International Journal of Advanced Research in Electronics and Communication Engineering (IJARECE)
Volume 3, Issue 8, August 2014

Transmission Characteristics and Design Considerations of Different Acousto-Optic Modulators in Optical Transmission Communication Systems

Ahmed Nabih Zaki Rashed[1*], Hamdy A. Sharshar[2] and Heba Abd El-hamid[3]
[1,2,3]Electronics and Electrical Communications Engineering Department
Faculty of Electronic Engineering, Menouf 32951, Menoufia University, EGYPT

***Abstract*— This paper has presented the important transmission characteristics of AOM for high speed device and improved performance efficiency such as transmission efficiency, 3-dB bandwidth, modulation frequency, rise time, diffraction efficiency, switching time, transient time response, switching speed, power width product, total pulse broadening, transmission bit rates and modulation bandwidth with using maximum time division multiplexing (MTDM) and non return to zero (NRZ) coding under wide range of the affecting parameters.**

Index Terms— Transmission efficiency, modulation depth, switching time, rise time, and figure of merit.

I. INTRODUCTION

Acousto-optic components are typically used internal or external to laser equipment for the electronic control of the intensity (modulation) and or position (deflection) of the laser beam [1-3]. Interaction of acoustic waves and light occur in optical materials when the acoustic wave generates a refractive index wave, which acts as a sinusoidal grating in the optical material. An incident laser beam passing through this grating will be diffracted into several orders. With appropriate design of the modulator or deflector and proper adjustment of the incident angle between the laser light and the axis of acoustic propagation in the optical material (Bragg angle), the first order beam can be made to have the highest efficiency By virtue of having no moving parts our acousto-optic modulators (AOMs) are able to amplitude modulate a laser beam at very high speed. For example modulation bandwidths in excess of 50 MHz are readily achievable [4-6]. In an AOM a laser beam is caused to interact with a high frequency ultrasonic sound wave inside an optically polished block of crystal or glass (the interaction medium). By carefully orientating the laser with respect to the sound waves the beam can be made to reflect off the acoustic wavefronts (Bragg diffraction). Therefore, when the sound field is present the beam is deflected and when it is absent the beam passes through undeviated. By switching the sound field on and off very rapidly the deflected beam appears and disappears in response (digital modulation). By varying the amplitude of the acoustic waves the intensity of the deflected beam can similarly be modulated (analogue modulation). It is usual to choose the deflected beam as the one that is used in the optical system because it can be switched on and off with high extinction ratio (typically > 40dB) and intensity can be varied from zero to more that 85% of the incident beam. The rate at which the beam can be modulated is governed by the time it takes the acoustic wavefronts to traverse the laser beam [7], which depends on the beam diameter and the acoustic velocity in the interaction medium. The sound waves are generated by a transducer, usually a thin wafer of lithium niobate, that is bonded onto the interaction medium using a highly efficient cold-weld metallic bonding process. When a high frequency electrical signal is applied to the transducer it vibrates, generating the acoustic wave. The signal is derived from an RF driver, which generates a high frequency carrier that is itself modulated by an analogue or digital input signal.

Once the acousto-optic material is selected, it is optically polished [8]. The surfaces of the material that are to be the optical windows are optically antireflection coated to reduce optical reflections, which uses multi-layer dielectric broadband or antireflection coatings on the acousto-optic modulator optical windows. Typical losses are from a few percent for external cavity devices to 0.2 percent for intra-cavity devices. The side of the material that the acoustic energy is to originate from has a Lithium Niobate transducer metal vacuum bonded to the modulator medium. The transducer converts RF energy applied to it into acoustic energy. Metal bonding provides very good acoustic coupling and uses only high quality metal bonds. Then the transducer is lapped to the fundamental resonant frequency such as 80 MHz. The top surface of the transducer is then metalized with the transducer shape and size defined in this process. The modulator is then tuned to match the electrical impedance of the RF driver, which will supply the RF energy at the frequency of the transducer's resonant frequency [9].

II. SCHEMATIC VIEW OF ACOUSTO-OPTIC MODULATOR

Interaction of acoustic waves and light occur in optical materials when the acoustic wave generates a refractive index wave, which acts as a sinusoidal grating in the optical material. An incident laser beam passing through this grating will be diffracted into several orders. With appropriate design of the modulator or deflector and proper adjustment of the incident angle between the laser light and the axis of acoustic propagation in the optical material (Bragg angle), the first order beam can be made to have the highest efficiency [7]. With acousto optics, both deflection as well as modulation of the amplitude of the beam are A variety of different acousto optic materials are used depending on the laser parameters such as laser wavelength (optical transmission range), polarization, and power density [10]. As shown in Fig. 1, this device operates by Bragg diffraction of an incident light beam from a moving acoustic wavefront. The intensity of light diffracted into the output beam is dependent on the power of the acoustic beam which is in turn dependent on the modulation signal input to the driver. The modulation signal to optical output transfer function is monotonic but non linear. For proper modulator operation, the optical beam and sound beam must interact with the proper relationship. This requires that several conditions be met simultaneously. First, the acoustic beam (modulator housing) must be slightly rotated off perpendicular to the optical beam so that the Bragg angle condition is met as shown in Fig. 1. This can be accomplished either side of perpendicular with only a slight difference in performance as described later.

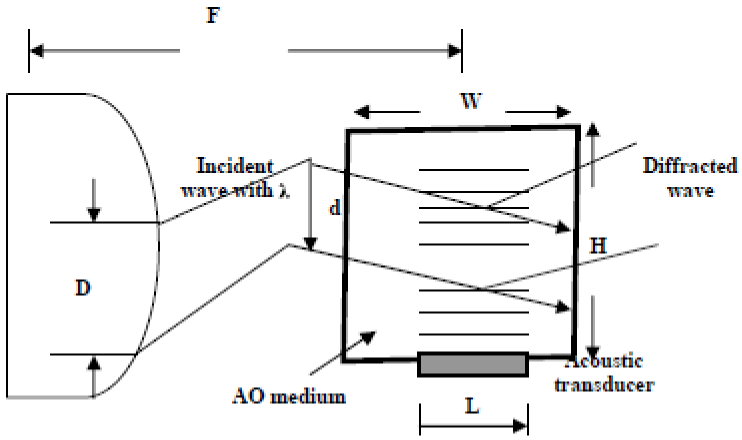


Fig. 1. Schematic view of acousto-optic modulator.

Once the acousto optic material is selected, it is optically polished. The surfaces of the material that are to be the optical windows are optically coated to reduce optical reflections. Typical losses are from a few percent for external cavity devices to 0.2 percent for intra cavity devices. The side of the material that the acoustic energy is to originate from has a Lithium Niobate transducer metal vacuum bonded to the modulator medium. The transducer converts RF energy applied to it into acoustic energy. Metal bonding provides very good acoustic coupling. Then the transducer is lapped to the fundamental resonant frequency such as 80 MHz. The top surface of the transducer is then metalized with the transducer shape and size defined in this process. The modulator is then tuned to match the electrical impedance of the RF driver, which will supply the RF energy at the frequency of the transducer's resonant frequency [8, 9]. The RF driver is typically a fixed frequency oscillator and usually consists of a crystal oscillator, an amplitude modulator with an interface, which accepts input modulation, digital and/or analog, and a RF amplifier, which supplies the acousto optic modulator with the level of radio frequency power needed to achieve the highest diffraction efficiency.

III. Model Analysis

When an acoustic wave is launched into the optical medium, it generates a refractive index wave that behaves like a sinusoidal grating. An incident laser beam passing through this granting will diffract the laser beam into several orders. With appropriate design, the first order beam has the highest efficiency [8-10]. Its angular position is linearly proportional to the acoustic frequency, so that the higher the frequency, the larger the diffracted angle.

$$\theta = \frac{\lambda f_a}{V_a} \quad , \qquad (1)$$

Where θ is the angle between the incident laser beam and the diffracted laser beam, with the acoustic wave direction propagating at the base of the triangle formed by the three vectors and unity, is the optical wavelength in f_a is the acoustic frequency, and V_a is the acoustic velocity. The intensity of light diffracted (deflected) is proportional to the acoustic power (P_a), the material figure of merit (M_2), geometric factors (W/H), W is the acousto optic modultor width, H is the acousto optic modultor height and inversely proportional to the square of the wavelength. This is seen in the following equation [11, 12]:

$$\eta = \frac{\pi}{\lambda}\sqrt{\frac{M_2 P_a W}{2H}} \quad , \qquad (2)$$

A large AO figure of merit is desired for device applications. There are several AO figures of merit that have been used for judging the usefulness of an AO material . The relevant one to be used depends on the specific applications which is given by the following formula:

$$M_2 = \frac{n^6 \, p^2}{\rho V_a^3} \qquad (3)$$

With acousto optics, both deflection as well as modulation of the amplitude of the beam are A variety of different acousto optic materials are used depending on the laser parameters such as laser wavelength (optical transmission range), polarization, and power density [13, 14]. If the beam waist location is determined in air before the modulator is introduced, then the lens should be moved away from the modulator location to account for the increased optical path length inside the modulator crystal. To obtain the proper optical beam waist diameter (d) stipulated in the device data sheets requires the following relationship [15, 16]:

$$d = \frac{1.27 F \lambda}{D} \quad , \qquad (4)$$

Where D is the input laser beam diameter, F is the focal length of input focusing lens, and λ is the light wavelength of laser diode. Under optimum conditions, the modulator rise time (τ_r) is given by:

$$\tau_r = \frac{0.66\, d}{V_a} \quad , \tag{5}$$

Where d is the optical beam waist diameter, and Va is the acoustic wave velocity. The signal content is essentially the fundamental of the square wave drive which is down to 50% modulation (3 dB) at:

$$f_{3-dB} = \frac{1}{2\,\tau_r} \quad , \tag{6}$$

If a particular application permits operation at less than 100% signal modulation, a relationship from [16], the modulation frequency can be utilized:

$$f_m = \frac{0.29\,\sqrt{\alpha}}{\tau_r} \quad , \tag{7}$$

Where f_m is the Signal modulation frequency, and α is the attenuation in dB/mm, which that modulation will suffer. For different selected acousto optic materials based AOMs, the investigation of both the thermal and spectral variations of the effective refractive index require empirical equation. The set of parameters required to completely characterize the temperature dependence of the refractive index is given below, Sellmeier equation is under the form [17, 18]:

$$n = \sqrt{\frac{A_1\lambda^2}{\lambda^2 - A_2^2} + \frac{A_3\lambda^2}{\lambda^2 - A_4^2} + \frac{A_5\lambda^2}{\lambda^2 - A_6^2}} \quad , \tag{8}$$

Where the Sellemeier coefficients and acousto-optic parameters for TiO_2, $PbMoO_4$, BGO, TeO_2, and GaP, are listed in the following Table 1.

Table 1: Sellemeier coefficients for acousto-optic materials based AOMs [3, 5, 9, 12].

