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A Reduction of the Half-Wave Voltage for Lithium Niobate Electro-Optic Mach-Zehnder Modulator

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Abstracts: In this research, it proposes theoretically model to controlling on half-wave voltage of modulator, in which it uses studying the factor of effective of refractive index difference Δn_{eff}, this using analysis distribution of refractive index for LN material before and after voltage is applied (i.e., with and without applied voltage), and uses analysis a factor of propagation constant difference Δβ, before and after voltage is applied where it depends on the wavelength, these leads to it controls on the half-wave voltage Vπ using a reduction half-wave voltage up to 1V. Also, it achieves an excellent solution for solve the fundamental optical mode with effective factor is n_{eff}. Finally, the modulator with an effect effective refractive index difference Δn_{eff}have lower applied voltage up to 10V, and with an effective propagation constant difference the operating voltage is from value of 20V.

Keywords: Pockel- effect, Lithium niobate material LN, Push-pull drive, MZI modulator, Optical interferometer.

1. INTRODUCTION

For microwave, and optoelectronics devices, electro optic modulators are main components. amongst the different product platforms studied, including plasmonics [1], aln [2], polymers [3], si [4], graphene [5], and inp [6], the lithium niobate ln utilizes greatest in high level modulator technologies. practical applications have included front ends of particle radio waves for rf signal through fiber networks [7], quantum photonics networks [8], temporary imaging systems [9], eo frequency combs [10], and telecommunication systems [11-15]. nevertheless, each inp and si modulators depend on switching methods (i.e., quantum confinement stark impact and carrier injection) that are inherently nonlinear, absorbent, and prone to fluctuations in temperature, posing growing challenges for potential ultra-high-speed data transmission [16, 17]. other system drawbacks include high optical loss (plasmonics) [18], reduced long-term stability (polymer) [19], challenging graphene scalability [20], and poor switching efficiency (aln)[2]. there is an urgent need for electro-optic modulators which support the highest data rates on the smallest footprints while being power efficient [13, 21-24] to meet the fast growing bandwidth requirements of future communication networks [25-29]. such modern optoelectronic apps need suitable modulators with large bandwidth, low optical insertion loss, low drive voltage, excellent signal performance, high extinction ratio and compatible with large-scale production at the same time [13, 15, 30]. modern modulators designed for analog systems are mainly depend on lithium niobate ln [31, 32], indium phosphide [33], gallium arsenide [34] and today, silicon [17]. such devices have demonstrated good performance in terms of linearity and energy managing [35]; but, for broadband performance, commercial solutions need large millimeter or even need centimeter-sized moving wave structures and are restricted to speeds under 110 ghz [36]. optical modulators are essential components that serve as data encoding mechanisms from the field of electric to the field of optic [37]. the free-carrier dispersion effect [38-40] that relies on optical modulation in silicone. sadly, the unrestricted carrier wave dispersal is inherently non-linear or absorbent, which diminishes the optic transmission amplitude but when using advanced modulation formats, can cause signal distortions. great capabilities of an optical modulator in different product stages [22, 23, 41, 42] have been made enormous abilities the property of electrooptic modulation arising after linear effects is extremely good [14, 43], lithium niobate (ln) stays a favored material among them. ln modulators exhibit incomparable results for generating multilevel high-build rate enormous abilities the property of electrooptic modulation arising after linear effects is extremely good [14, 43], lithium niobate (LN) stays a favored material among them. LN modulators exhibit incomparable results for generating multilevel high-build rate transmissions thus is considered a solution for guides on extremely long haul [44]. Today's available commercially phase modulator of lithium niobate material is usually depend on substance LN quartzes wherever ion in diffusion or proton exchange technologies causes a weak optical index variation [45]. The variation of low indexes produces large half-wave voltage with small optical confinement; thus is achieved the voltage needed by shift the light phase through 180o, between arms. The Vπ of an ordinary commercial phase modulator operated at 1525-1605 nm, for instance, is 7.5 V at 30 GHz [15]. In commercially LN phase modulators the microwave electrodes must be positioned farther from the optical wave guide to reduce the loss of absorption leading to increased voltage of the drive. As a consequence, these electro-optic modulators with half-wave voltage length product is larger than 10Vcm, but considered as a large volume (i.e., bulk) with the effectiveness of modulation is lower [41]. Also, it uses hybrid Si/LN push-pull optical modulator, where the optical modulator consists of two waveguides, (i.e., silicone waveguide and LN membrane waveguide), in this modulator the phase shift is π/2, instead of π, thus a half-wave voltage requires to achieve phase shift π/2, this can accomplish by opposite polarity in each arm, as shown in figure (1). Thus, it is driven voltage which induces in arm one appositive phase change, but in another arm a negative phase change (i.e., opposite polarity), further, a length of devices is 3mm, and 5mm, with half-wave voltages Vπ are 7.4V, and 5.1V respectively, therefore a half-wave voltage Vπ is reduced using a large length of modulator, where Vπ is 1.4V, and 1V with length of device is 2cm [13]. In this paper, a push-pull modulator is achieved by proposed simulation of analytical model for design MZIM as shown in figure (2), with length of devices about 5mm into 50mm, the gap between electrodes is 10um, half-wave voltage is 1-2V, window of wavelength λ is 850,1330nm, with refractive index no is 2.2494, 2.2192 respectively, power absorption loss α is 0.085 dB/mm, effective refractive index neff is 2.205, and half-wave electric field Eπ is 5-15 V/mm. In this paper, the phase shift which result by half-wave voltage Vπ is from type π/2, and not π, where the polarity is opposite in both arms, thus it uses this technique to enhancement the controlling of switching for modulator by analysis an effective refractive index difference Δn_{eff} and propagation constant difference $\Delta\beta$ with and without applied voltage.

