Performance Analysis of OOK-NRZ and OOK-RZ digital Modulation Techniques for Free Space Optical Communication System

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Abstract---The performance of modulation techniques is frequently compared in terms of the average received optical power required to achieve a desired bit error rate at a given data rate. The power spectral density of OOK-NRZ and OOK-RZ data signals with pulse duty cycles and modulation formats have significant power contents at DC and low frequencies. Whereas the bandwidth efficiency depends on the duty cycle. Moreover the RZ does not support sample clock recovery at the receiver because it allows a long low signal without any 0 to 1 transition. Therefore, bit stuffing is necessary which further decreases bandwidth efficiency.

Keywords---*ON Off Keying, Pulse Width Modulation, Return to Zero, Non Return to Zero, Power Spectral Density.*

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I. INTRODUCTION

In this class signaling schemes, the data have not been translated to a much higher carrier frequency prior to intensity modulation of the optical source. Thus, a significant portion of the signal power is restricted to the DC region Baseband modulation techniques [1]. Because the spectrum of the modulated data is in the vicinity of DC Baseband schemes that include, among others, OOK and the family of pulse time modulation (PTM) techniques, are more tolerant to the effects of the multipath channel OOK is the simplest technique, in which the intensity of an optical source is directly modulated by the information sequence. In distinction, PTM techniques use the information sequence to vary some time-dependent property of a pulse train Popular examples of such schemes include pulse width modulation (PWM), in which the width of the pulses convey the information, and PPM, in which the information is represented by the position of the pulses within fixed time frames. In DPIM, the

information is represented by the number of empty slots between pulses, potentially allowing higher data rates and improvements in power efficiency compared to OOK and PPM [1][2]. Dual-header pulse interval modulation (DH-PIM), which is a variation on PIM reduces the number of 'empty' slots, and therefore symbol length, by introducing a second pulse at the start of the information symbol. The technique offers a trade-off between the lower bandwidth requirement of the longer pulse and the subsequent higher average optical power requirement At higher bit rates, the scheme is both bandwidth and power efficient compared to PPM. Contrasting the fixed symbol length of PPM, both DPIM and DH-PIM offer symbol synchronization due to the pulse always being at the start of the symbol [3]. To minimize the performance degradation of pulse modulation schemes adopted in a highly dispersive indoor environment with a large delay spread, maximum likelihood sequence detection (MLSD) as well as decision feedback equalizer can be employed, but at the cost of higher system complexity [5].

II. ON–OFF KEYING

OOK is the most reported modulation techniques for IM/DD in optical communication. This is apparently due to its simplicity. In simple representation bit one an optical pulse that occupies the entire or part of the bit duration while a bit zero is represented by the absence of an optical pulse Both the return-to-zero (RZ) and nonreturn- to-zero (NRZ) schemes can be applied [4]. In the NRZ scheme, a pulse with duration equal to the bit duration is transmitted to represent 1 while in the RZ scheme the pulse occupies only the partial duration of bit Figure1 shows the single mapping of OOK-NRZ and OOK-RZ with a duty cycle g = 0 5 for average transmitted power of *P*avg Hence, the envelop for OOK-NRZ is given by [6]

$$p(t)=\begin{cases}2P_r & fort\in[0,T_b]\\ 0 & elsewhere\end{cases} \quad (1)$$

where T_b is the bit duration and *P*r is the average power

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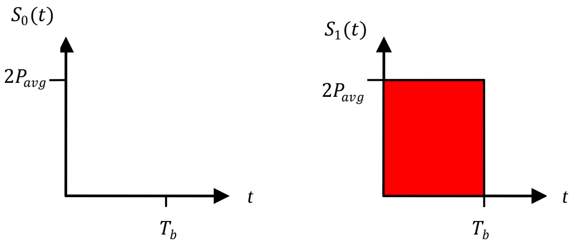

Fig. 1 Waveforms for On Off Keying using Non Return Zero

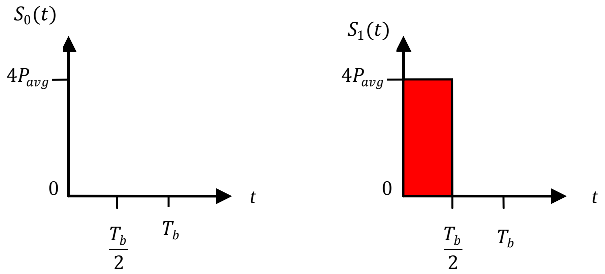

Fig. 2 Waveforms for On Off Keying using Return Zero (g = 0.5)

The simplicity of OOK has led to its use in commercial optical wireless systems such as IrDA, Fast IR links operating below 4 Mbit/s. In these communication links, return-to zero- inverted (RZI) signaling is used, where a pulse represents a zero rather than a one [7]. At bit rates up to and including 115.2 kbit/s, the pulse duration is nominally 3/16 of the bit duration. For data rates of 0.576 and 1.152 Mbit/s, the pulse duration is nominally 1/4 of the bit duration PPM is also used at higher date rates (>4 Mbps) The electrical power spectral densities (PSDs) of the OOK-NRZ and OOK-RZ (g = 0.5) Assuming independently and identically distributed (IID) one and zeros are given by

$$S_{OOK-NRZ}(f)=(P_rR)^2T_b\left(\frac{\sin\pi fT_b}{\pi fT_b}\right)^2\left[1+\frac{1}{T_b}\delta(f)\right] \qquad (1.2)$$

$$S_{OOK-RZ(\gamma=0.5)}(f)(f)=(P_rR)^2T_b\left(\frac{\sin\pi fT_b/2}{\pi fT_b/2}\right)^2\left[1+\frac{1}{T_b}\sum_{n=-\infty}^{\infty}\delta\left(f-\frac{n}{T_b}\right)\right] \qquad (1.3)$$

where δ( ) is the Dirac delta function.