Coefficients	Acousto-optic materials based AOMs				
	Titanium dioxide (TiO_2)	Lead Molybdate ($PbMoO_4$)	Bismuth Germanate (BGO)	Tellurium dioxide (TeO_2)	Gallium Phosphide (GaP)
A_1	7.654	0.0143	6.654	3.765	9.76
A_2	0.345 (T/T_0)	1.231 $(T/T_0)^2$	0.0345 $(T/T_0)^2$	0.4245 (T/T_0)	1.876 (T/T_0)
A_3	43.54	3.654	23.546	56.23	0.765
A_4	0.0376 (T/T_0)	0.00543 $(T/T_0)^2$	0.0032 $(T/T_0)^2$	0.0213 (T/T_0)	0.0543 (T/T_0)
A_5	0.0	0.5376	0.08453	0.0	0.0
A_6	0.0	213.54 $(T/T_0)^2$	316.65 $(T/T_0)^2$	0.0	0.0

Where T is the ambient temperature, and T_0 is the room temperature respectively. The signal quality factor Q determines the interaction regime between the acoustic signal and optical signal, which Q is given by [19]:

$$Q = \frac{2\pi\,\lambda\,L}{n\,V_a} \tag{9}$$

Where L is the distance the laser beam travels through the acoustic wave (acoustic beam length) as shown in Fig. 1, and n is the refractive index of the materials based AOMs. The Q value can be expressed in dB units as the following formula:

$$Q_{dB} = 10 \log Q \tag{10}$$

The bit error rate (BER) can be estimated that gives the upper limit for the signal transmission because some degradation occurs at the AOM system [20].

$$BER = \frac{\exp\left(-0.5\,Q^2\right)}{Q\sqrt{2\pi}} \tag{11}$$

For AOMs the principal performance parameter is the modulation speed which is primarily determined by the transit time, T_t. The transit time, T_t, and the pulse broadening due to rise time are given by [21, 22]:

$$T_t = \frac{d}{V_a} \quad , \tag{12}$$

$$\Delta\tau = \frac{\tau_r}{0.85} \quad , \tag{13}$$

To obtain a high modulation speed, T_t, should be as small as possible. In practice, the illuminating optical wave front is usually brought to a focus within the interaction region of the AOM. Therefore the switching speed (SS) can be given by [23, 24]:

$$SS = \frac{1}{T_t} \tag{14}$$

The relation between power width product, PWP, and switching speed, SS, for acousto-optic modulators can be estimated numerically based on MATLAB curve fitting program [25]:

$$PWP = 2.54SS - 1.65SS^2 + 1.0654SS^3 \tag{15}$$

To obtain a high modulation speed, the transit time should be as small as possible. In practice, the illuminating optical wavefront is usually brought to a focus within the interaction region of the AOM. Therefore the transmission bit rate based on non return to zero (NRZ) code is given by [23]:

$$B_{R(NRZ)} = \frac{0.7}{\Delta\tau} \tag{16}$$

The material dispersion based AOM, $D_{mat.}$ which is given by the following equation [15-17]:

$$D_{mat} = -\left(\frac{L\,\Delta\lambda\,\lambda}{c}\right)\cdot\left(\frac{d^2n}{d\lambda^2}\right) \quad , \tag{17}$$

Where Δλ is the spectral linewidth of the optical source in nm, and c is the speed of light ($3x10^8$ m/sec) and L is the interaction length between acoustic and optical signals. The effective index of the mode obtained from the optical simulation is used to calculate the transmittance of an optical signal through the modulator or modulation efficiency η_m using the following equations:

$$\eta_m = \exp(-\alpha\,L) \tag{18}$$

The modal dispersion delay, D_{modal} for a multi mode step-index modulator with interaction length L is given by:

$$D_{modal} = L\,\Delta n\,/c \quad , \qquad (19)$$

Where Δn is relative refractive index difference which is given by the following formula [18, 19]:

$$\Delta n = \sqrt{0.5\,M_2\,\frac{P_a}{H\,W}} \qquad (20)$$

The total dispersion coefficient, $D_t=D_{mat.}+D_{modal.}$ In addition to providing sufficient power to the receiver, the system must also satisfy the bandwidth requirements imposed by the rate at which data are transmitted. Then the total pulse broadening, and maximum transmission bit rate using Maximum time division multiplexing can be expressed as the following formulas [21, 24, 25]:

$$\tau = D_t\,\Delta\lambda\,L \quad , \qquad (21)$$

$$B_{R(MTDM)} = \frac{0.25}{\tau} \quad , \qquad (22)$$

IV. Performance Analysis

The model has been investigated the acousto optic modulator devices for high speed transmission performance, wide modulation bandwidth and ultra high speed transient time response over wide range of the affecting parameters as listed in Table 2. transmission bit rates can be estimated based on maximum time division multiplexing techniques.

Table 2. List of the parameters used in the simulation [1, 5, 8, 12, 17].

Operating parameter		Value and unit
Ambient temperature, T		300 K ≤ T ≤ 340 K
Room temperature, T_0		300 K
Acoustic frequency, f_a		10 MHz
Operating signal laser wavelength, λ		0.85 μm ≤ λ ≤ 1.55 μm
Focal length, F		3 mm
Acoustic power, P_a		0.5 Watt ≤ P_a ≤ 5 Watt
Laser beam diameter, D		0.1mm-0.6 mm
Spectral line width of laser diode, Δλ		Δλ=0.1 nm
Modulator height, H		5 mm
Modulator width, W		5 mm
Interaction length, L		0.05 mm ≤ L ≤ 0.1 mm
TiO_2 based AOM device	Material density, ρ	4.23 g/cm^3
	Acoustic velocity, υ_a	7.93 mm/μsec
	Attenuation, α	1 dB/mm
	Photoelastic coefficient, p	0.05
$PbMoO_4$ based AOM device	Acoustic velocity, υ_a	3.63 mm/μsec
	Attenuation, α	5.5 dB/mm
	Photoelastic coefficient, p	0.28
	Material density, ρ	6.95 g/cm^3
BGO based AOM device	Acoustic velocity, υ_a	3.42 mm/μsec
	Attenuation, α	1.6 dB/mm
	Photoelastic coefficient, p	0.25
	Material density, ρ	9.22 g/cm^3
TeO_2 based AOM device	Acoustic velocity, υ_a	4.2 mm/μsec
	Attenuation, α	6.3 dB/mm
	Photoelastic coefficient, p	0.09
	Material density, ρ	6 g/cm^3
GaP based AOM device	Acoustic velocity, υ_a	4.13 mm/μsec
	Attenuation, α	2 dB/mm
	Photoelastic coefficient, p	0.082
	Material density, ρ	4.13 g/cm^3

Based on the clarified figures from Figs. (2-28), and based on the basic mathematical relations model with the assistant of operating parameters, the following facts are assured:

i) Figs. (2-5) have assured that diffraction angle and figure of merit increase with increasing operating optical signal wavelength for different acousto-optic modulators under the same operating conditions considerations. It is indicated that GaP AOM has presented the highest diffraction angle in comparison with other AOMs. Figure of merit of AOMs degraded with increasing ambient temperature. As well as it is observed that $PbMoO_4$ AOM has presented the highest figure of merit in comparison with other AOMs under study considerations.

ii) Figs. (6-8) have indicated that diffraction efficiency increases with increasing acoustic signal power and decreasing with increasing ambient temperatures for different AOMs under study. It is observed that $PbMoO_4$ AOM has presented the highest diffraction efficiency in comparison with other AOMs under study considerations.

iii) Fig. (9, 10) have indicated that modulator rise time decreases and 3-dB frequency bandwidth increases with increasing laser beam diameter for different AOMs under study considerations. It is observed that TiO_2 AOM has presented the lowest rise time that means to be considered the highest transmission bit rate and modulation speed in comparison with other different AOMs.

iv) Fig. 11 has proved that modulation frequency increases with increasing laser beam diameter for different AOMs under study considerations. It is observed that TeO_2 AOM has presented the highest modulation frequency in comparison with other different AOMs.

v) Figs. (12-17) have indicated that signal quality increases and bit error rate decreases with increasing both interaction length between acoustic signal and optical signal and operating optical signal wavelength for different AOMs under study considerations. It is theoretically that $PbMoO_4$ AOM has presented the highest signal quality and the lowest bit error rate in comparison with other different AOMs.

vi) Figs. (18, 19) have demonstrated that switching transient time increases and switching speed decreases with increasing operating optical signal wavelength for different AOMs under study considerations. It is observed that TiO_2 AOM has presented the lowest switching transient time that means to be considered the highest switching speed in comparison with other different AOMs.

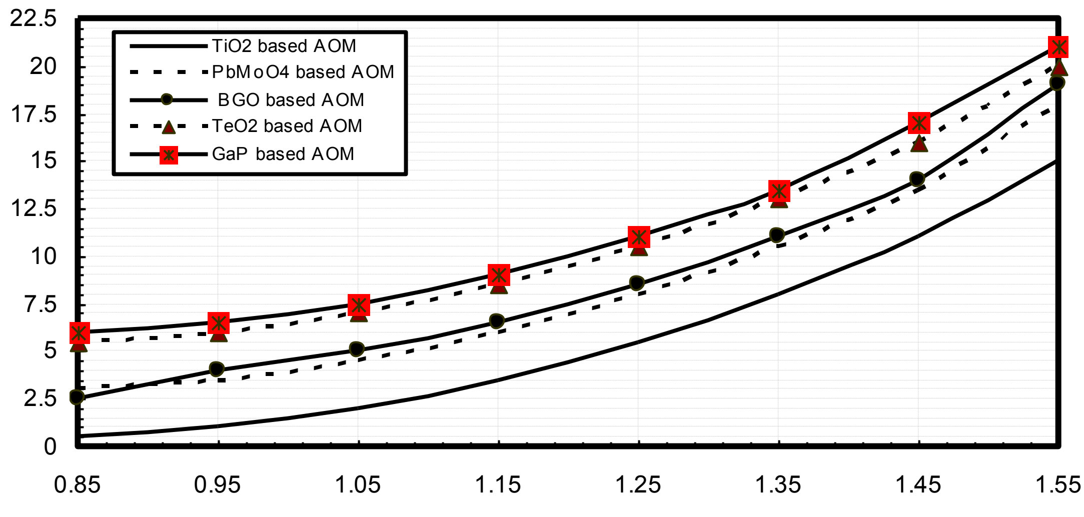


Fig. 2. Diffraction angle in relation to operating optical signal wavelength for different acousto-optic modulators at the assumed set of the operating parameters.