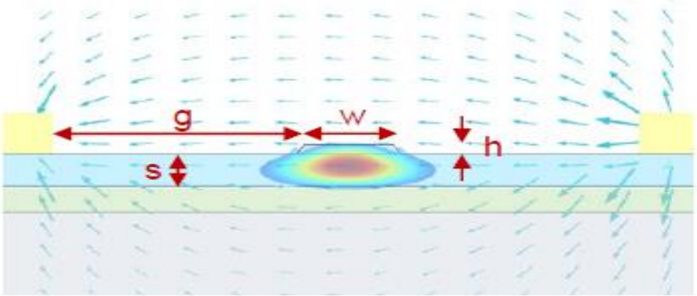

Figure 1. Cross section of push-pull optical modulator with phase shift is π/2, where the electric field drives between two electrodes

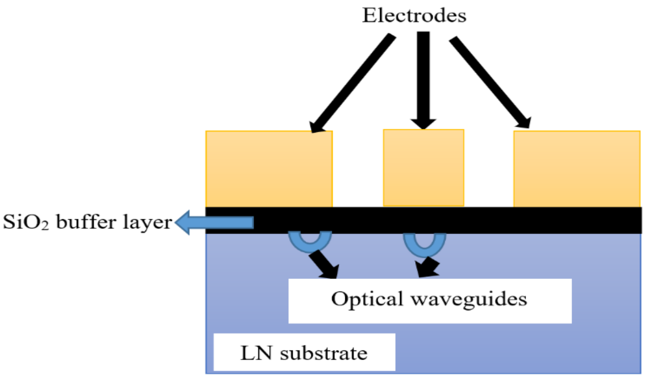

Figure 2. Z-Cut LN electro-optic modulator

2.RESEARCH METHOD

It is necessary to solve for the basic optical mode of the system under the influence of an applied electric field in order to calculate the half-wave voltage length product VπL. It can then determine the value of VπL new [41, 46].

$$V_\pi L = \frac{\lambda_o}{2\Delta n_{eff}} = \frac{\pi V_o}{\Delta\beta} \qquad (1)$$

Where V_o is applied voltage, L is length of optical modulator in mm, $\Delta\beta$ is propagation constant difference of the mode between propagation constant without and with applied voltage β_o and β_1 respectively, λ_o is free optical frequency, and Δn_{eff} is effective refractive index difference of the mode where it is between with and without the applied voltage $\Delta n \; and \; n_o$ respectively:

$$\Delta\beta = \beta_1 - \beta_o = \frac{\pi n^3 E_{dc} r_{33}}{\lambda} - \frac{2\pi n_{eff}}{\lambda} \qquad (2)$$

$$\Delta n_{eff} = n_o - \frac{1}{2} n_o^3 r E = n_o - \Delta n \qquad (3)$$

The methodology (1), generally shows the instance of the MZI modulator:

$$\frac{2I_{out} - I_o}{I_o} = 2\left(\frac{2\Delta n E_\pi L}{\lambda}\right)\left[\left(\frac{2\Delta n E_\pi L}{\lambda} - 1\right) + \left(1 - \frac{2\Delta n E_\pi L}{\lambda}\right) cos\, \Delta\emptyset\right] \qquad (4)$$

