Derivative and analysis of the amplitude detection peak (ADP) for direct detection of digital optical receivers and determining the range of noise effect on the system

اشتقاق وتحليل القيمة المثلى لكسب الكاشف (ADP) المستقبلات الضوئية الرقمية ذات الكشف المباشر وايجاد مدى تأثير الضوضاء على المنظومة

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ABSTRACT

In this paper, the equations which limit the (ADP) for receiver circuits by the effect of noise had derived. The effect of laser intensity on the direct detection of digital optical communication system is also analyzed and studied. We found that, a best performance gain is obtained depending on the maximum value of the signal to noise ratio (S/N). optimizing the (ADP) gain reduces the impact of the this noise on the system performance and power penalty bit error rate (BER) and yields a power penalty which is relatively less affected by ionization rate of the detector. The Mat lab language is used to clarify the graphics in this work .

المستخلص :

في هذا البحث اشتقت المعادلات التي تحدد القيمة العظمى لكسب الكاشف (ADP) لدوائر الاستلام بوجود تأثير الضوضاء. كذلك فقد تم تحليل ودراسة تأثير ضوضاء وشدة الليزر على دوائر الاستقبال لحساب أعظم حساسية لدائرة الكشف في منظومة الاتصالات الضوئية الرقمية ذات الكشف المباشر. وأثبت أن أفضل أداء لربح المنظومة يعتمد على أعلى قيمة لمقدار نسبة الإشارة أي الضوضاء (S/N). أن هذه النسبة يمكن تقليلها عند اختيار القيمة المثلى لكسب الكاشف ونسبة الخطأ لكل بت (BER). واستخدم لغة الماتلاب (Matlap) لتوضيح الرسومات في هذا البحث.

List of Symbols :

symbol	Description	unit
R	Responsiveness of the detector	VW^{-1}
V_s	r.m.s value of the fundamental component of the signal voltage	V
H	r.m.s value of the fundamental component of the irradiance area of the detector	W/cm^2
A_d	The sensitive area of the detector	cm^2
Q	The signal to noise ration (s/n) at the decision time	-
g	Optimum gain	-
p	Optical power received during a signal bit	W
d	The threshold level for the decision cct	
$\delta_o;\delta_1$	The standard deviation of the total noise associated with space	-
BER	Bit –error -rate	bit
r	The extinction ratio of the semiconductor lager	
q	Electron charge	ev
F_o	The excess noise factor associated with the randomness of the APD	-
B	The incident at the bit rate	Bit/s
$I_1;I_2$	The second personicks integral (current)	amp
P_{av}	The average respired power	W
S_{RIN}	The average spectral density of the relative intensity noise of the lager source	dB /H_z
$(\Delta_p)_{RIN}$	Total power penalty	dB
f	Frequency	Hz
K	feedback gain system Forward	-
H(f)	The transfer function of the receiver filter	-

1- Introduction

The primary limitation in detecting low intensity radiation is the presence of noise (random fluctuation in the output signal) a rising the detector, from the source of radiation, or from the electronic circuiting processing the detector signal. Three prominent noise source are thermal or Johnson noise, shot noise and 1/f noise [1].

The background limited in performance (BLIP) is define as noise can be minimized by operating detectors at optimum temperatures and band widths. If the internally generated noise is low, detector performance might be limited by the environmental radiative noise [2].

In designing digital optical communication system based on semiconductor arrays lasers at wavelength (810 nm), it was able to specify the influence of intensity noise on receiver performance. The laser-related sources of intensity fluctuations include intrinsic intensity noise [3, 4], the optical feedback noise [5], mode-partition noise [6, 7].

The effect of these noise sources on the performance of coherent optical systems can be suppressed by employing a balanced front-end receiver [8, 9].

The performance degradation of a direct-detection receiver in the presence of mode-partition noise [7, 10]. In this research, we discuss the influence of laser intrinsic intensity noise on the performance of APD-based receivers. The dependence of the penalty imposed by intensity fluctuations with laser extinction ratio, APD gain and impact ionization rate are quantified in detail [11].

