels at the assumed set of parameters.

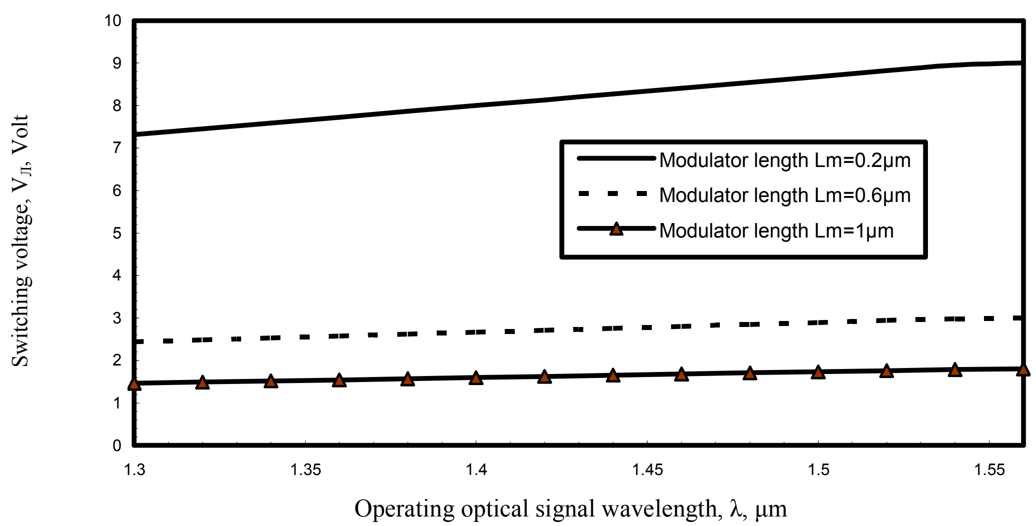

Fig. 8. Variations of switching voltage against optical signal wavelength at the assumed set of parameters.

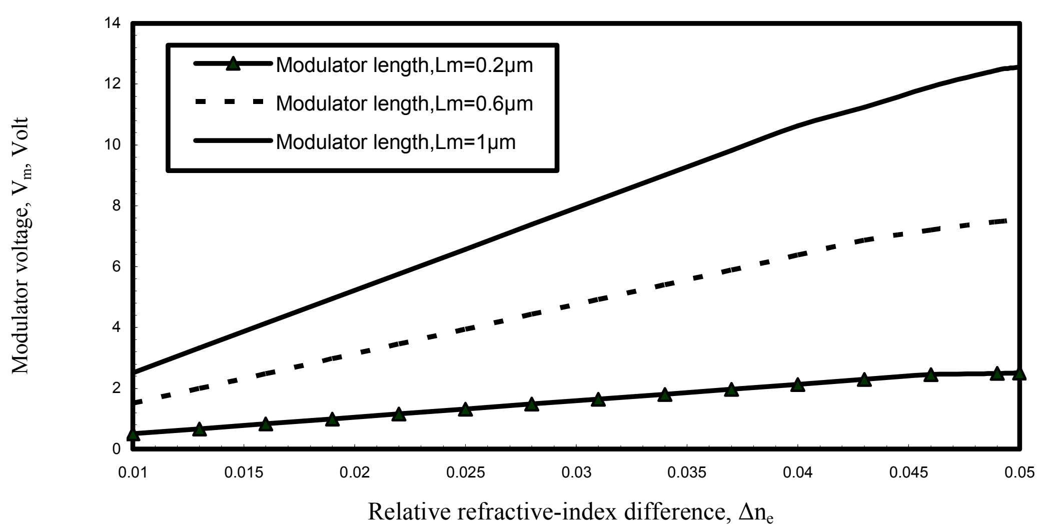

Fig. 9. Variations of modulator voltage against relative refractive index difference at the assumed set of parameters.

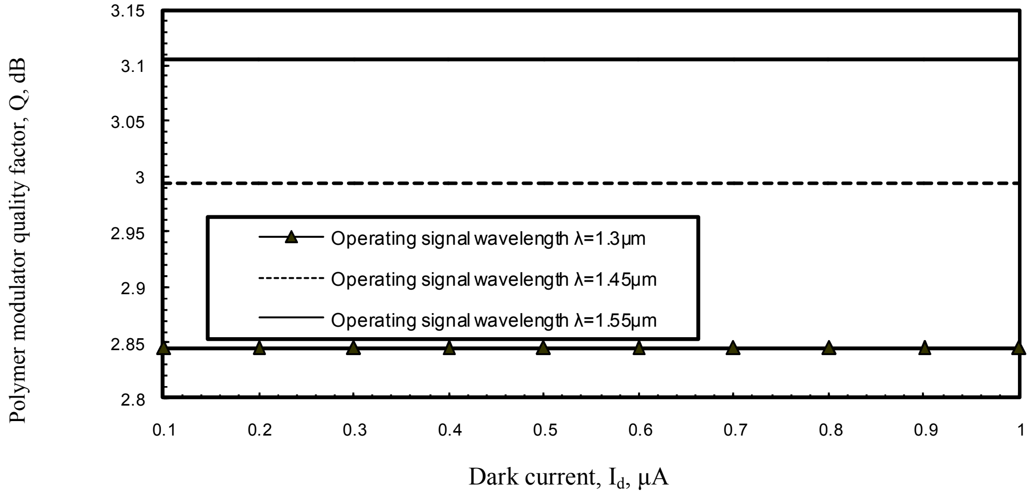

Fig. 10. Variations of polymer modulator quality factor versus dark current at the assumed set of parameters.