Here, E_π is half wave electric field in V/mm. Thus, simplified the equation

$$\frac{2I_{out} - I_o}{I_o} = 2\left(\frac{2\Delta n E_\pi L}{\lambda}\right)\left[\frac{2\Delta n E_\pi L - \lambda + (\lambda - 2\Delta n E_\pi L) cos\, \Delta\emptyset}{\lambda}\right]$$

$$\frac{2I_{out} - I_o}{I_o} = \frac{(8\Delta n^2 E_\pi^2 L^2 - 4\lambda\Delta n E_\pi L + (4\lambda\Delta n E_\pi L - 8\Delta n^2 E_\pi^2 L^2) cos\, \Delta\emptyset)}{\lambda^2}$$

$$2I_{out} - I_o = \frac{I_o(8\Delta n^2 E_\pi^2 L^2 - 4\lambda\Delta n E_\pi L + (4\lambda\Delta n E_\pi L - 8\Delta n^2 E_\pi^2 L^2) cos\, \Delta\emptyset)}{\lambda^2}$$

$$2I_{out} = \frac{I_o\left(8\Delta n^2 E_\pi^2 L^2 - 4\lambda \Delta n E_\pi L + (4\lambda \Delta n E_\pi L - 8\Delta n^2 E_\pi^2 L^2)\cos \Delta \emptyset\right)}{\lambda^2} + I_o$$

$$2I_{out} = I_o[\lambda^2 + 8\Delta n^2 E_\pi^2 L^2 - 4\lambda \Delta n E_\pi L$$
$$+(4\lambda \Delta n E_\pi L - 8\Delta n^2 E_\pi^2 L^2)\cos \Delta \emptyset](\lambda^2)^{-1} \qquad (5)$$

The expression "△ Ø", is the complex phase change with an attenuation α dB/mm, and n_{eff} is effective refractive index [47].

$$\triangle \emptyset = \frac{2\pi n_{eff} L}{\lambda} - i\frac{\alpha L}{2} \qquad (6)$$

$$2I_{out} = I_o[\lambda^2 + 8\Delta n^2 E_\pi^2 L^2 - 4\lambda \Delta n E_\pi L + (4\lambda \Delta n E_\pi L - 8\Delta n^2 E_\pi^2 L^2)\cos\left(\frac{2\pi n_{eff} L}{\lambda} - i\frac{\alpha L}{2}\right)](\lambda^2)^{-1} \qquad (7)$$

$$2I_{out} = \frac{I_o[\lambda^2 + \frac{2\Delta n^2 E_\pi^2 \lambda^2}{V_\pi^2 \Delta n_{eff}^2} - \frac{2\Delta n E_\pi \lambda^2}{V_\pi \Delta n_{eff}} + \left(\frac{2\Delta n E_\pi \lambda^2}{V_\pi \Delta n_{eff}} - \frac{2\Delta n^2 E_\pi^2 \lambda^2}{V_\pi^2 \Delta n_{eff}^2}\right)\cos\left(\frac{\pi n_{eff}}{V_\pi \Delta n_{eff}} - i\frac{\alpha\lambda}{4V_\pi \Delta n_{eff}}\right)]}{\lambda^2}$$

$$2I_{out} = \frac{I_o[\lambda^2 + \frac{8\Delta n^2 E_\pi^2 \pi^2 V_o^2}{V_\pi^2 \Delta\beta^2} - \frac{4\lambda \Delta n E_\pi \pi V_o}{V_\pi \Delta\beta} + \left(\frac{4\lambda \Delta n E_\pi \pi V_o}{V_\pi \Delta\beta} - \frac{8\Delta n^2 E_\pi^2 \pi^2 V_o^2}{V_\pi^2 \Delta\beta^2}\right)\cos\left(\frac{2\pi^2 V_o n_{eff}}{\lambda V_\pi \Delta\beta} - i\frac{\alpha\pi V_o}{2V_\pi \Delta\beta}\right)]}{\lambda^2}$$

The equation (8 and 9) are an expression of analytical model for LN modulator with take in account a calculate the effective refractive index difference Δn_{eff} and the propagation constant difference $\Delta\beta$. respectively with and without applied voltage.