The main intrinsic source of noise in semiconductor laser is the random spontaneous emission events which disturb both photon population and carriel concentration. The power spectral density of this noise is frequency dependent and can be obtained by solving the laser rate equations [3].
The white relative intensity noise (RIN) corresponding to the effective value while the intensity noise is taken (logic cct.) in the digital electronic system to be the same in the (ON) and (off) states [12]. As shown in fig (1), and is justified when the laser is operation threshold, since the noise inside the cavity comes from the fluctuation in the number of carries which is clamped at threshold [13].

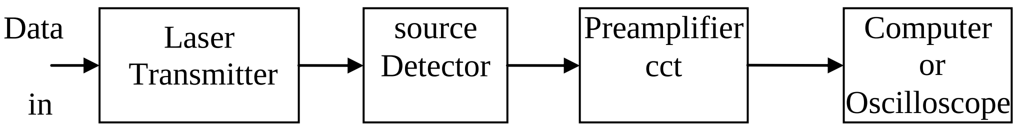

Fig (1) Data information between transmitter and receiver system

2- Theory:

One of the simplest descriptions of detector performance is the Responsiveness, which is the detector o/p per unit i/p. The Responsiveness is[4] :

$$R = \frac{Vs}{H \times A_d} \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where the units of (R) are VW^{-1}, (Vs) is the rms value of the fundamental component of the signal voltage, (H) is the rms value of the fundamental component of the irradiance area of the detector in W /cm^2, A_d is the sensitive area of the detector in cm^2, the reader should note that it may be necessary to specify other condition of measurement [14].

To derive and analysis a general expression for the sensitivity of optical receivers in the presence of laser intensity noise. The analysis includes circuit noise, shot noise, and a adapts personicks treatment, which assumes (Gaussien) probability distribution for the noise sources, consider an APD-based digital optical receiver, on which a random bit stream consisting of (1) and (0) (ON and off states) is incident at the bit rate (B). Referring to the input of the decision circuit, the signal to noise ratio (S/N) at the decision time can be expression [15].

$$Q = \frac{s_1 - d}{\delta} = \frac{d - s_0}{\delta_0} \ldots\ldots\ldots\ldots\ldots\ldots(2a)$$

$$= \sqrt{2}erfc^{-1}(2po) \ldots\ldots\ldots\ldots\ldots\ldots(2b)$$

Where s_1=Rg p_1, is the detection signal in the state assuming on average APD gain (g) and optical power received during a signal bit (P_1), (d) is the threshold level for the decision cct. δ_0 (δ_1) the standard deviation of the total noise associated with (space) state, erfc^{-1} the argument of the complementary error function when (a bit-error-rate (BER) at $P_o = 10^{-9}$ W).
The variance of the total noise into three components:

1- thermal cct. Noise (δ^2th).
2- shot noise (δ^2sh).
3- laser intensity –induced noise(δ^2int).
$\delta_o^2 = \delta^2 th + r(\delta^2 sh)_1 + \delta^2(int)$……………….(3a)
$\delta_1^2 = \delta^2 th + (\delta^2 sh)_1 + \delta^2 (int)$……………….(3b)
where r= P_o/P_1 is the extinction ratio of the semiconductor laser.
$(\delta^2 sh)_1 = 2q\, R\, g^2\, F_o\, I_1\, B\, P_1$………………………(4)
$(\delta^2 sh)_1$ the variance of the shot noise which gain in the detection system.

Here, q is the electronic charge, F_o the excess noise factor associated with the randomness of the APD multiplication process and can be evaluated using McIntyre's expression [16].