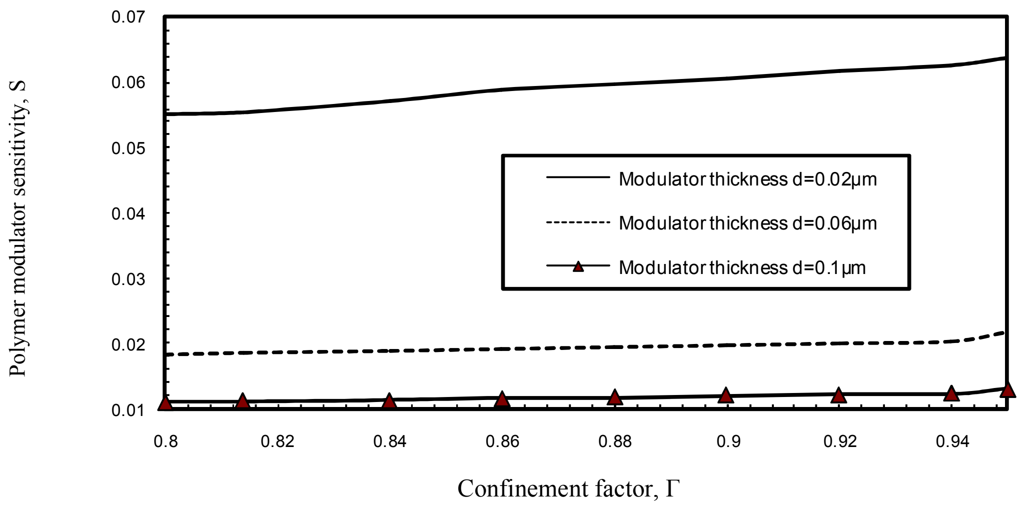

Fig. 11. Variations of polymer modulator sensitivity versus confinement factor at the assumed set of parameters.

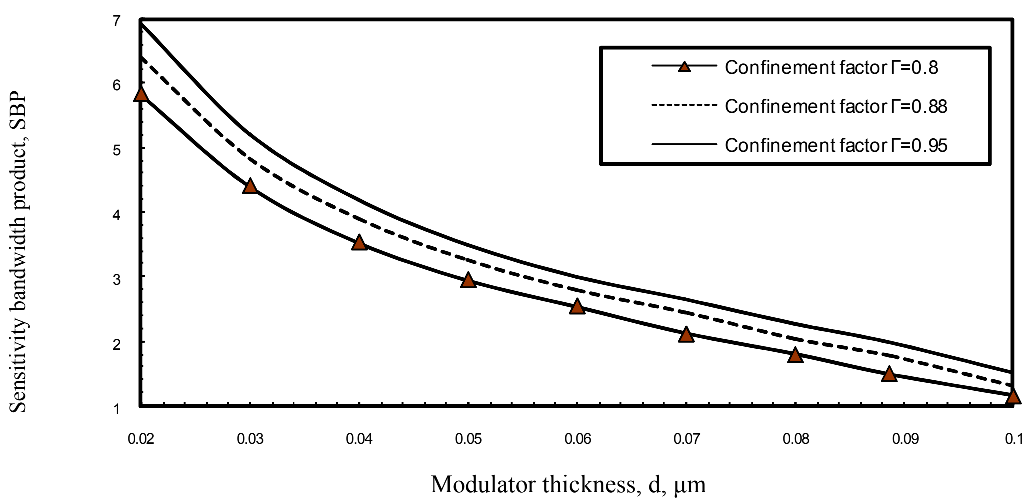

Fig. 12. Variations of sensitivity bandwidth product against modulator thickness at the assumed set of parameters.

viii) Fig. 12 has assured that as modulator thickness increases and confinement factor decreases, this leads to decrease in modulator sensitivity bandwidth product.

IV. CONCLUSIONS

In a summary, this paper has presented the high speed performance of electrooptic polymer modulator devices in advanced optical communication systems. The transmitted signal bandwidth, modulator signal quality factor, transmission bit rate, switching and modulating voltages, modulator sensitivity and sensitivity bandwidth product have been investigated over wide range of the affecting parameters as the good criteria of the high speed performance for fast operation. It is theoretically found that the increased operating optical signal wavelength, ambient temperature, modulator length, and relative refractive index difference, this results in the decreased of transmitted signal bandwidth, and transmission bit rates, and the increased switching and modulating voltages. It is also evident that the increased confinement factor and the decreased modulator thickness, this leads to the increased modulator sensitivity. As well as the increased modulator thickness and the decreased confinement, this results in the decreased modulator sensitivity bandwidth product.

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