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Multilevel Signal Analyzer Tool for Optical Communication System

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ABSTRACT

This paper presents an educational software interface tool for analyzing and estimating the bit error rate (BER) of an optical communication system. Currently BER estimation tool required expensive measurement equipment such as serial data analyzer (SDA) and BER Tester. Besides cost, all this equipment has limited BER estimation based on standard format and is not suitable for custom analysis because of time constraint to use equipment even during offline estimation. This educational software interface tool is developed using OPTISYSTEM software and built-in MATLAB command. OPTISYSTEM is used to design the PAM two levels, four levels, and eight levels system, while MATLAB is used as an interface to build the BER estimation tool for measuring the PAM multilevel modulation technique. The MATLAB GUI system for measuring BER is design using Gaussian probability errors approximation method. The designed BER estimation tool simulation, is able to plot the eye diagram, BER diagram, Q-factor value, threshold value, and the most important function is to analysis the BER value for two levels, four levels and eight levels of a PAM optical communication systems. The performance of the develop analyzer has been validated with the build in analyzer of OptiSystem.

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1. INTRODUCTION

Optical communication plays an important role in providing high capacity communication network to all society worldwide. Generally, optical communication is used for long haul data transmission with high bit rate because of losses in fiber optic is very small. Optical signal is also immune to electromagnetic interference compared to electrical signal [1-3]. Conventional optical communication employed simple modulation is called as On-Off Keying based on non-return-to-zero (NRZ). For high bit rate, OOK based on return-to-zero (RZ) is used in order to extend fiber span. Due to the rapid growth of internet users, the capacity of optical system also needs to be upgraded as well. For the next generation of high capacity optical communication network, advance modulation with high spectral efficiency (SE) is the best option [4-7]. Multilevel signal modulation is proposed to be one the candidate because it will be able to increase the SE[4].

Recently, M-PAM or M-ary ASK has been studied for metro application[8]. The advantages of this system including 1) higher SE compared to OOK, 2) lower modulation bandwidth, 3) robust to chromatic dispersion (CD), 4) compatible with simple intensity modulation and direct detection (IM-DD) scheme, and 5) cost efficient system. However, in order to design and develop the complete optical system based on M-PAM, a conventional binary or 2 levels signal analyzer is incapable of estimating the performance of the received signal such as optimum threshold level, mean and variance for each signal level, maximum Q-factor, and minimum symbol error rate. Therefore, in this paper, we report the development of multilevel signal analyzer to estimate the performance parameters. The rest of the paper is organized as follows: section 2 presents the introduction of BER calculation method. the mathematic formula for calculating the threshold level, Q-factor, and bit or symbol error rate for binary and M-PAM. Section 3 discussed the simulation setup of M-PAM optical system, flowchart of the multilevel signal analyzer process and also demonstrates the results obtained from the developed analyzer. Finally, section 4 concluded this research.

2. MULTILEVEL ANALYZER DEVELOPMENT

2.1 Bit Error Rate

In digital transmission, the bit error rate or bit error ratio (BER) is the number of received binary bits that have been altered due to noise and interference, divided by the total number of transferred bits during a studied time interval. BER is a unit less performance parameter, often expressed as a percentage number.

The basic equation to determine the BER is as follow:

$$BER = \frac{\sum \text{bit recevied error}}{\sum \text{bit transmitted}} \tag{1}$$

In order to use this formula, bit to bit comparison between recovered bit and transmitted bit must be obtain. However, bit to bit error calculation is not practical because it is time consuming for huge bits and required large random access memory (RAM) of computer. In modern communication engineering, probability of error method with Gaussian approximation is more a convenient method to estimate the BER [2, 9].

2.2 Q-factor and Probability of Error for Binary

Figure 1 shows the probability density function (pdf) of a received binary signal with symbol S_0 and symbol S_1. In this derivation, we assume that the pdf is Gaussian. The bad received bit is the overlapping region between pdf of symbol S_0 and symbol S_1.