In addition, it is weighting factor introduced and depends on the i/p and o/p pulse shapes [15]. From equations (2a) and (2b) assume that the laser intensity noise is the same for both states. This assumption is justified when the optical reflection on the laser source is suppressed and when off state is above threshold.
δ^2int produce to:
$\delta^2 sh = R^2 g^2 P^2_{av} I_2 B S_{RIN}$ ……………….(5)

when $P_{av}= 0.5\,(1+r)P_1$, is the average received power, I_2 is the second personicks integral and S_{RIN} the average spectral density of the relative intensity noise of the laser source:

$$S_{RIN} = \frac{S_p}{P_{av}^2} = \frac{4}{(1+r)^2}\frac{S_p}{P_1^2} = \frac{4}{(1+r)^2}(S_{RIN})_1 \text{……………………(6a)}$$

It is indicate that the RIN has a nearly uniform spectrum at low frequencies, therefore practical semiconductor lasers eq. (5) is still valid if the parameter S_{RIN} is replaced by the effective spectral density of (RIN):

$$S_{RIN} = \frac{\int_o^\infty S_{RIN}(f)\left|H(f)\right|^2 df}{I_2 B} \text{……………………………(6b)}$$

It is clear that RIN affects receiver sensitivity via the parameter d [17]. Also the intensity noise can lead to a bit-error –rate(BER) floor where the receiver performance can not be improved with increasing the received optical power. This occurs when the value of RIN [13,18].

$$(S_{RIN})\,floor = \left(\frac{1-r}{1+r}\right)^2 \times \frac{1}{Q^2 I_2 B} \text{……………………(7)}$$

From eq. (7), the following facts can be listed:-
(a) the (BER) floor occurs at lower values of RIN detector when the laser extinction ratio (r) increase.
(b) the level of (BER) floor is independent of APD parameters g and k.
(c) the (BER) floor is not affected by the receiver cct. noise.
(d) S_{RIN} is inversely proportional to the bit rat and its reduced at a rate of 10 dB/Hz for one decade increase in bit rate [19].
When:
$(\Delta P)_{RIN}$ = -5 log d (PIN receiver)…………………(8)
Hence $(\Delta P)_{RIN}$ is dependent on extinction ratio since (d) is a function of r [17]. Which gives total power penalty:

$$(\Delta P)_{tot.} = 20\log\left(\frac{1+r}{1-r}\right) + 10\log\left[1+\sqrt{1-d}+\frac{4rd}{(1+r)^2}\right] - 10\log d \text{…………(9)}$$

3- Illustrative examples and Results

Optical receiver operating at 1.7 μ m wavelength with APD detection when B=5 G bit/s when K=0.4, in the i/p data system of simulation, and MOSFET amplifier with RL= 5.3 kΩ, cp(total)=3.38 PF, FET noise figure =1.98, operating temp = 300k, these values give an amplifier noise power δ^2_{th} 1.2 $\times 10^{-12}$ A^2 and 10^{-13} A^2 at 5G bit /s and 10 G bit/s [17].

The receiver sensitivity is evaluated at BER=10^{-8}, assuming ideal detector efficiency, also in these values appears in the fig (2). Fig (2) illustrate the performance of detector (RIN) for the two values (5, 10) G bit/s. Fig(3a) shows the total penalty variations with the level of detector source and assuming a laser source with r=0 to system penalty below 0.5 dB, the maximum allowable RIN is -118.5 dB/Hz at B= 5 G bit/s and -120.3 dB/Hz at B=10 G bit/s. the dependence of total penalty on extinction ratio is given in fig (3b), (i.e. $(\Delta P)_{RIN}$=0) which is independent on bit rate. The main conclusion to be draw from thing figs.(3) is that the penalty imposed by RIN is a strong function of extinction ratio.