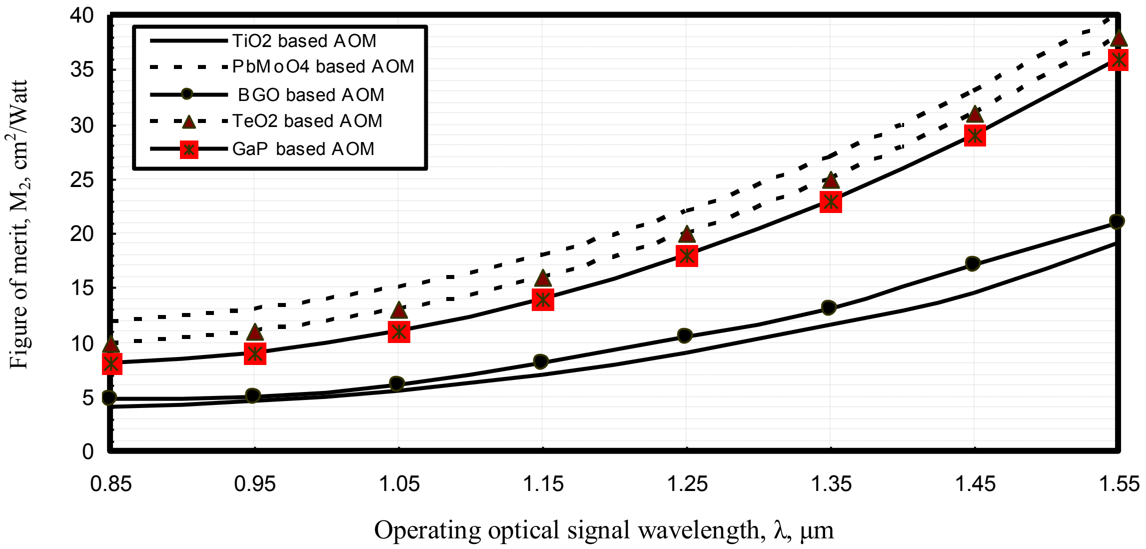


Fig. 3. Figure of merit in relation to operating optical signal wavelength and room temperature (T_0=300 K) for different acousto-optic modulators at the assumed set of the operating parameters.

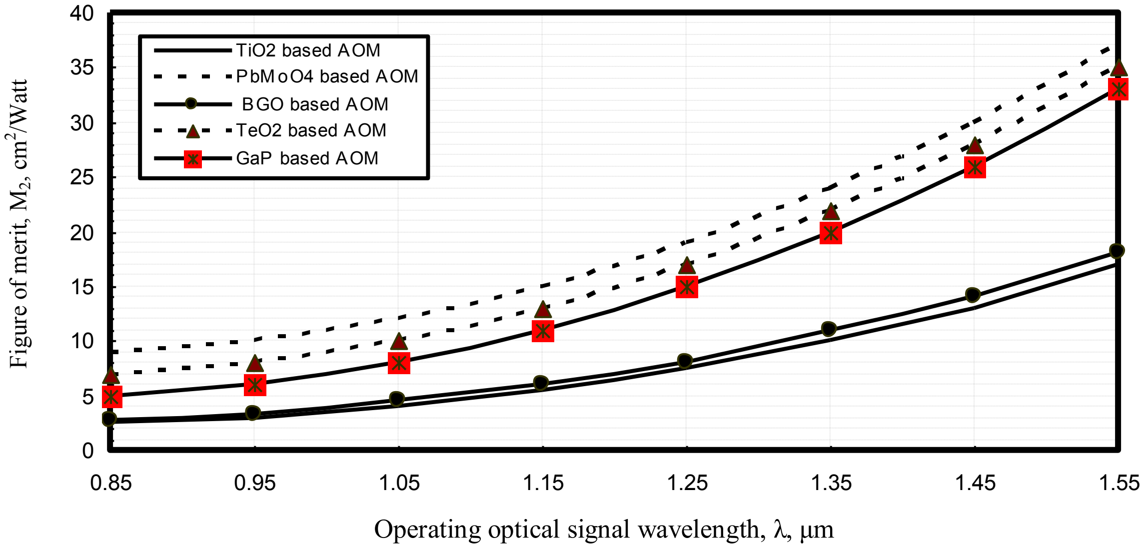


Fig. 4. Figure of merit in relation to operating optical signal wavelength and ambient temperature (T=320 K) for different acousto-optic modulators at the assumed set of the operating parameters.

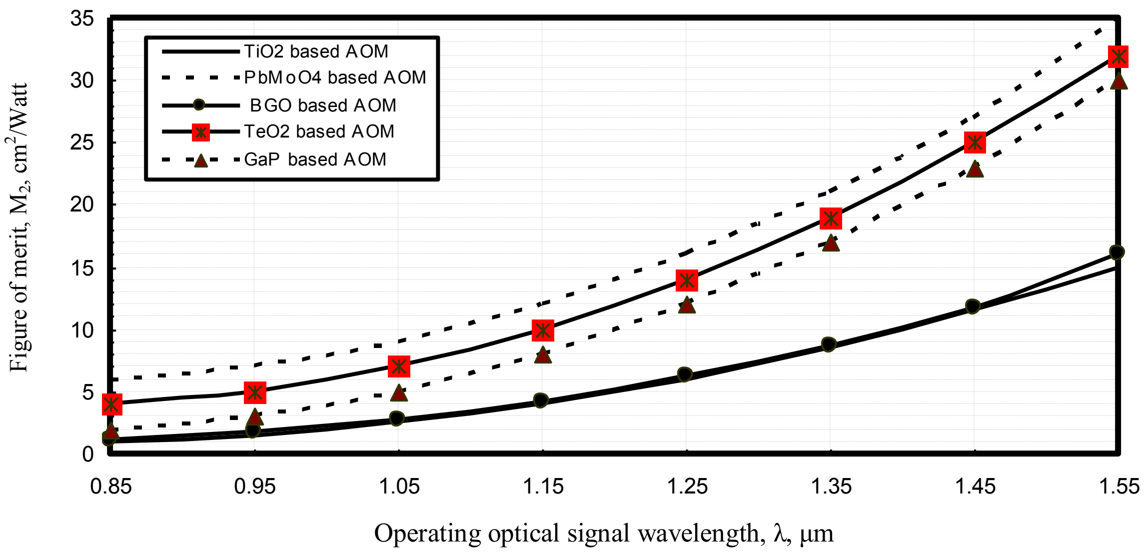


Fig. 5. Figure of merit in relation to operating optical signal wavelength and ambient temperature (T=340 K) for different acousto-optic modulators at the assumed set of the operating parameters.

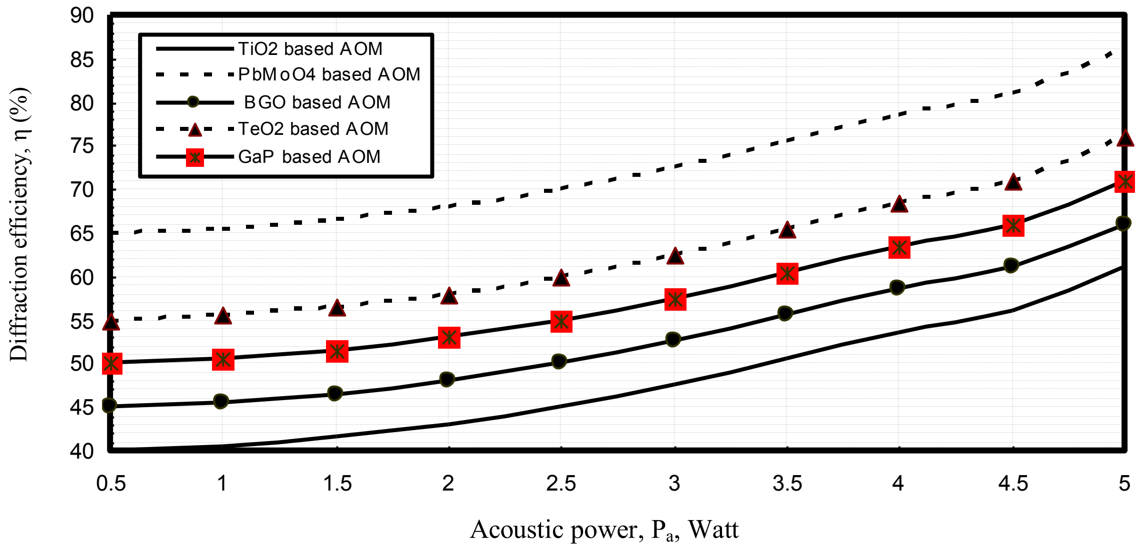


Fig. 6. Diffraction efficiency in relation to acoustic power and room temperature (T_0=300 K) with third optical transmission window (λ=1.55 μm) for different acousto-optic modulators at the assumed set of the operating parameters.

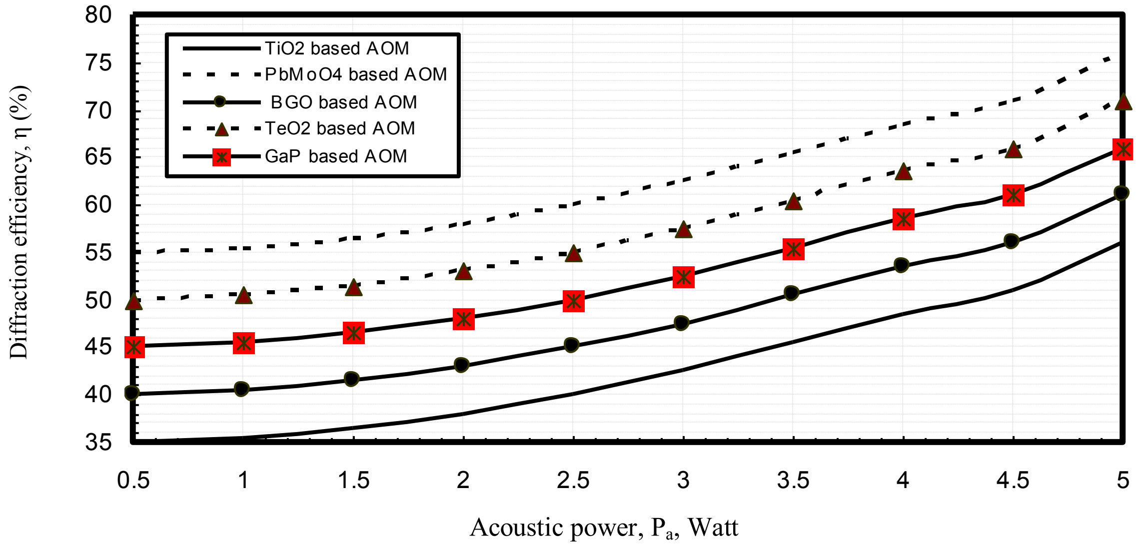


Fig. 7. Diffraction efficiency in relation to acoustic power and ambient temperature (T=320 K) with third optical transmission window (λ=1.55 μm) for different acousto-optic modulators at the assumed set of the operating parameters.

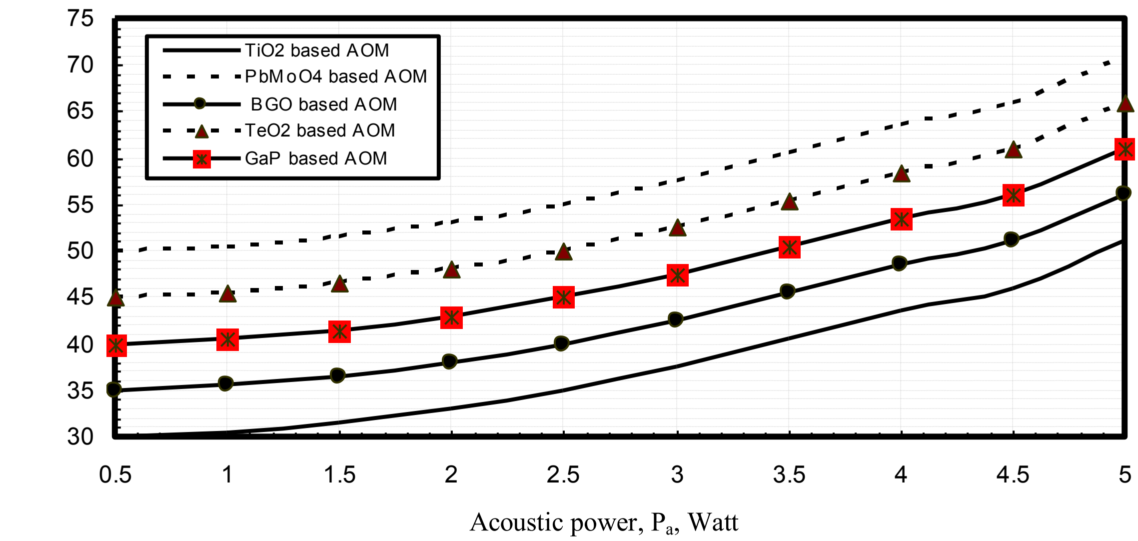


Fig. 8. Diffraction efficiency in relation to acoustic power and ambient temperature (T=340 K) with third optical transmission window (λ=1.55 μm) for different acousto-optic modulators at the assumed set of the operating parameters.