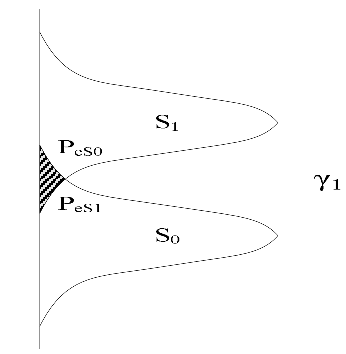

Figure 1. Probability density function of a received binary signal

It is very important to select the optimum threshold value for the decision circuit in order to minimize the error. The threshold value is given by equation (2)

$$\gamma_1 = \frac{(\mu_1 - \sigma_1) + (\mu_0 + \sigma_0)}{2} \tag{2}$$

where μ_i and σ_i is the mean and standard deviation for $S_i = \{S_0, S_1\}$, respectively.

The Q-factor is

$$Q = \frac{u_1 - u_0}{\sigma_1 + \sigma_0} \tag{3}$$

The probability of error when S_0 is transmitted is:

$$P\left(e/S_0\right) = \frac{1}{\sqrt{2\pi}\sigma_0}\int_{\gamma_1}^{\infty} e^{-\left(\frac{\gamma_1-\mu_0}{\sqrt{2}\sigma_0}\right)^2}$$
$$= \frac{1}{2} erfc\left(\frac{\gamma_1 - \mu_0}{\sqrt{2}\sigma_0}\right) \tag{4}$$

For similar threshold value, the probability of error when S_1 is transmitted is:

$$P\left(e/S_1\right) = \frac{1}{\sqrt{2\pi}\sigma_1}\int_{-\infty}^{\gamma_1} e^{-\left(\frac{\mu_1-\gamma_1}{\sqrt{2}\sigma_1}\right)^2}$$
$$= \frac{1}{2} erfc\left(\frac{\mu_1 - \gamma_1}{\sqrt{2}\sigma_1}\right) \tag{5}$$

$P\left(e/S_0\right)$ and $P\left(e/S_1\right)$ are contributing to total probability of error, thus, the probability of error for binary is given by:

$$P_e = p_{S0}P\left(e/S_0\right) + p_{S1}P\left(e/S_1\right) \tag{6}$$

where p_{S0} and p_{S1} are probability of S_0 and S_1, respectively.

2.3 Q-factor and Probability of Error for Unipolar M-PAM

Unipolar M-PAM is a multilevel baseband signal with M signal levels or symbols. There are M-1 threshold values and the i th threshold value is:

$$\gamma_k = \frac{(\mu_k - \sigma_k) + (\mu_{k-1} - \sigma_{k-1})}{2} \tag{7}$$

where μ_k and σ_k is the mean and standard deviation for $S_k = \left\{S_0, S_1, ..., S_{M-1}\right\}$, respectively.

The Q-factor is

$$Q_k = \frac{u_k - u_{k-1}}{\sigma_k + \sigma_{k-1}} \tag{8}$$

The probability of error is given by:

$$P_{eM-PAM} = \sum_{k=0}^{M-1} p_k \left[\sum_{l=0, l\neq k}^{M-1} \frac{1}{2} erfc\left(\frac{A_{kl}}{\sqrt{2}}\right)\right] \tag{9}$$

where p_k is probability of $S_k = \left\{S_0, S_1, ..., S_{M-1}\right\}$ and

$$A_{kl} = \begin{cases} \dfrac{\gamma_l - \mu_k}{\sigma_k} & for\, k < l \\ \dfrac{\mu_k - \gamma_{l+1}}{\sigma_k} & for\, l < k \end{cases}$$