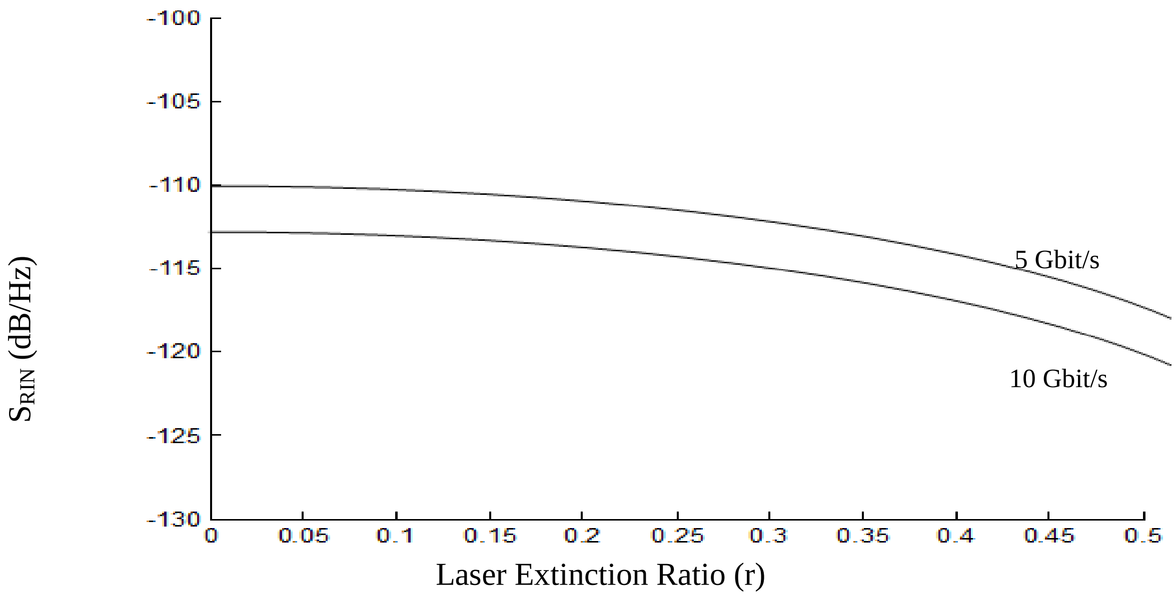

Figure (2) variation of (S_{RIN}) at BER=10^{-9} with laser extinction ratio

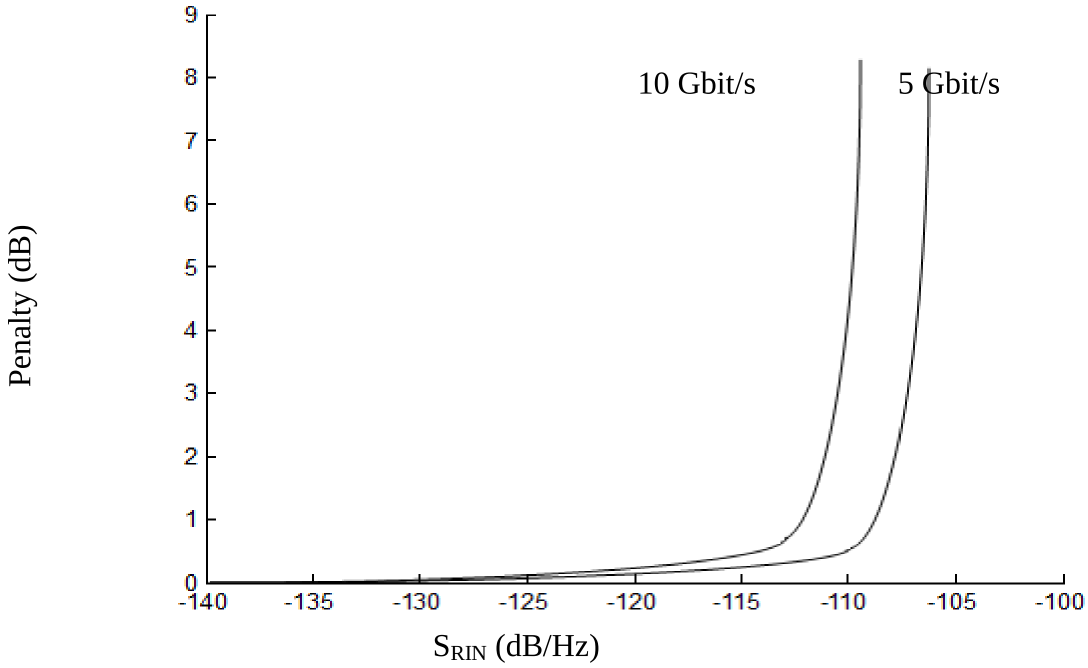

Figure (3) [a] Performance of PIN receiver in the presence of intensity

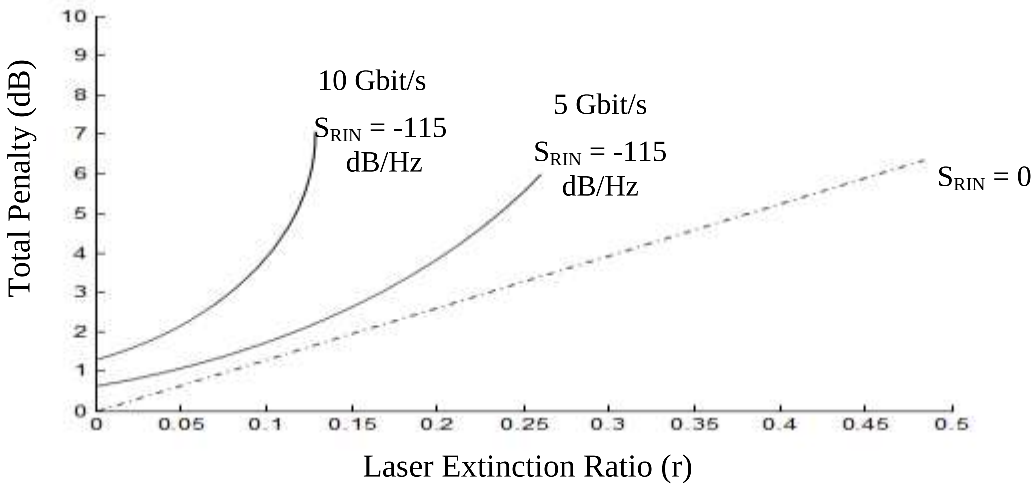

Figure (3) [b] Variation of total penalty at B=(5:10) Gbit/s with laser extinction ratio

Figs (3-a,b) performance of PIN receiver in the presence of intensity noise

From fig. (4) to appears the receiver sensitivity and system penalty as a function of APD gain for RIN= -110 dB/Hz and B=5 G bit/s, r=0. Additional results corresponding to the purpose. Note that the optimum gain (g opt.) which minimized (Pav) (i.e. maximized receiver sensitivity) is reduced in the presence of RIN. Although the penalty is higher at k=0.7 compared with k=0.3, the difference in system penalty is less than (1dB) over all the values of the gain.