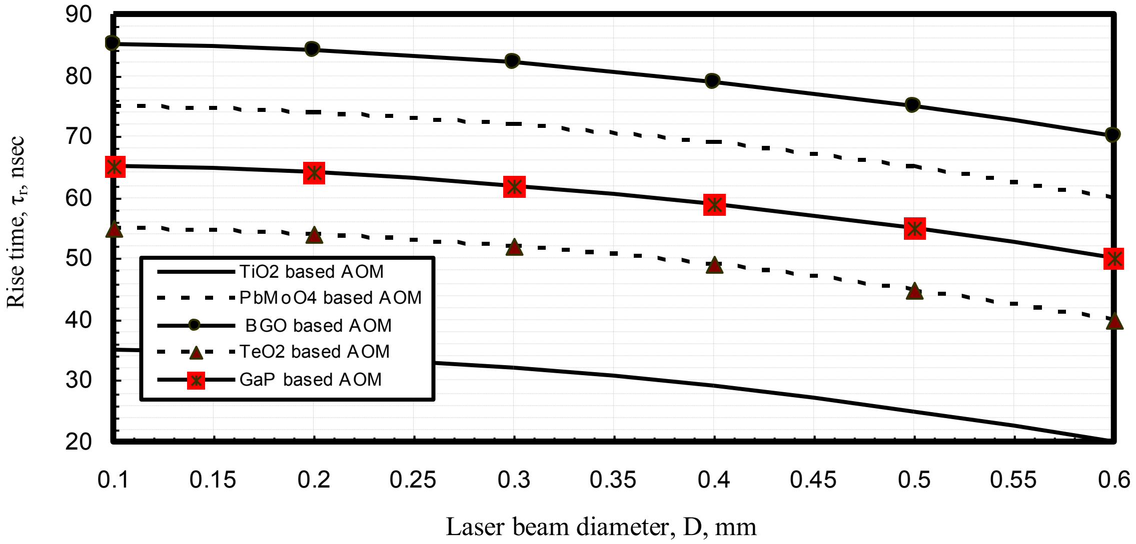


Fig. 9. modulator rise time in relation to laser beam diameter for different acousto-optic modulators at the assumed set of the operating parameters.

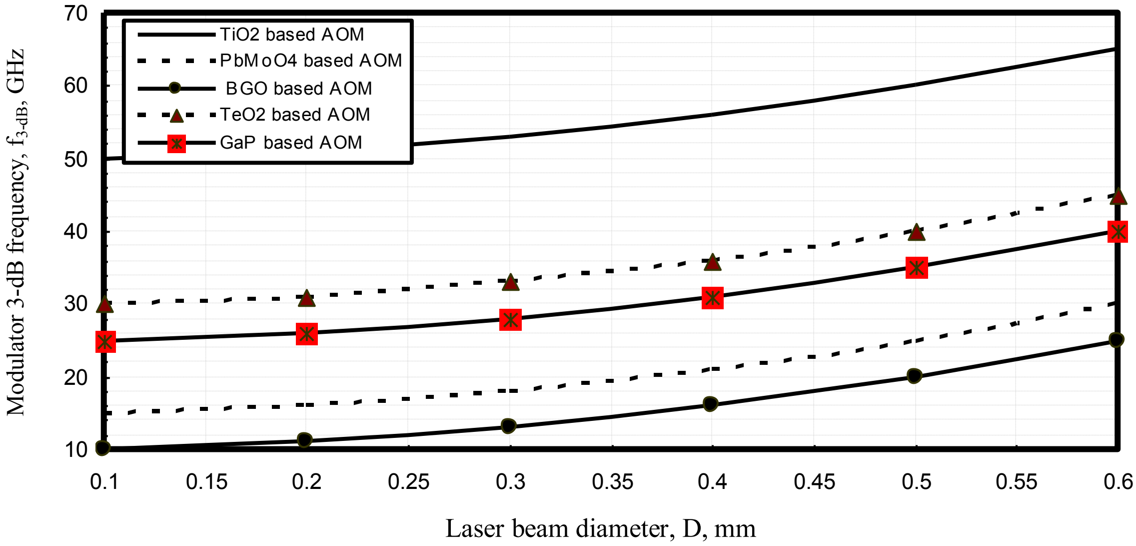
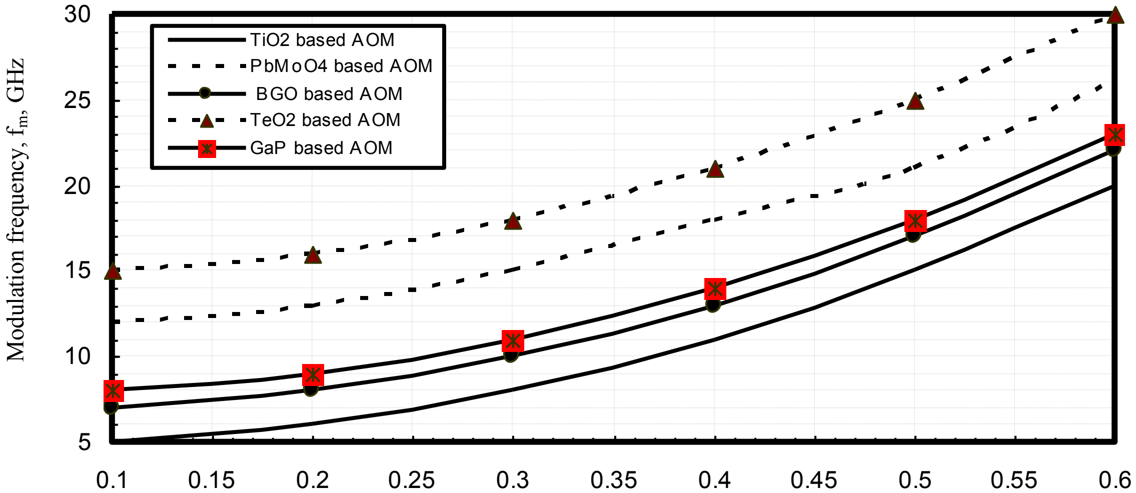
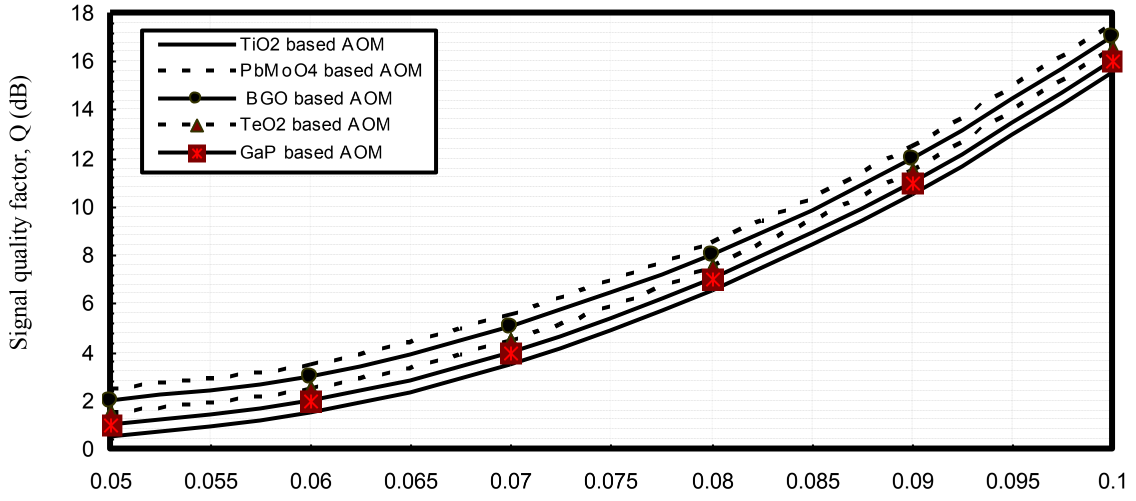


Fig. 10. Modulator 3-dB frequency in relation to laser beam diameter for different acousto-optic modulators at the assumed set of the operating parameters.



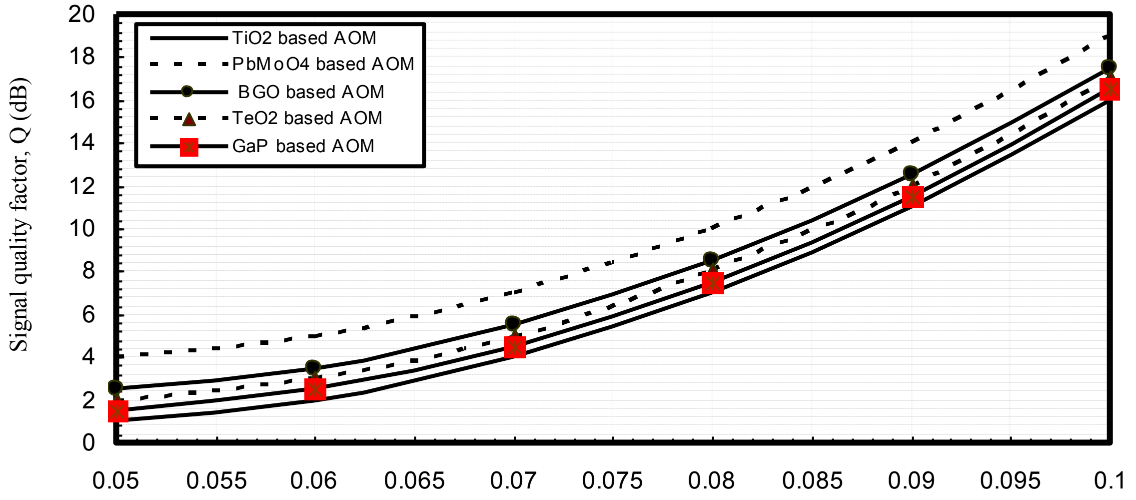
Laser beam diameter, D, mm

Fig. 11. Required modulation frequency in relation to laser beam diameter for different acousto-optic modulators at the assumed set of the operating parameters.



Interaction length, L, mm

Fig. 12. Signal quality factor in relation to interaction length with first optical transmission window (λ=0.85 μm) for different acousto-optic modulators at the assumed set of the operating parameters.