$$I_{out} = I_o\Big[\lambda^2 V_\pi^2 \Delta n_{eff}^2 + 2\Delta n^2 E_\pi^2 \lambda^2 - 2\Delta n E_\pi V_\pi \Delta n_{eff} \lambda^2 + \left(2\Delta n E_\pi V_\pi \Delta n_{eff} \lambda^2 - 2\Delta n^2 E_\pi^2 \lambda^2\right)\cos\left(\frac{\pi n_{eff}}{V_\pi \Delta n_{eff}} - i\frac{\alpha\lambda}{4V_\pi \Delta n_{eff}}\right)\Big]\left(2\lambda^2 V_\pi^2 \Delta n_{eff}^2\right)^{-1} \qquad (8)$$

$$I_{out} = I_o\Big[\lambda^2 V_\pi^2 \Delta\beta^2 + 8\pi^2 \Delta n^2 E_\pi^2 V_o^2 - 4\pi\lambda\Delta n E_\pi V_o \Delta\beta V_\pi + (4\pi\lambda\Delta n E_\pi V_o \Delta\beta V_\pi - 8\pi^2 \Delta n^2 E_\pi^2 V_o^2)\, cos\left(\frac{2\pi^2 V_o n_{eff}}{\lambda V_\pi \Delta\beta} - i\frac{\alpha\pi V_o}{2V_\pi \Delta\beta}\right)\Big](2\lambda^2 V_\pi^2 \Delta\beta^2)^{-1} \qquad (9)$$

3. RESULTS AND ANALYSIS

In this paper, the change of refractive index induces when a drive of voltage and this manner represents a new distribution of refractive index within LN waveguide of the mode at specific wavelength thus, a fundamental optical mode analyses as shown in fig. (3). This case will make a better and uniform controlling in our hands the half-wave voltage Vπ will reduces by the phase change that will results. The switching phenomena for modulator will can control by select a certain distribution for refractive index of LN material, at result the half-wave voltage introduces the switching voltage for any optical device using the technique of electro-optic effect, therefore a distribution of refractive index through LN is constant when the voltage is not applied where a refractive index is not change and this considers a modulator in the case off-state (i.e., no modulation signal voltage) as shown in fig.(4). Also, in the same case, the propagation constant difference uses to producing an opposite polarity for electrodes using phase-change $\frac{\pi}{2}$ within each arm. In this case, the optical wavelength introduces effective parameter for increasing a propagation constant where it can control on the propagation constant by select a suitable wavelength and uses an appropriate half-wave voltage length product VπL with fundamental optical mode therefore, the fundamental optical mode analysis also and establishes a better performance for switching-phenomena of modulator by a controlling on half-wave voltage by a reduction half-wave voltage up to 1V, therefore, the propagation constant β_1 changes with applied voltage and causes opposite polarity within arms as shown in fig. (5), on the other hand, when no-applied voltage the propagation constant β_0 is not change (i.e., no modulation signal voltage), this considers off-state of modulator, as shown in fig.(6). It can notice the modulator that based on the difference of effective refractive index Δn_{eff} it shows an applied voltage reaches to 10V and this value considers sufficient because of the sinusoidal signal is damping over 10V with related to for applied voltage for the modulator and based on propagation constant difference Δβ, the applied voltage is continuous signal from value of 20V, as shown in figs. (7 and 8). Also, it finds two factors to solve mode profile of waveguide or fundamental optical mode, the first by factor of an effective refractive index difference Δn_{eff}, and the second factor is the propagation constant differenceΔβ, therefore in the second factor the effective refractive index n_{eff} considers an effective factor, because the n_{eff} have the special case with related to the wavelength since it measures the velocity of the wavelength for the particular wavelength through the propagation in the waveguide [42], thus this method considers excellent and possess specialty way to solve the fundamental optical mode.

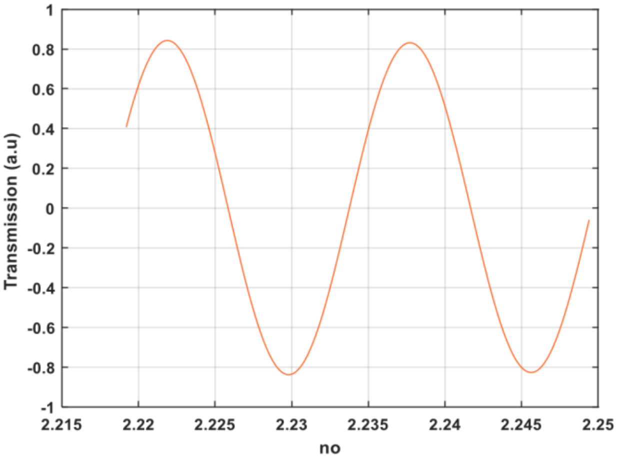

Figure 3. Refractive index (no), without applied voltage.