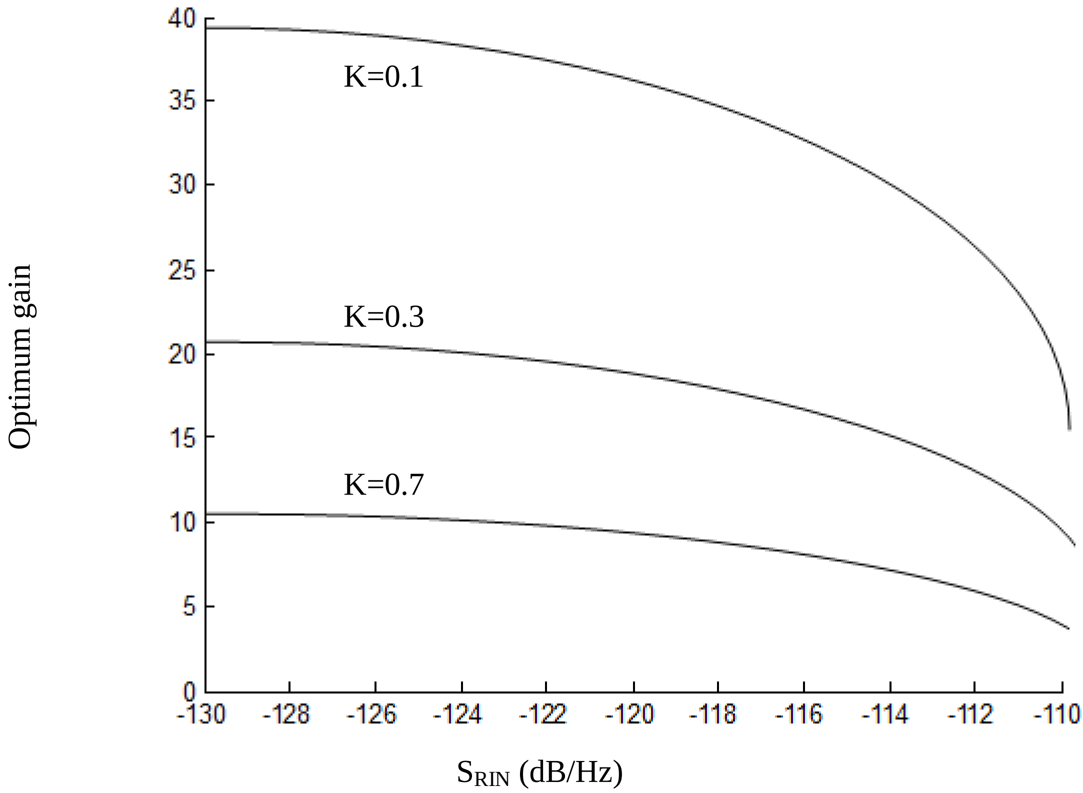

Figure (4) The variation of S_{RIN} vs optimum gain

To investigate the variation of optimum gain with RIN, we plot fig.(5) for three values of k:1 (very noisy ADP), 0.3 and 0.1. Other system parameters are given in fig(4), the last conclusion can be founded, where receiver sensitivity evaluated at optimum gain is plotted against RIN detection.