2.4 Simulation of Optical Communication System

The performance of optical communication system can be obtained by analyzing the received signal at the receiver side. At this point, the transmitted signal has been exposed with various imperfections of medium and devices. In order to see the seriousness of this problem, eye-diagram and BER estimation are the typical performance parameters require to be determined. In order to obtain the received signal, a complete optical communication system should be developed. In this research, an optical communication system is developed using OptiSystem software platform. The advantages of OptiSystem including; most components available in library, easy to integrate with other software platform including Matlab, and parameter modification is more easier compare to real optical communication system. In this research, 2-PAM or non-return-to-zero (NRZ), 4-PAM and 8-PAM based on the intensity modulation have been developed and simulated. Figure 2 shows the simulation setup for 2, 4 and 8-PAM. 2^N-1 bits sequence of pseudo random binary signal (PRBS) at R bit rate is mapped to 2, 4 and 8-PAM symbol sequence. This symbol sequence is then converted to baseband signal for modulating the 1550nm continuous wave (CW) laser using external modulator. In order to vary the received optical power, an optical attenuator is inserted before the photo diode. The attenuated optical signal is converted to electrical signal via p-i-n photo diode. The noise signal pass through a low pass filter with 0.75*R Hz of cutoff frequency. This filtered signal is then saved in a mat file of matlab software.

2.5 Development of Multilevel Signal Analyzer

The developed optical system in OptiSystem platform is very useful for studying any transmission issues. In order to determine the performance of signal, the build in BER Analyzer is available. This analyzer provides the eye-diagram, Q-factor, threshold level and BER. However, this analyzer is limited to binary signal such as NRZ and RZ. In order to analyze for 4-PAM and 8-PAM, a Matlab programme is developed to calculate the SER. The input source for this analyzer is the received signal of an optical system that has been developed and simulated using OptiSystem. In order to obtain the received signal, Matlab Cosimulator tool has been attached to the simulation setup of an optical communication system. Figure 3 depicts the flowchart in developing a multilevel signal analyzer. Firstly, the saved data from the simulation of OptiSystem is loaded to a matlab workspace. The signal is then grouped depending on the symbol. The mean and standard deviation for each symbol are calculated. Then the threshold level is estimated based on the mean and standard deviation of symbol.