Interaction length, L, mm

Fig. 13. Signal quality factor in relation to interaction length with second optical transmission window (λ=1.30 μm) for different acousto-optic modulators at the assumed set of the operating parameters.

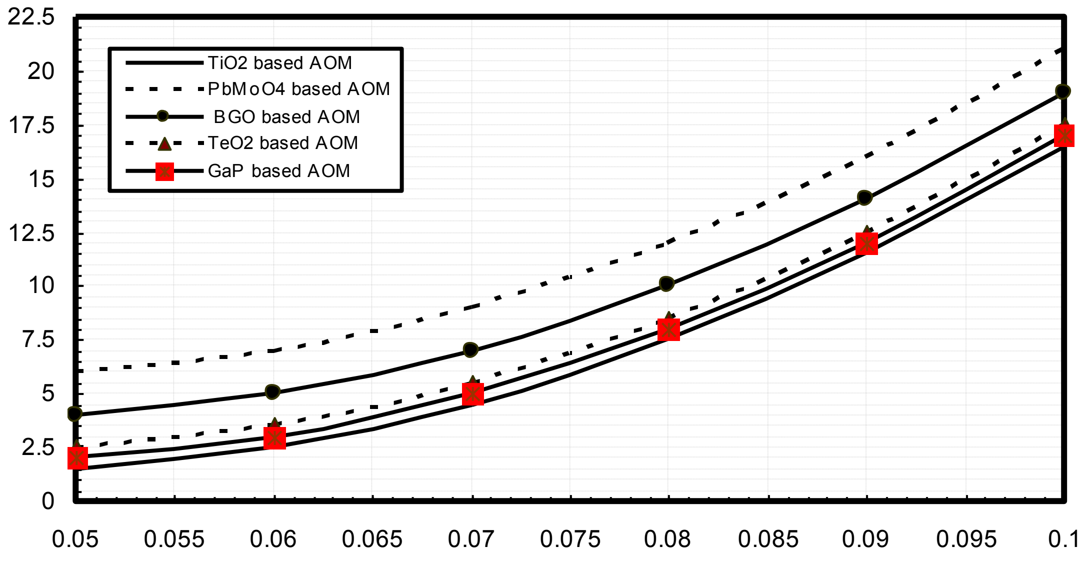


Fig. 14. Signal quality factor in relation to interaction length with third optical transmission window (λ=1.55 μm) for different acousto-optic modulators at the assumed set of the operating parameters.

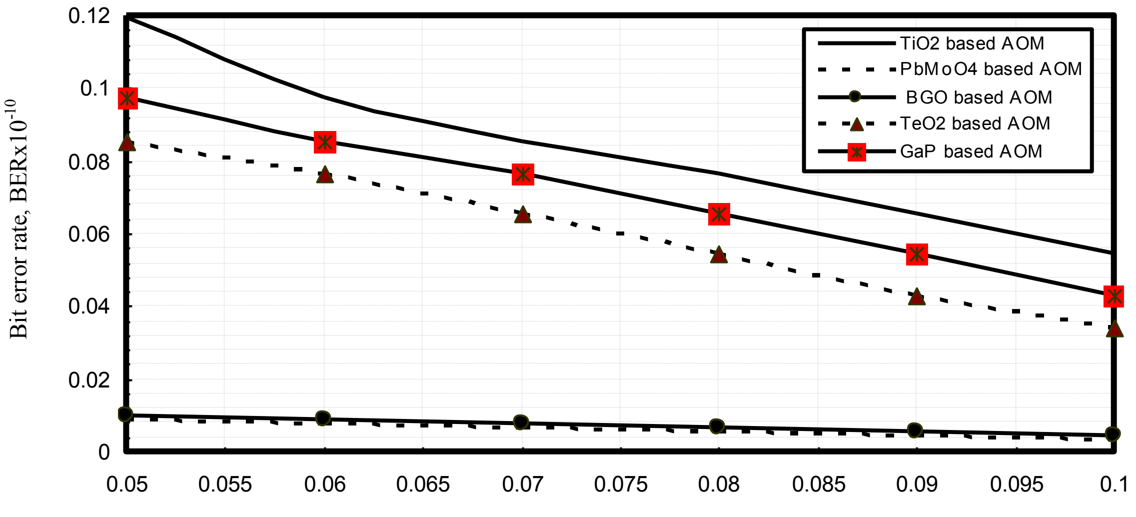


Fig. 15. Bit error rate in relation to interaction length with first optical transmission window (λ=0.85 μm) for different acousto-optic modulators at the assumed set of the operating parameters.

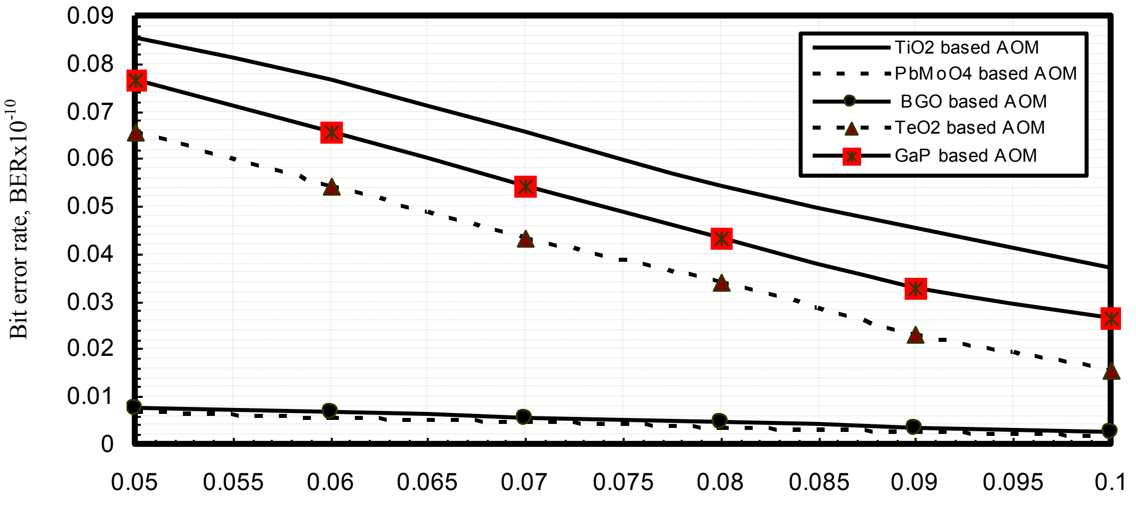


Fig. 16. Bit error rate in relation to interaction length with second optical transmission window (λ=1.30 μm) for different acousto-optic modulators at the assumed set of the operating parameters.

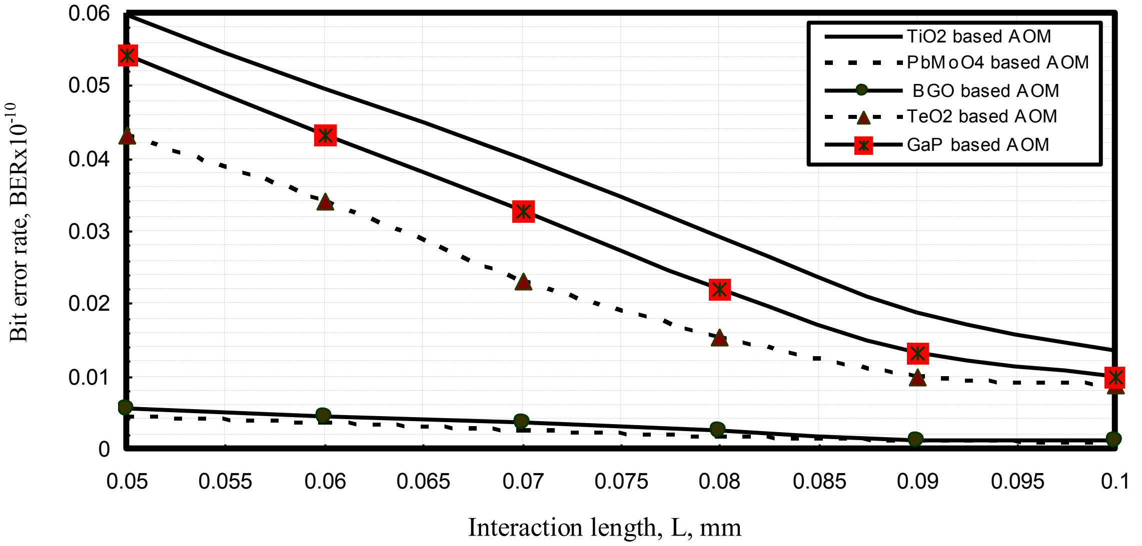


Fig. 17. Bit error rate in relation to interaction length with third optical transmission window (λ=1.55 μm) for different acousto-optic modulators at the assumed set of the operating parameters.

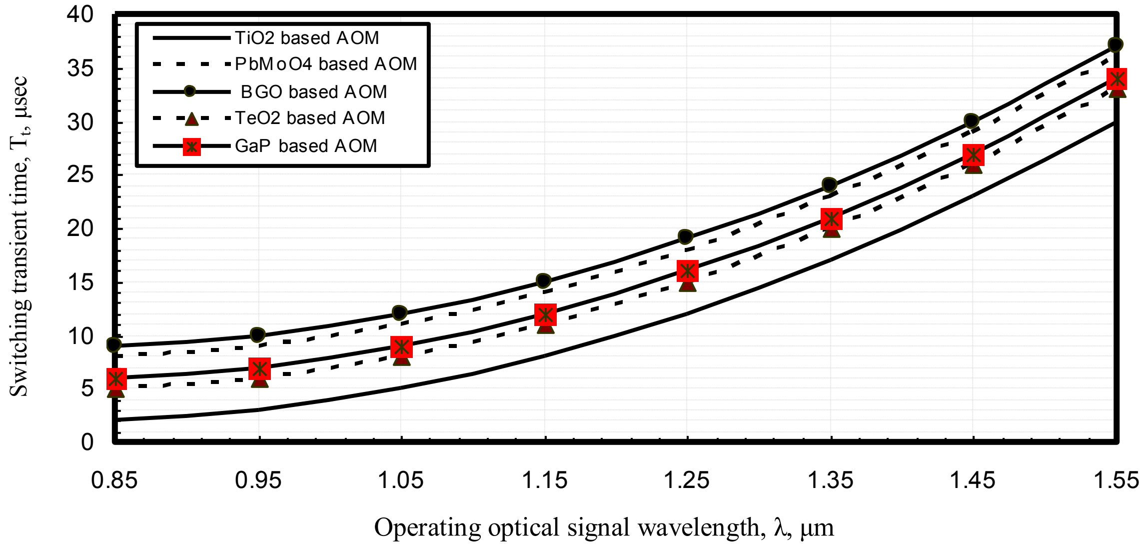


Fig. 18. Switching transient time in relation to operating optical signal for different acousto-optic modulators at the assumed set of the operating parameters.