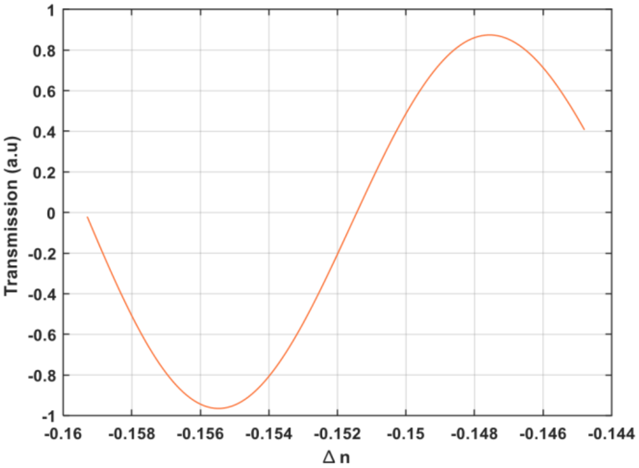

Figure 4. Refractive index change (Δn), with applied voltage.

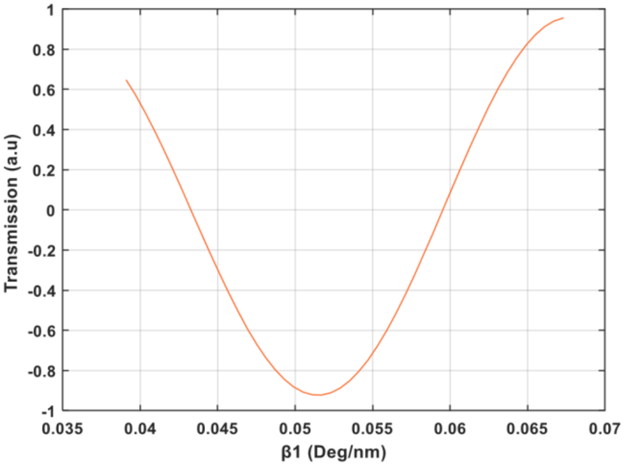

Figure 5. Propagation constant (β1), with applied voltage.

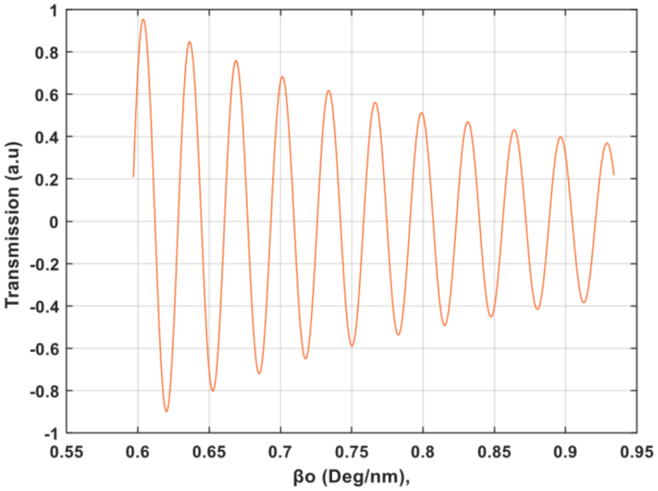

Figure 6. Propagation constant (βo), without applied voltage.

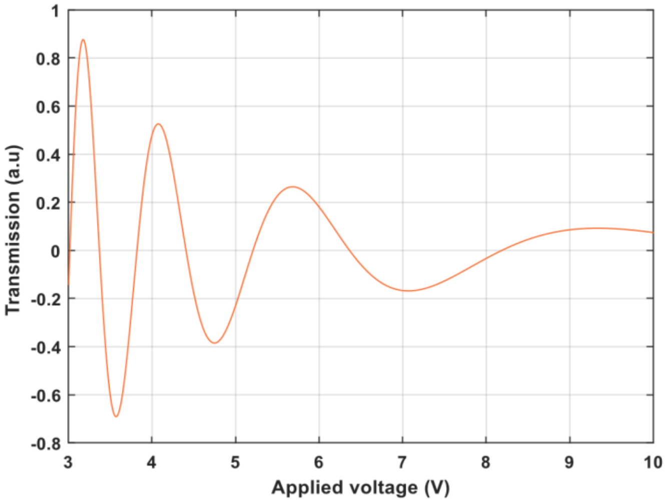

Figure 7. Applied voltage (V), using effective refractive index difference.