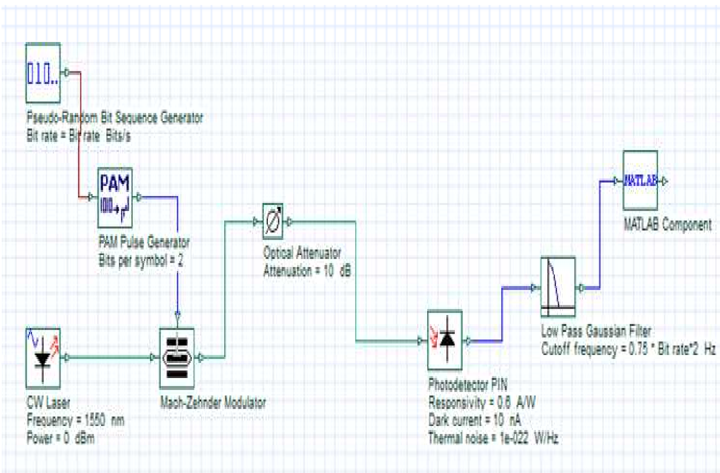

Figure 2. Simulation setup

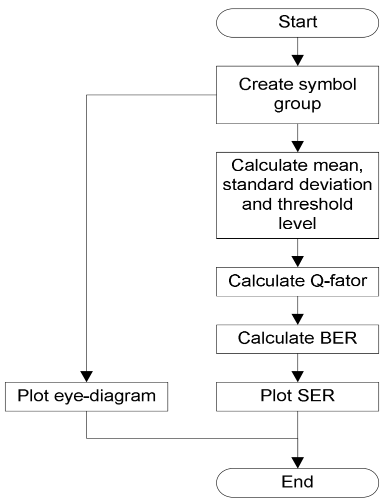

Figure 3. Flowchart of multilevel signal analyzer

3. RESULT AND ANALYSIS

The developed multilevel analyzer has been used to analyze data file of 2-PAM, 4-PAM and 8-PAM signals. For each multilevel signal, this analyzer provides a visual presentation of system performance including eye diagram and estimation SER using Gaussian approximation. Other important parameters such as Q factor, threshold and SER are also given in numerical format. Figure 4, Figure 5 and Figure 6 depict the eye diagram for 2-PAM, 4-PAM and 8-PAM, respectively. 2-PAM contains a single eye because it has 2 symbols which are level 0 (first symbol) and level 1(second symbol). Meanwhile, 4-PAM contains 3 small eyes because it has 4 symbols which is level 0 (first symbol), level 1(Second symbol), level 2(Third symbol) and, level 3(Fourth symbol). 8-PAM contains 7 small eyes because it has 8 symbols which is level 0 (first symbol), level 1 (second symbol), level 2 (third symbol), level 3 (fourth symbol), level 4 (fifth symbol), level 5 (sixth symbol), level 6 (seventh symbol), and level 7(eighth symbol). Figure 7, Figure 8 and Figure 9 illustrates the SER calculated base on Gaussian approximation over the symbol period for 2-PAM, 4-PAM and 8-PAM, respectively. The best sampling point for 2-PAM, 4-PAM and 8-PAM is at 80 ps, 70 ps and 150 ps, respectively. At this sampling point, minimum value of SER is obtained. At the best sampling point, the Q-factor, threshold level and SER are determined as shown in Table 1, Table 2 and Table 3 for 2-PAM, 4-PAM and 8-PAM, respectively.