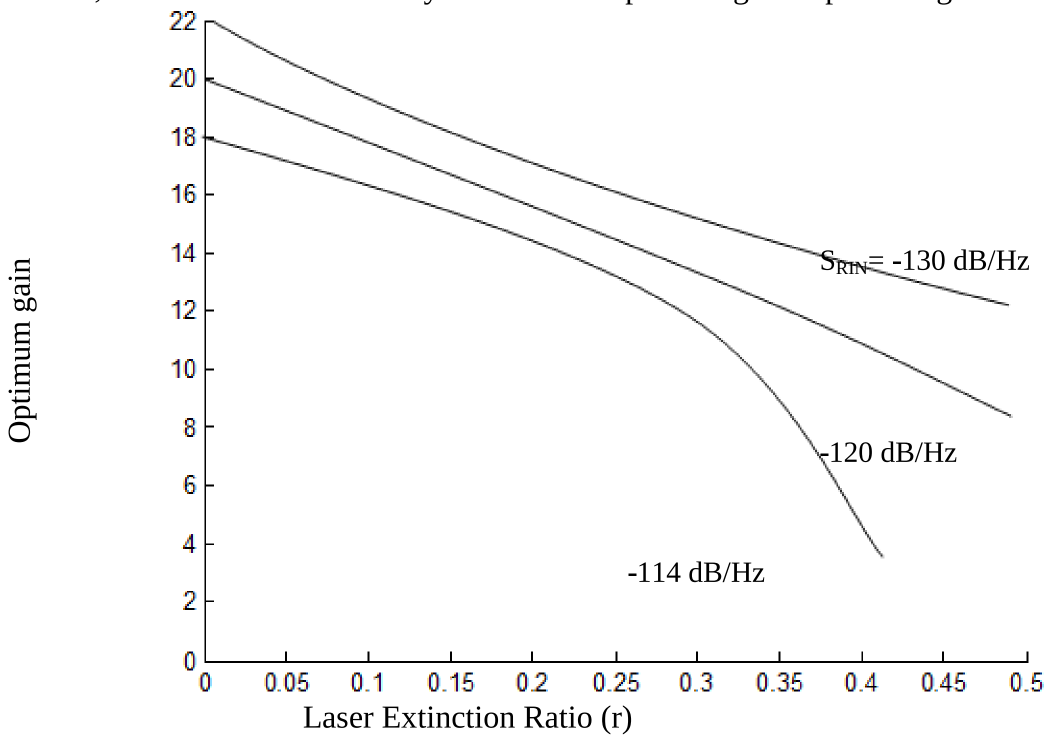

Figure (5)the relationship between optimum gain vs laser extinction ration

To discuss the key role played by the laser source extinction ratio on system efficiency, plotted in fig.(6) the variation of total penalty with (r) taking RIN as a parameter [20].

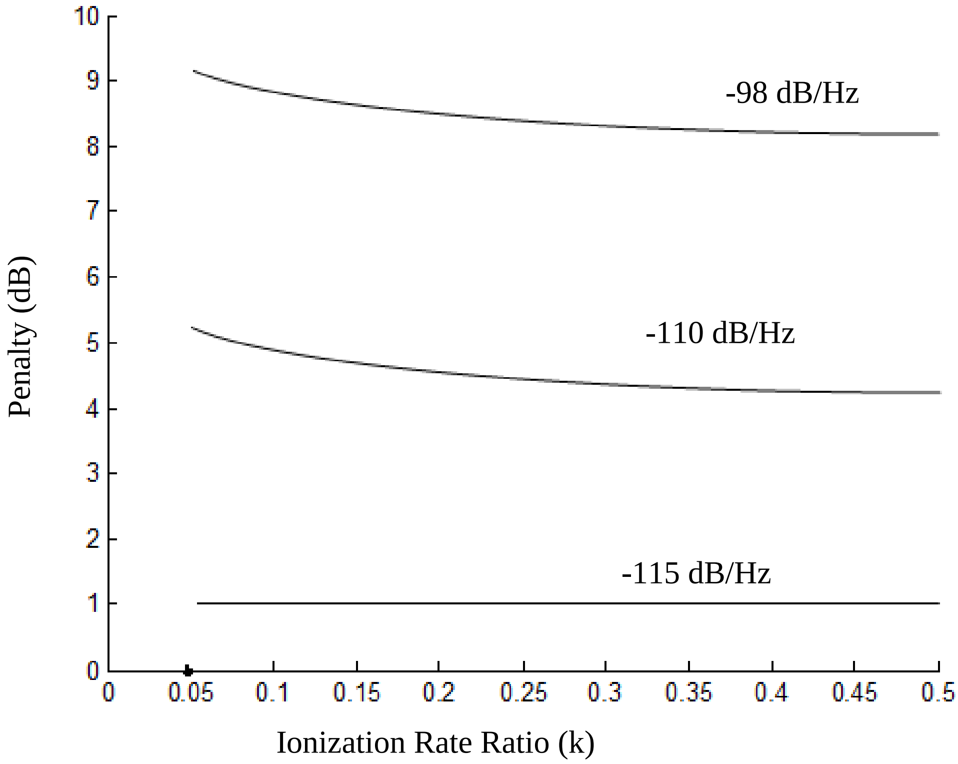

Figure (6) RIN-induced penalty vs. APD impact ionization

The total penalty is estimated with respect to -35.7 dBm corresponding to the receiver sensitivity in the noise intensity and extinction ratio assuming that: B=5 G bit/s and k= 0.3, summarizes the influence of impact ionization rate ratio (k) on intensity noise penalty, three values of RIN (detection) are considered (-115 dB/Hz, -110 dB/Hz and -108 dB/Hz). The penalty is calculated as the difference between optimized receiver sensitivity with and without (RIN detection).