III. PSDs of OOK-NRZ and OOK-RZ

The PSDs of OOK-NRZ and OOK-RZ are plotted in Figure 3. The pow axis is normalized to the average electrical power multiplied by the bit duration (*P*r*R*)2 *T*b and the frequency axis is normalized to the bit rate *R*b (=1/*T*b) Both curves were plotted using the same average optical power *P*r.

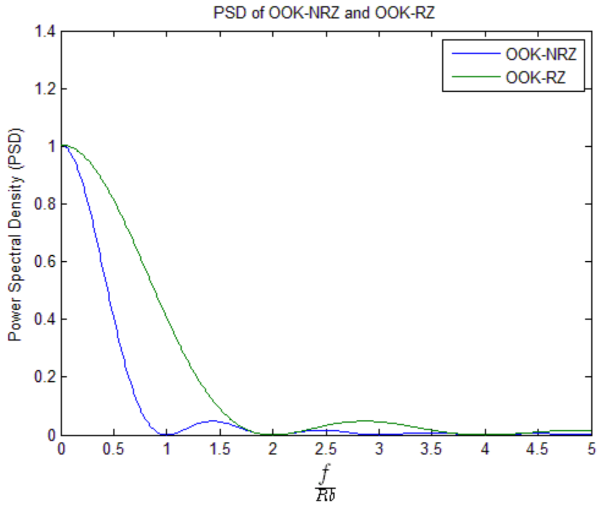

Fig. 3 PSD of OOK-NRZ and OOK-RZ (g = 0 5)

IV PSD of PPM

For most of the modulation techniques the bandwidth requirement is normally defined as the span from DC to the first null in the PSD of the transmitted signal. As expected, OOK-RZ (g = 0.5) has twice the bandwidth requirement of OOKNRZ, since the pulses are only half as wide Both OOK-NRZ and OOK-RZ (g = 0.5) have discrete terms at DC, with a weight *P*r 2 OOK-RZ (g = 0.5) also has discrete terms at odd multiples of the bit rate Figure 3. The impulse at $f = R_b$ can be used to recover the clock signal at the receiver OOK-NRZ, on the other hand, has spectral nulls at multiples of the bit rate, and consequently requires the introduction of some nonlinearity in order to achieve clock recovery. Both OOK-NRZ and OOK-RZ have significant power contents at DC and low frequencies. This characteristic means that electrical high-pass filtering is not effective in reducing the interference produced by artificial sources of ambient light, since high cut-on frequencies cannot be used without introducing significant baseline wander. Comparing the areas under the two curves it is evident that, for a given average optical transmit power, OOK-RZ (g = 0.5) has twice the average electrical power of OOK-NRZ. The OOK-NRZ has power efficiency ηp of 2 and bandwidth efficiency η*B* of 1. The OOK-RZ has the same power efficiency as OOK-NRZ; however, bandwidth efficiency depends on the duty cycle. The bandwidth efficiency for g = 1/4 is 0.25 Furthermore, RZ does not support sample clock recovery at the receiver because it allows a long low signal without any 0 to 1 transition. Therefore, bit stuffing is necessary which further decreases bandwidth efficiency.

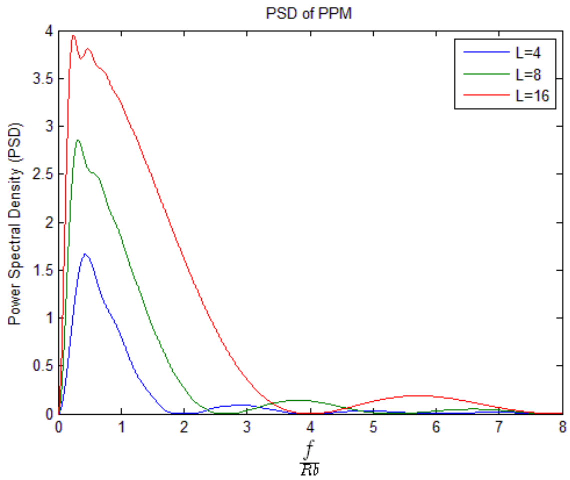

Fig. 4 PSD of PPM for L = 4, 8 and 16

The PSD of PPM for L = 4, 8 and 16 is shown in Figure 4. The three curves were constructed using the same average optical power, using rectangular pulse shapes occupying the full slot duration. The power axis is normalized to the average electrical power multiplied by the duration The frequency axis is normalized to the bit rate Rb. From Figure 4, it is easily seen that unlike OOK, the PSD of PPM falls to zero at DC for all values of L. This phenomenon provides an increased resistance to baseline wander over DC schemes and allows the use of higher cut on frequencies when mitigating high-pass filtering is employed to combat artificial light interference. As expected, by observing the positions of the first spectral nulls, it is clear that the bandwidth requirement increases as L increases. Furthermore, comparing the areas under the curves, it may also be observed that for a given average optical power, the detected electrical power increases as L increases.

V. CONCLUSION

In this paper simulation results shown for the power spectral density of of OOK-NRZ and OOK-RZ data signals with pulse duty cycles and modulation formats have significant power contents at DC and low frequencies. These results shows that electrical high-pass filtering is not effective in reducing the interference produced by artificial sources of ambient light. By comparing the areas under the curves, it may also be observed that for a given average optical power, the detected electrical power increases as L increases.

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