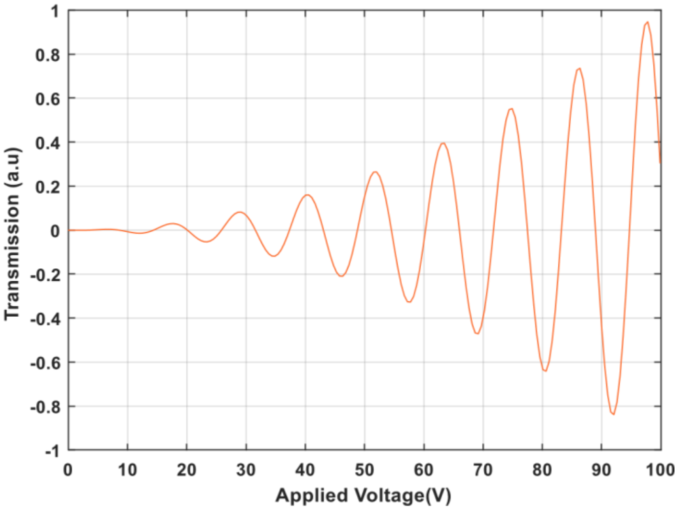

Figure 8. **Applied voltage (V) ,** using propagation constant difference.

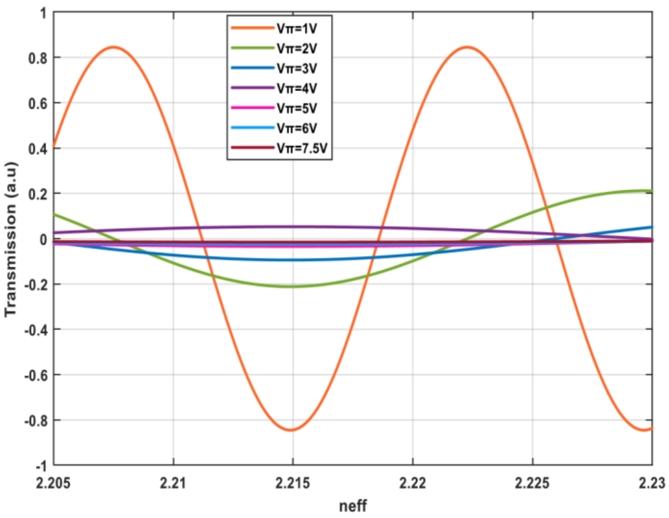

Figure 9. . Effective refractive index (neff), with effect parameter of propagation of constant difference

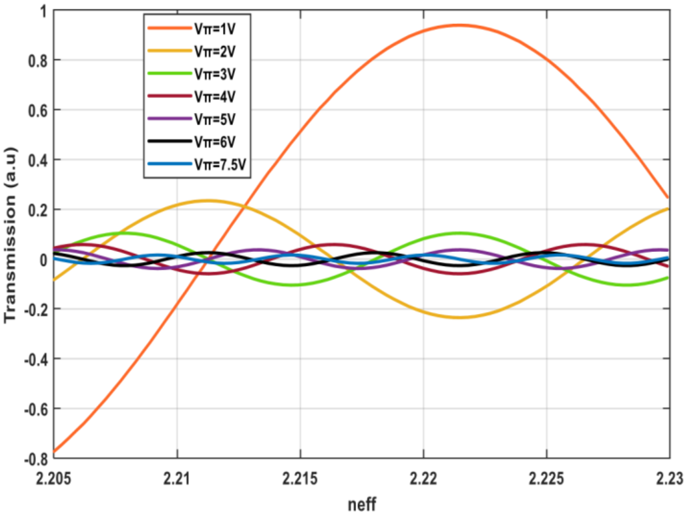

Figure 10. Effective refractive index (neff), with effect parameter of effective index difference

CONCLUSION

In this research, it achieves an analysis of the fundamental optical mode and a controlling of the switching phenomena or on/off state by proposed analytical model LN for the optical modulator to a reduction half-wave voltage Vπ, this model involves a two effective factors, the first is effective refractive index difference ∆neff, and the second is the propagation constant difference ∆β. Also, it accomplishes a better performance for modulator with a good controlling for switching on/off state using a reduction half-wave voltage up to 1V, on other hand by a propagation constant difference it achieves a good controlling switching with a better performance by analysis the optical mode for the modulator. Adding, it accomplishes a low driving voltage up to 10V for modulator by factor of the effective refractive index difference, and by factor of the propagation constant difference it achieves operating voltage that starts from 20V.

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