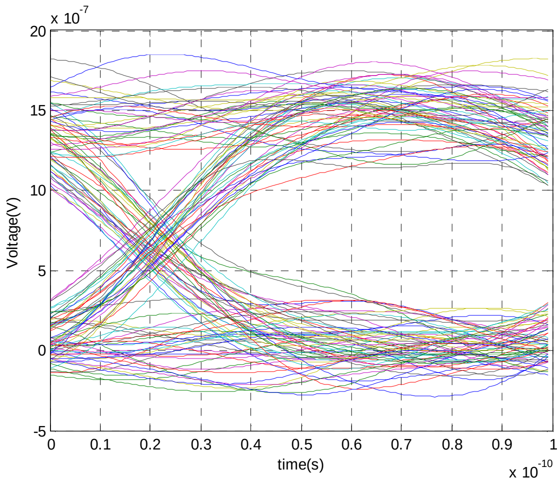

Figure 4. Eye diagram for 2-PAM

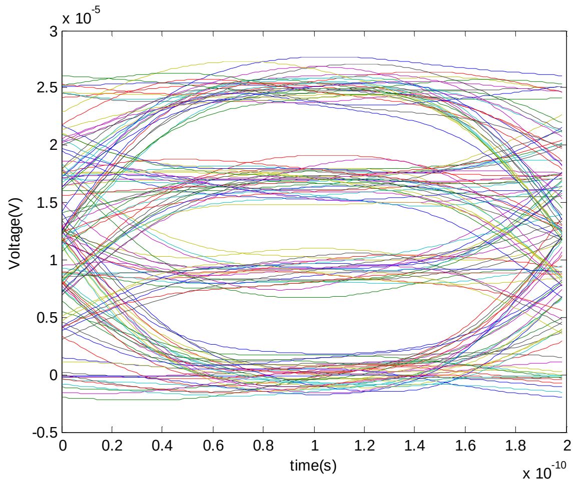

Figure 5. Eye diagram of 4-PAM

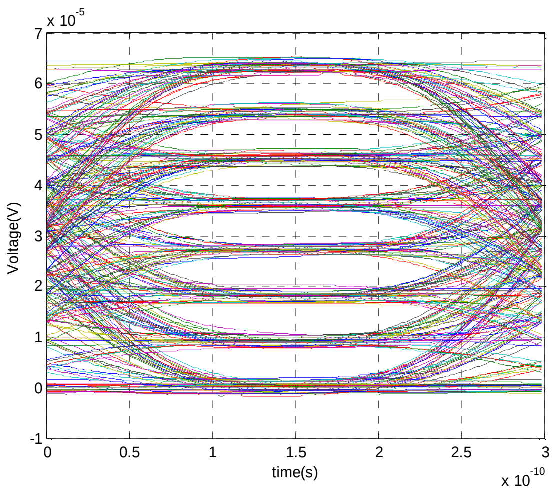

Figure 6. Eye Diagram of 8-PAM

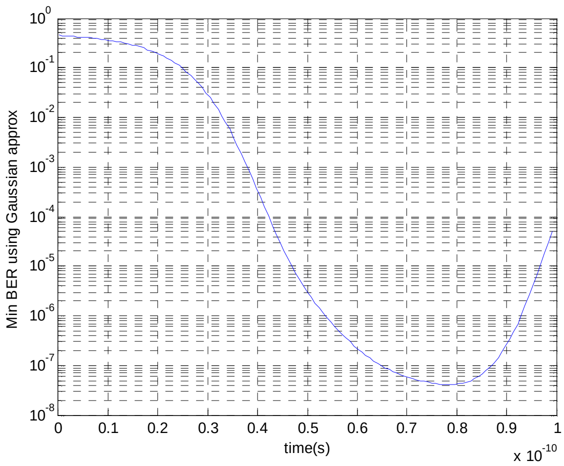

Figure 7. SER of NRZ

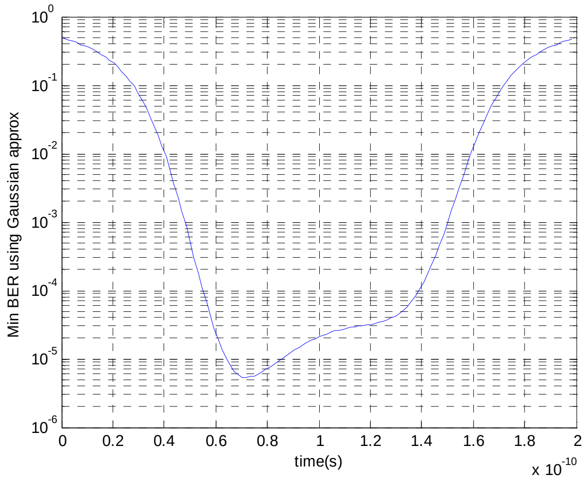

Figure 8. SER of 4-PAM

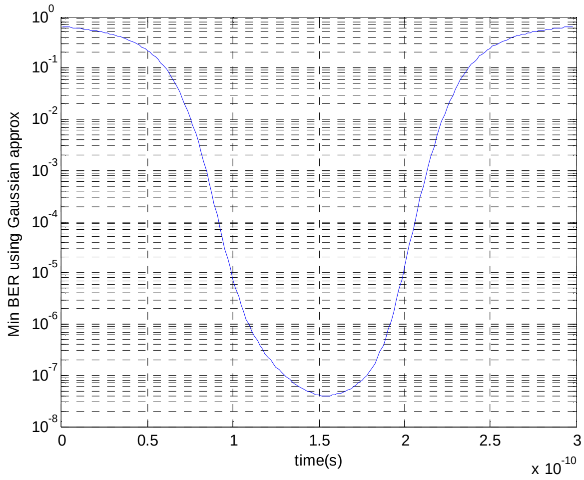

Figure 9. SER of 8-PAM

Table 1. Value From The Result (NRZ)

Q-Factor	5.8113
Threshold	$7.4465x10^{-7}$ V
Ber	4.1601 $X10^{-8}$

Table 2. Value from the Result (4- Pam)