4- Conclusions:

These points' summaries the following conclusions:-

1- The power penalty can be considerably decreased by applying a laser diode operating with low extinction ratio.
2- The analytical expression for (R) has been developed using the Gaussian approximation to estimate the power penalty due to laser intensity fluctuations for various system parameters.
3- The APD receiver is more influenced by (RIN detector) as compared with a (PIN detector) counter part. and the optimized APD gain reduces the power penalty imposed by total noise systems.
4- The level of (BER) increases with increasing laser extinction ratio.
5- The (RIN) penalty increases with reducing APD ionization rate ratio and this effective is more pronounced for k<0.438.

5-References:

1- Meissinger, H. F. (simulation of infrared systems), proc. Onst. Radio Engrs; Vol. 47,No.2, P1586 (1959).

2- Kazovsky. L. (Impact of laser phase noise on optical heterodyne communications system), IEEE journal of quantum electronics, Vol. 18, No. 9, P 964-965, (1982).

3- Dutta, N. K. and G. P. (long-wavelength semiconductor laser), New York; ch.5 P 53, (1987).

4- Garvey, M. J. and Quinn (sources of intensity noise in wide-band digital optical communication system) light wave Technol. Vol. 6, No. 9, P 1285-1293, (2009).

5- Woodward, S. L. and Koren (RIN in multi section DBR Laser), IEEE photonic technol. Lett., Vol. 2, No.2, P(202-206), 1993.

6- Schimpe, R. A. (intensity distribution of semiconductor laser emission due to the excitation of satellite modes) IEEE proc., Vol. 122, No. 3, P156-160, (1985).

7- Ogawa, K. S. (analysis of mode partition noise in laser system) IEEE J. Quantum electronic, Vol. QE-19, No. 5, P. 875-878, (1968).

8- Hall, K. L. and Burros, G. A. (Balanced dual detector receiver for optical heterodyne communications at G bit/s rates) electron Letts, Vol. 93; P 518, (2008).

9- Alexander, S. A. (Design of wide-bond optical heterodyne balanced mixer receivers), J. light wave Technol., Vol. 5, No. 4, P 586 (1988).

10- Cartledge, J. C. (performance implications of mode partition fluctuations in nearly single longitudinal mode lasers); J. light wave Technol.; Vol. 10, No. 3, P 626-632, (1994).

11- Shen, T. M. and Arawal, G. P. (computer simulation and noise analysis of the system performance of 155μm signal frequency semiconductor lasers) J. light wave Technol. Vol. L. T. 6, No. 6 P 659-702 (1989).

12- Chan, V. W. S. and Jeromin, L. L. (modulation design for heterodyne optical communication systems), proceedings of globcom ,IEEE, Inc., (1983).

13- Agrawal, G. P. and Shen T. M (effect of fiber far end reflections on the bit error rate in optical communication with signal freq. semiconductor laser) J. Light wave Technol., Vol. LT-S., No. 5, P 59-63, (1986).

14- Thaler. S. and Meltzer. S. A. (introduction to detector the element of the infrared system) ch6, P 270, (1975).

15- Personick, S. D. (Receiver design for digital optical communication system), system Tech. J., Vol. 56, No. 3, P953, (1985).

16- Mcintyre, R. J. (multiplication noise in uniform avalanche diodes), IEEE Trans. Electron devices, Vol. 14, No. 2, P 152 (1967).

17- Personick, S. D. and Smith, R. G. (receiver design for optical fifer communication systems), in semiconductor devices for communication, (1980).

18- Takano; Mito (evaluation of power penalties caused by feedback noise distributed feed back laser diodes), J. light wave Technol. Vol. 7, No. 5, P675, (2006).

19- Petermann; K. D. (laser diode modulation and noise), Tokyo: Kluwer academic publishes; ch. 10; P 1262 (2009).

20- Okoshi, T. H. and matthews, M. R. (Degradation of bit error rate in coherent optical communications due to spectral spread of the transmitter journal of light wave technology Vol. L. T. 6, No. 10, P 1024-1033, (2004).