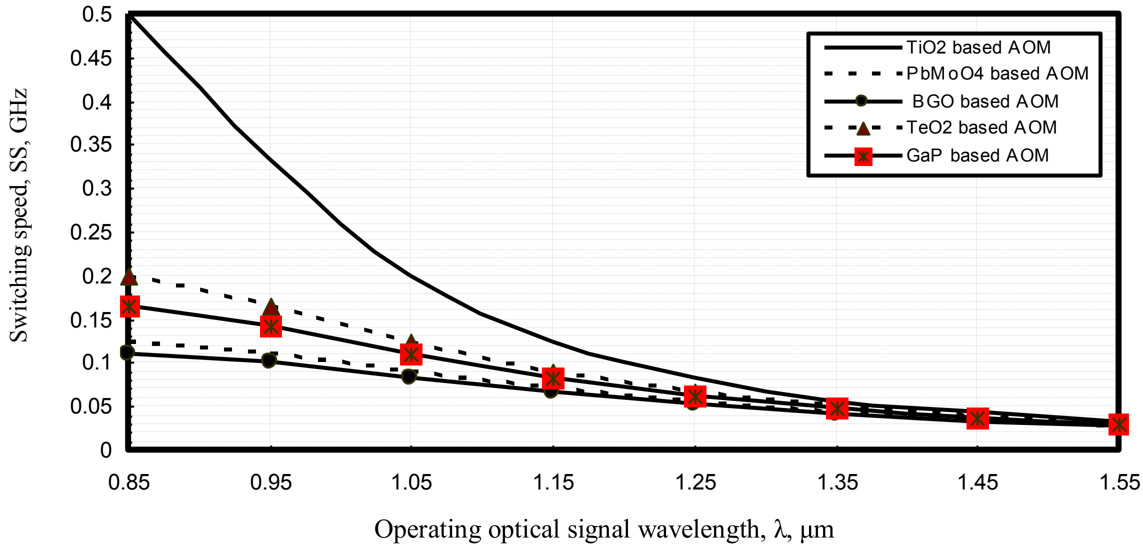


Fig. 19. Switching speed in relation to operating optical signal for different acousto-optic modulators at the assumed set of the operating parameters.

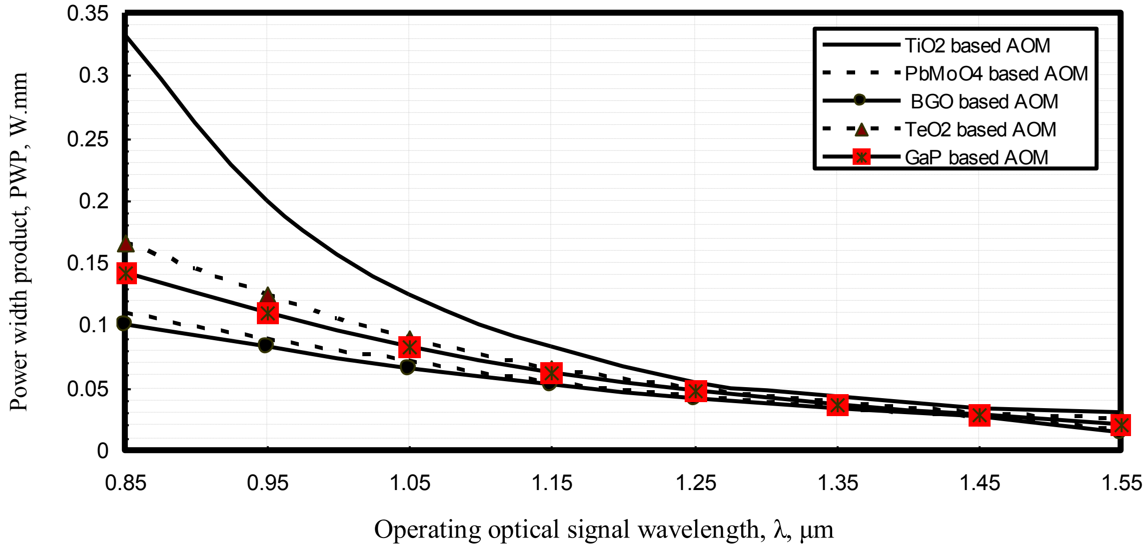


Fig. 20. Power width product in relation to operating optical signal for different acousto-optic modulators at the assumed set of the operating parameters.

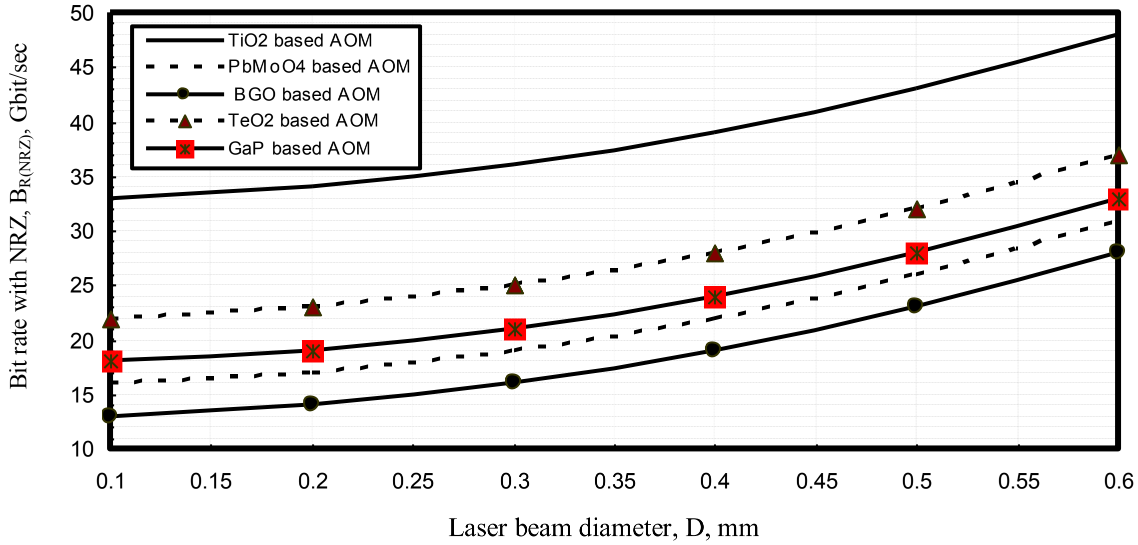
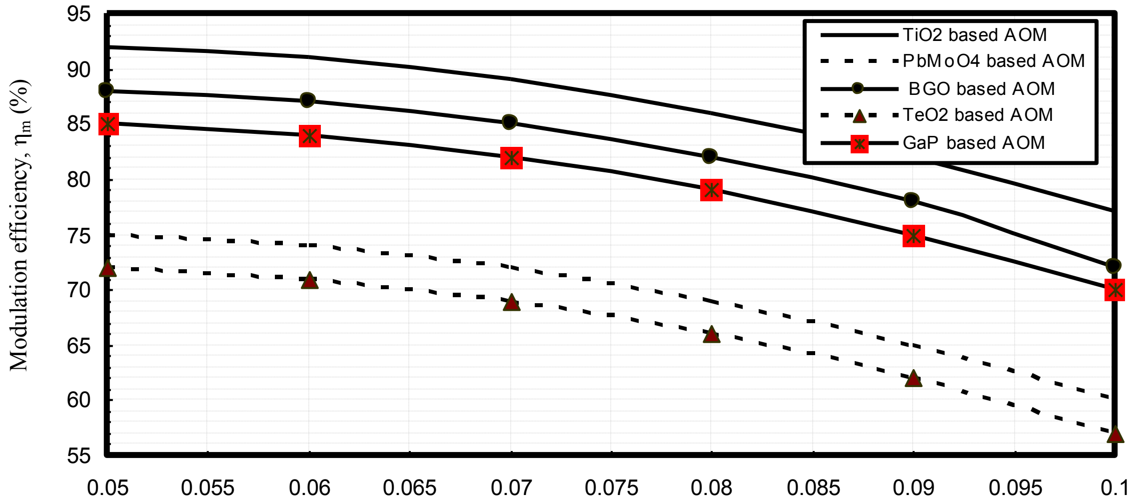


Fig. 21. Non return to zero transmission bit rate in relation to laser beam diameter with third operating optical signal wavelength transmission (λ=1.55 μm) for different acousto-optic modulators at the assumed set of the operating parameters.



Interaction length, L, mm

Fig. 22. Modulation efficiency in relation to interaction length for different acousto-optic modulators at the assumed set of the operating parameters.

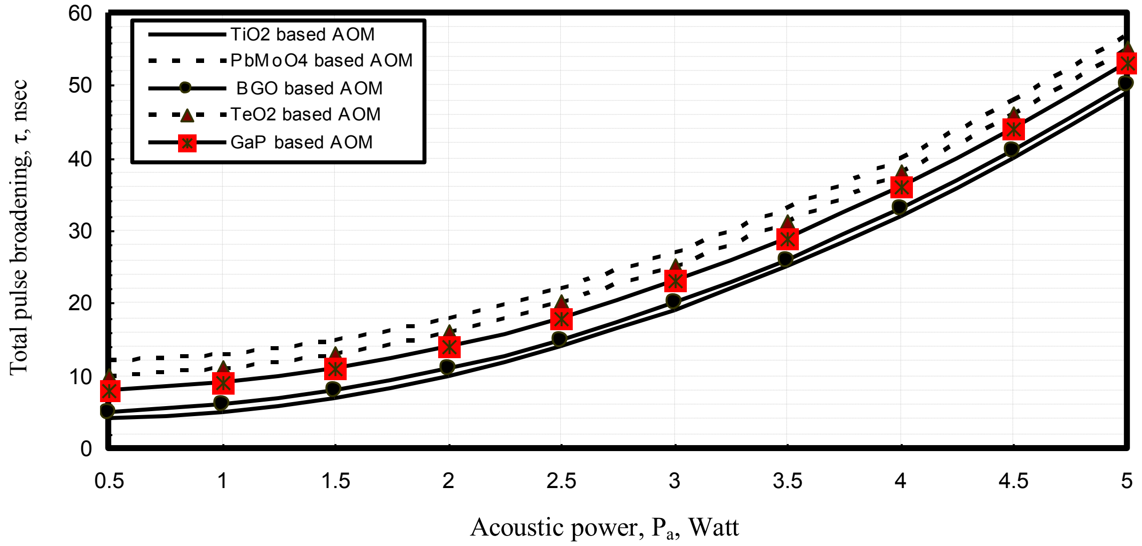


Fig. 23. Total pulse broadening in relation to acoustic power with room temperature (T_0=300 K) and operating optical signal wavelength (λ=1.55 μm) for different acousto-optic modulators at the assumed set of the operating parameters.