Q-factor	Threshold	Min BER
5.0465	$4.44\ x10^{-6}$	
4.3627	$1.283\ x10^{-5}$	$5.3745\ x10^{-6}$
4.5463	$2.088\ x10^{-5}$	

Table 3. Value from the Result (8 level PAM)

Q-factor	Threshold	Min BER
6.1576	$4.69\ x10^{-6}$	
6.7193	$1.354\ x10^{-5}$	$3.9942x10^{-8}$
7.0266	$2.272\ x10^{-5}$	
6.9032	$3.167\ x10^{-5}$	
6.3315	$4.073\ x10^{-5}$	
5.6469	$4.986\ x10^{-5}$	
5.2397	$5.899\ x10^{-5}$	

In order to validate the BER result produce using the developed analyzer, a comparison against the build in BER analyzer of OptiSystem has been done as shown in Figure 10. The figure shows that the developed analyzer has close match with the build in BER analyzer of OptiSystem. This confirmed that our developed analyzer algorithm and matlab coding are valid.

Figure 11 shows the comparison between 2-PAM and 8-PAM using the developed analyzer. 8-PAM optical system requires around 20 dB SNR more compared to 2-PAM. Theoretically, in additive white Gaussian noise channel, SNR penalty is around 11 dB for equal signal level and noise variance[10]. In this optical system, other impairments contribute additional power penalty.

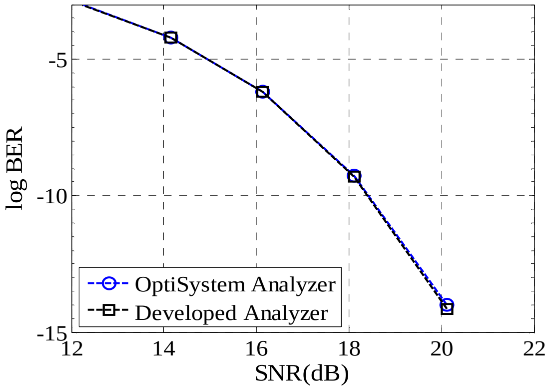

Figure 10. Comparison of log BER performance between OptiSystem and Developed Analyzerfor 2-PAM

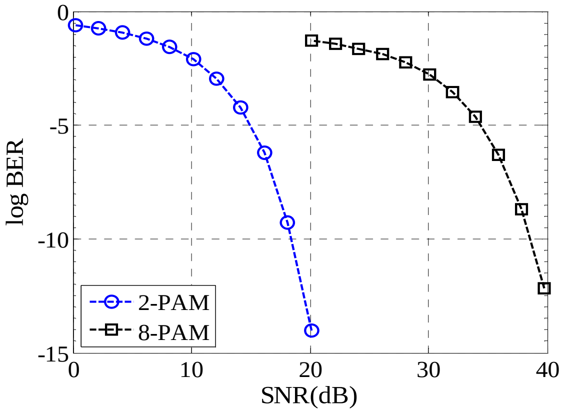

Figure 11. log BER versus SNR for 2-PAM and 8-PAM

4. CONCLUSION

In this paper, the mathematical formula that has been used to calculate the threshold value, Q-factor and bit or symbol error rate based on probability of error method for binary and M-PAM optical system has been discussed. Matlab software has used to develop the multilevel signal analyzer. The performances of 2, 4 and 8-PAM optical communication system have been analyzed using this developed analyzer. Based on the BER performance of 2-PAM, the developed analyzer gives valid estimation compared to build in OptiSystem Analyzer.

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Rahmat Talib received the BEng in electrical engineering from Universiti Kebangsaan Malaysia, in 1996 and MEng in telecommunication engineering from Universiti Teknologi Malaysia in 2004. He is currently working toward his PhD in electrical engineering at Universiti Tun Hussein Onn Malaysia. He is a student member of IEEE and Optical Society of America(OSA). His research interests include optical fibre communication, multiplexing technique and software defined radio (SDR).