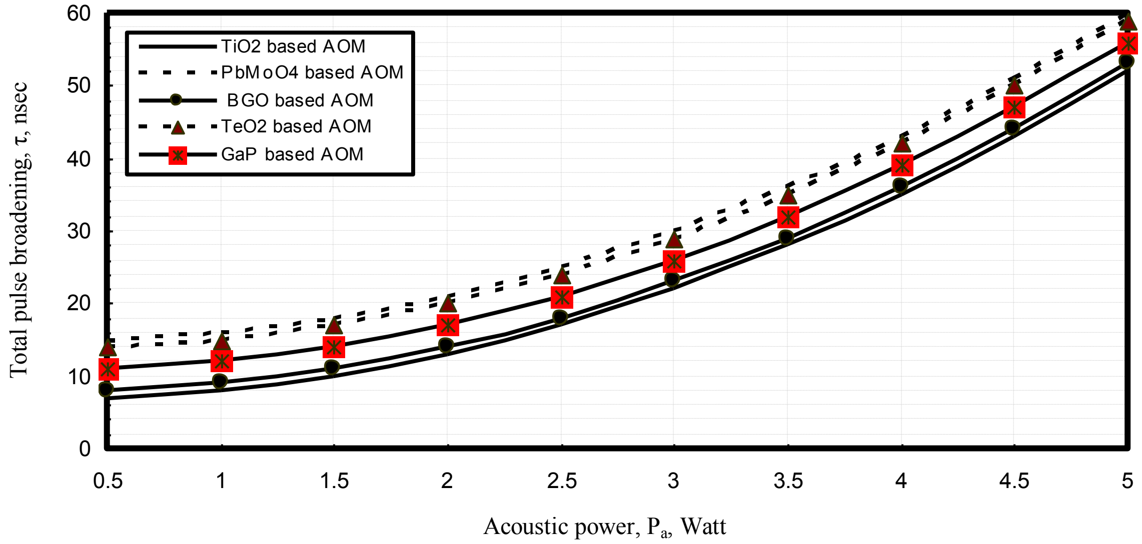


Fig. 24. Total pulse broadening in relation to acoustic power with ambient temperature (T=320 K) and operating optical signal wavelength (λ=1.55 μm) for different acousto-optic modulators at the assumed set of the operating parameters.

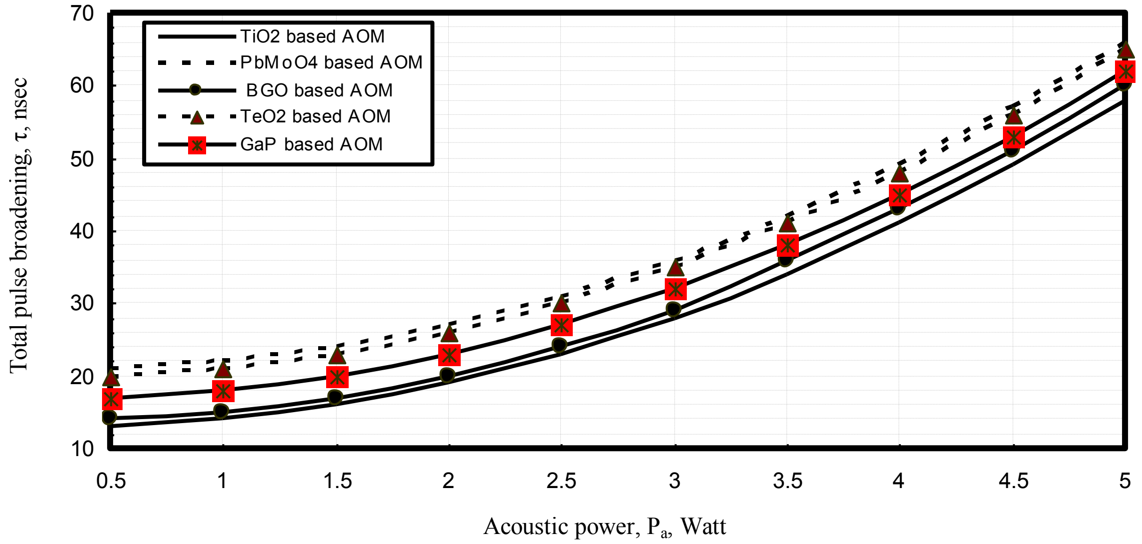


Fig. 25. Total pulse broadening in relation to acoustic power with ambient temperature (T=340 K) and operating optical signal wavelength (λ=1.55 μm) for different acousto-optic modulators at the assumed set of the operating parameters.

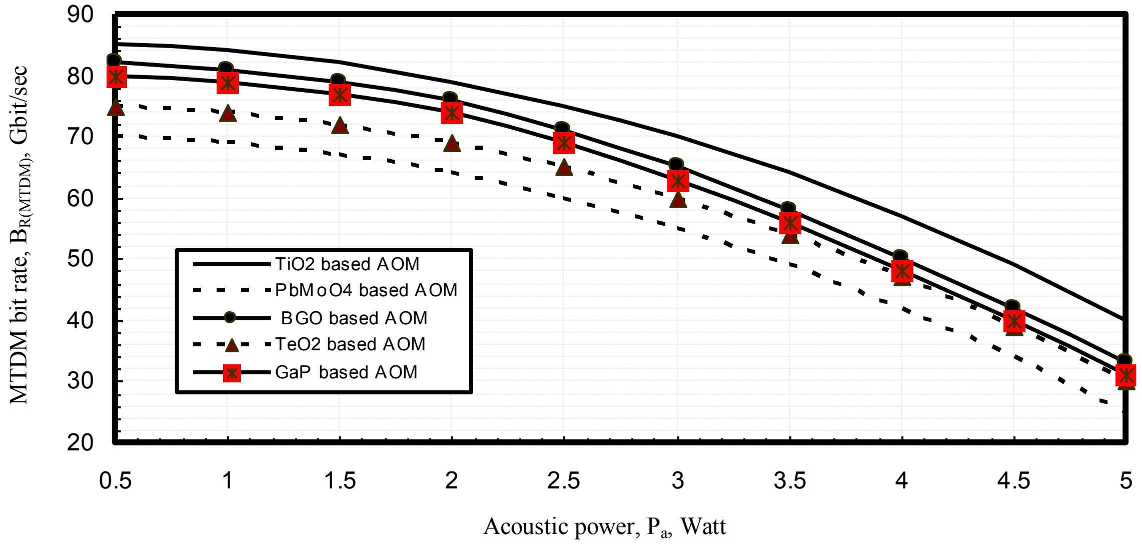


Fig. 26. MTDM transmission bit rate in relation to acoustic power with room temperature (T_0=300 K) and operating optical signal wavelength (λ=1.55 μm) for different acousto-optic modulators at the assumed set of the operating parameters.

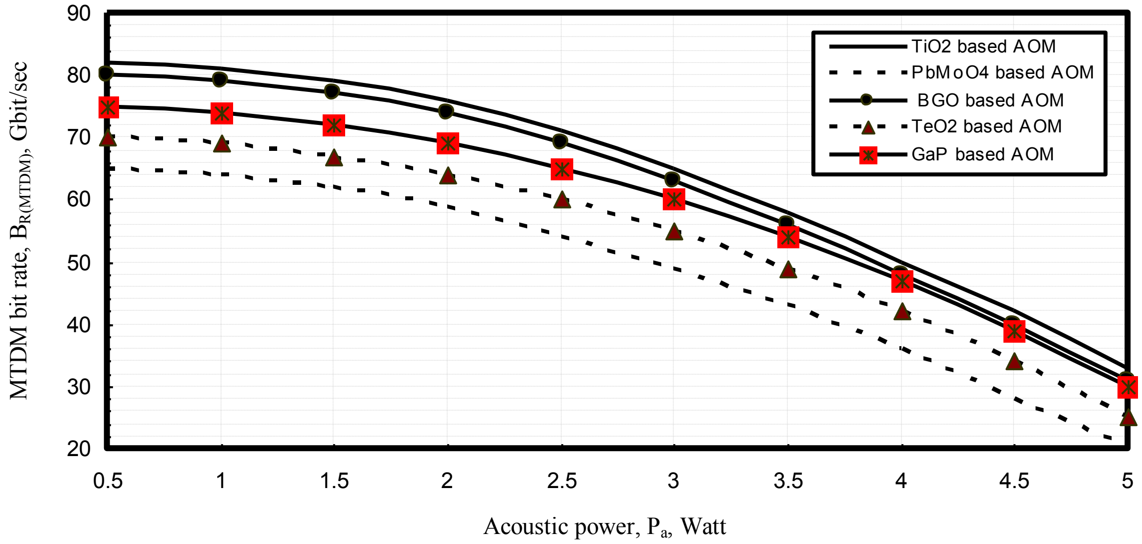


Fig. 27. MTDM transmission bit rate in relation to acoustic power with ambient temperature (T=320 K) and operating optical signal wavelength (λ=1.55 μm) for different acousto-optic modulators at the assumed set of the operating parameters.

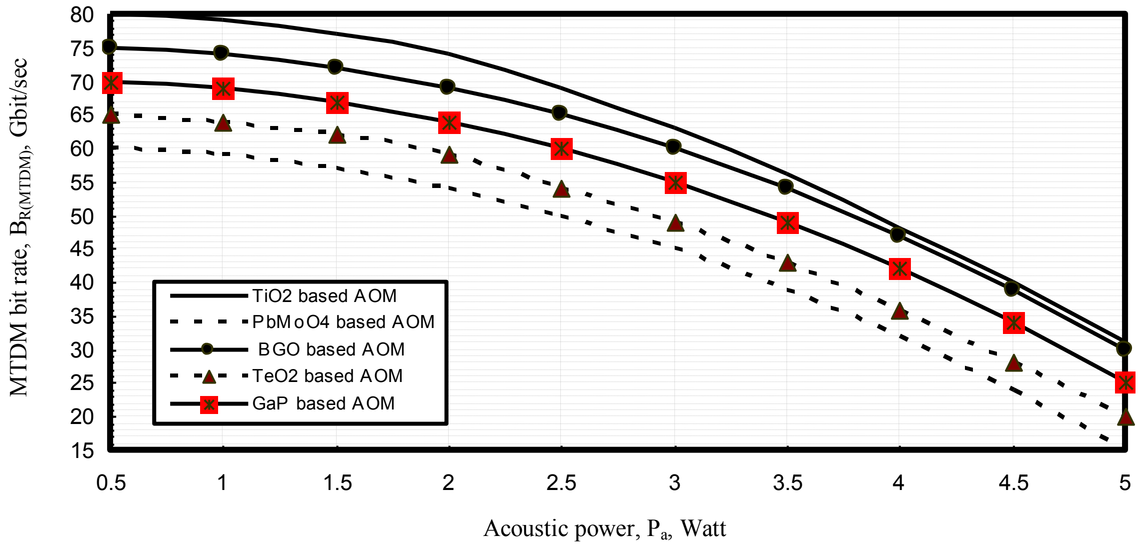


Fig. 28. MTDM transmission bit rate in relation to acoustic power with ambient temperature (T=340 K) and operating optical signal wavelength (λ=1.55 μm) for different acousto-optic modulators at the assumed set of the operating parameters.

vii) Fig. 20 has indicated that power width product decreases with increasing operating optical signal wavelength for different AOMs under study considerations. It is theoretically that BGO AOM has presented the lowest power width product in comparison with other different AOMs.

viii) Fig. 21 has indicated that transmission bit rate increases with increasing laser beam diameter for different AOMs under study considerations. It is theoretically that TiO_2 AOM presented the highest transmission bit rates with using NRZ coding technique in comparison with other different AOMs.

ix) Fig. 22 has demonstrated that modulation efficiency decreases with increasing interaction length between acoustic signal and optical signal for different AOMs under study considerations. It is that TiO_2 AOM presented the highest modulation efficiency in comparison with other different AOMs.

x) Figs. (23-28) have indicated that total pulse broadening increases and MTDM transmission bit rates decrease with increasing acoustic signal power for different AOMs under study. As well as it is observed that TiO_2 AOM presented the highest transmission bit rates and the lowest total pulse broadening in comparison with other different AOMs.

IV. CONCLUSIONS

In a summary, appearance of infrared (IR) diode lasers which are especially attractive for fiber optic applications and spectrometers because of small size and high efficiency in the spectral range where most of industrial gases have characteristic absorption bands resulted in the interest of the efficiency light control devices, which can be coupled with the above sources. We have deeply investigated the best candidate materials based acousto-optic modulators and we have compared our theoretical results with their experimental results [22] as listed in Table 3 below. It is theoretically found that TiO_2 AOM has presented the highest switching speed, modulation efficiency and transmission bit rate in comparison with other different AOMs under study considerations.

Table 3. comparison our theoretical results with their experimental results under the same operating conditions.

Design parameters	Our theoretical results for different AOMs [Same conditions of operation: T_0=300 K, P_a=2.5 Watt, W=H=5 mm, λ=1.55 μm, L=0.05 mm, D=3mm and F=3 mm and Δλ=0.1 nm]					Their experimental results [22]
	TiO_2 AOM	$PbMoO_4$ AOM	BGO AOM	TeO_2 AOM	GaP AOM	Si-Te AOM
Diffraction angle, θ, degree	15	18	19	20	21	16
Figure of merit, M, cm^2/W	$15x10^{-11}$	$35x10^{-11}$	$16x10^{-11}$	$32x10^{-11}$	$30x10^{-11}$	$17x10^{-11}$
Diffraction efficiency, η (%)	45 %	70 %	50 %	60 %	55 %	47 %
3-dB Frequency, $f_{3\text{-dB}}$, GHz	32	72	82	52	62	31
Modulation frequency, f_m, GHz	8	15	10	18	11	7.5
Signal quality, Q (dB)	7.5 dB	12 dB	10 dB	8.5 dB	8 dB	7 dB
Bit error rate, $BERx10^{-10}$	0.04	0.0032	0.0045	0.023	0.045	0.0425
Switching time, T_t, μsec	0.033	0.0277	0.027	0.03	0.0294	0.035
Switching speed, SS, GHz	36	19	16	25	21	35
Power width product, PWP, W.mm	0.03	0.0154	0.015	0.054	0.02	0.0365
Bit rate with NRZ, $B_{R(NRZ)}$, Gbit/sec	40	23	20	30	25	38.65
Modulation efficiency, η_m(%)	92 %	75 %	88 %	72 %	85 %	90 %
Pulse broadening, τ, nsec	15	22	16	20	18	16.5
MTDM bit rate, $B_{R(MTDM)}$, Gbit/sec	75	60	71	65	69	72.5

REFERENCES

[1] J. Limpert, N. Deguil-Robin, I. Manek-Hönninger, F. Salin, T. Schreiber, A. Liem, F. Röser, H. Zellmer, A. Tünnermann, A. Courjaoud, C. Hönninger, and E. Mottay, “High Power Picosecond Fiber Amplifier Based on Nonlinear Spectral Compression,” Opt. Lett., Vol. 30, No. 3, pp. 714-716, 2005.

[2] P. K. Datta, S. Mukhopadhyay, S. K. Das, L. Tartara, A. Agnesi, and V. Degiorgio, “Enhancement of Stability and Efficiency of A nonlinear Mirror Mode Locked Nd:YVO4 Oscillator by An Active Q Switch,” Opt. Express, Vol. 12, No. 2, pp. 4041-4046, 2004.

[3] Ahmed Nabih Zaki Rashed, Abd El-Naser A. Mohammed, Mohamed M. E. El-Halawany, and Sakr Hanafy “High Performance of Plastic Optical Fibers within Conventional Amplification Technique in Advanced Local Area Optical Communication Networks,” International Journal of Multidisciplinary Sciences and Engineering (IJMSE), Vol. 2, No. 2, pp. 34-42, May 2011.

[4] Ahmed Nabih Zaki Rashed, “High Efficiency Laser Power Transmission With All Optical Amplification For High Transmission Capacity Submarine Cables,” Journal of Russian Laser Research, Vol. 34, No. 6, pp. 603-613, Nov. 2013.

[5] D. Y. Shen, D. Y. Tang, and K. Ueda, “Continuous Wave and Q Switched Mode Locking of a Nd:YVO4 Laser With A single Crystal GaAs Wafer,” Jpn. J. Appl. Phys., Vol. 42, No. 3, pp. 1224-1227, 2002.

[6] Ahmed Nabih Zaki Rashed, Abd El–Naser A. Mohamed, , Sakr A. S. Hanafy, and Amira I. M. Bendary “Electrooptic Polymer Modulators Performance Improvement With Pulse Code Modulation Scheme in Modern Optical Communication Networks,” International Journal of Computer Science and Telecommunications (IJCST), Vol. 2, No. 6, pp. 30-39, Sep. 2011.

[7] Ahmed Nabih Zaki Rashed, Hamdy A. Sharshar, “Error Probability and Laser Beam Propagation Analysis in Local Area Optical Wireless Communication Networks Using Pulse Position Modulation Technique under Atmospheric Turbulence Effects,” International Journal of Advanced Research in Electronics and Communication Engineering (IJARECE), Vol. 3, No.3, pp. 261-272, Mar. 2014.

[8] H. Jun Kim, and J. Song, “Full-Duplex WDM Based ROF System Using All-Optical SSB Frequency Up Conversion and Wavelength Re-Use Techniques” IEEE Transactions on Microwave Theory and Techniques, Vol. 49, No. 2, pp. 1354-1362, July 2010.

[9] Min Chen, Liang Zhou, Takahiro Hara, Yang Xiao and Victor C.M. Leung, "Advances in Multimedia Communications," International Journal of Communication Systems, Vol. 24, No. 10, pp. 1243-1245, 2011.

[10] A.Z. Genack, "Phase Sensitive Detection of Emission and Scattering by Electro Optic Demodulation," Journal of Luminescence, Vol. 32, No. 2, pp. 696-698, 2011.

[11] Ahmed Nabih Zaki Rashed, Mohamed A. Metwae'e, "Optical Filters Dimensions and Thermal Operation Conditions Impact on Its Transmission Considerations in Near Infrared (NIR) Optical Spectrum Transmission Region," Optoelectronics and Advanced Materials Journal– Rapid Communications, Vol. 8, No. 3-4, pp. 175 – 184, March-April 2014.

[12] Ahmed Nabih Zaki Rashed, Abd El-Naser A. Mohamed Mohamed S. F. Tabbour, and Ahmed B. El-Sherbeny, "Crosstalk Impact and Performance Evaluation of Optical Cross Connects in Different Transparent Wavelength Division Multiplexed Optical Transport Networks," International Journal of Advanced Research in Computer Science and Electronics Engineering (IJARCSEE), Vol. 3, No. 4, pp. 178-192, April 2014.

[13] A. Beyertt, D. Nickel, and A. Giesen, "Femtosecond Thin Disk Yb:KYW Regenerative Amplifier," Appl. Phys. B, Vol. 80, No. 6, pp. 655-660, 2005.

[14] Ahmed Nabih Zaki Rashed, "RLC Low Pass Filters Transmission Transient Performance Characteristics Analysis," International Journal of Advanced Research in Computer Engineering & Technology (IJARCET), Vol. 2, No. 9, pp. 2533-2541, Sep. 2013.

[15] Y. F. Chen, and S. W. Tsai, "Simultaneous Q Switching and Mode Locking in A diode Pumped Nd:YVO4-Cr4+:YAG Laser," IEEE J. of Quantum Electron., Vol. 37, No. 2, pp. 580-586, 2001.

[16] D. Y. Shen, D. Y. Tang, and K. Ueda, "Continuous Wave and Q Switched Mode Locking of a Nd:YVO4 Laser With A single Crystal GaAs Wafer," Jpn. J. Appl. Phys., Vol. 42, No. 3, pp. 1224-1227, 2002.

[17] Ahmed Nabih Zaki Rashed, "Submarine Fiber Cable Network Systems Cost Planning Considerations with Achieved High Transmission Capacity and Signal Quality Enhancement," Optics Communications, Elsevier Publisher, Vol. 311, pp. 44-54, Jan. 2014.

[18] P. K. Datta, S. Mukhopadhyay, S. K. Das, L. Tartara, A. Agnesi, and V. Degiorgio, "Enhancement of Stability and Efficiency of A nonlinear Mirror Mode Locked Nd:YVO4 Oscillator by An Active Q Switch," Opt. Express, Vol. 12, No. 2, pp. 4041-4046, 2004.

[19] Ahmed Nabih Zaki Rashed, Abd El-Naser A. Mohammed, Mohamed M. E. El-Halawany, and Mohammed S. F. Tabour "High Transmission Performance of Radio over Fiber Systems over Traditional Optical Fiber Communication Systems Using Different Coding Formats for Long Haul Applications," Nonlinear Optics and Quantum Optics, Vol. 44, No. 1, pp. 41–63, 2012.

[20] Ahmed Nabih Zaki Rashed, Abd El–Naser A. Mohamed, Mohamed Metwae'e, and Amira I. M. Bendary "Ultra High Speed Semiconductor Electrooptic Modulator Devices for Gigahertz Operation in Optical Communication Systems," International Electrical Engineering Journal, Vol. 2, No. 3, pp. 560-570, 2011.

[21] S. K. Young, C. C. Chong, "An Overview of Multigigabit Wireless through Millimeter Wave Technology: Potentials and Technical Challenges", EURASIP Journal on Wireless Communications and Networking, Article ID 78907, pp. 10-18, 2007.

[22] Ahmed Nabih Zaki Rashed, "Optical Network Management and Its Performance Evaluation for Both Future Cost Planning and Triple Play Solutions," Wireless Personal Communications Journal, Springer Publisher, Vo. 75, No.4, pp. 2005-2020, April 2014.

[23] Y. Young and E. Yao, "Design Consideration for Acousto-Optic Devices," Proceedings of IEEE, Vol. 69, No. 1, pp. 54-64, 2005.

[24] R. V. Johnson, "Temporal Response of the Acousto Optic Modulator in the High Scattering Efficiency Regime," Applied Optics, Vol. 18, No. 3, pp. 903-907, 2005.

[25] L.A. Kulakova, B.A. Matveev, B.T. Melekh, "Si-Te acousto-optic modulator for the 1.7-10.6 lm IR region," Journal of Non-Crystalline Solids, Vol. 266-269, pp. 969-972, 2000.

Author Profile

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 32951. 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. As well as he is editorial board member in high academic scientific International research Journals. Moreover he is a reviewer member in high impact scientific research international journals in the field of electronics, electrical communication systems, optoelectronics, information technology and advanced optical communication systems and networks. His personal electronic mail ID (E-mail:ahmed_733@yahoo.com). He has supervised four PhD students and three MSc. students successfully and four Ph. D students and Seven MSc. students are currently pursuing their research under guidance. His published paper under the title **"High reliability optical interconnections for short range applications in high performance optical communication systems"** in Optics and Laser Technology, Elsevier Publisher has achieved most popular download articles in 2013.

