Effects of artificial light interference on optical wireless systems employing DH-PIM

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Abstract

We examine the effects of artificial light interference on optical systems employing dual header pulse interval modulation (DH-PIM). This interference can be reduced using high pass filtering (HPF). However, the HPF generates an interference called baseline wander. We study the effects of changing the HPF cut-on frequency in the absence and presence of multipath propagation. Results show that depending on the value of the HPF cut-on frequency, the severity of baseline wander will vary and thus there is a trade off between the extent of artificial light interference rejection and the severity of baseline wander.

1. Introduction

Indoor optical wireless systems are subject to shot noise induced by the ambient light resulting from natural and artificial sources [1-3]. The artificial lights, and in particular fluorescent lamps, introduce a periodic interference signal at the receiver, which can contain harmonics up to 50 kHz for lamps driven by the mains frequency and up to 1 MHz when driven by high frequency electronic ballasts [4-6]. Electrical high-passing filter could be employed to reduce the effects of fluorescent light interference. However filtering results in a form of intersymbol interference (ISI) known as the baseline wander, which is more severe if the modulation technique spectrum has significant amount of power at low frequencies and DC.

Dual header pulse interval modulation (DH-PIM) offers efficient exploitation of many characteristics of optical wireless systems because of its built-in symbol synchronisation and relatively straightforward slot synchronisation, higher bit rate, shorter symbol length, reduced bandwidth requirements and improved immunity to multipath dispersion at high dispersive mediums [7-8]. However it requires slightly higher optical power and offers higher probability of errors compared with pulse position modulation (PPM) and digital pulse interval modulation (DPIM) [7-9]. DH-PIM symbol is composed of a header followed by a number of empty slots corresponding to the decimal value of input data word. The header duration could be either $\alpha T_s/2$ or αT_s, where α is a positive integer and T_s is the slot duration. Assuming M is the input data resolution and $L = 2^M$, the following notations will be used in this paper L-DH-PIM$_\alpha$, L-DPIM and L-PPM showing the values of L and α Previous studies have shown that the power spectral density (PSD) of DH-PIM pulse train contains low frequency and Dc components in contrast to PPM, which has no DC component [7]. Thus to reduce the effects of artificial lights and minimise the effect of baseline wander at the same time, the optimum cut-on frequency of the high pass filter needs identifying.

2. System Model

Figure 1 shows the system block diagram used in the study. M-bits input data are converted into a DH-PIM symbols that are transmitted through a transmitter filter with a unit-amplitude rectangular impulse response $p(t)$. Then the output of the transmitter filter is scaled by the peak photocurrent I_p and the channel interference (fluorescent light interference photocurrent) as well as the background shot noise $n(t)$, which is then passed though a high-pass filter followed by a matched filter with impulse response $r(t)$ matched to $p(t)$. The filter output is sampled at the end of each slot duration the output of which is compared with a threshold level, set midway between the amplitudes of a pulse and a zero, to re-generate the a pulse or empty slot depending on weather the signal is above or below the threshold level. A DH-PIM decoder then re-generates the M-bit data stream.

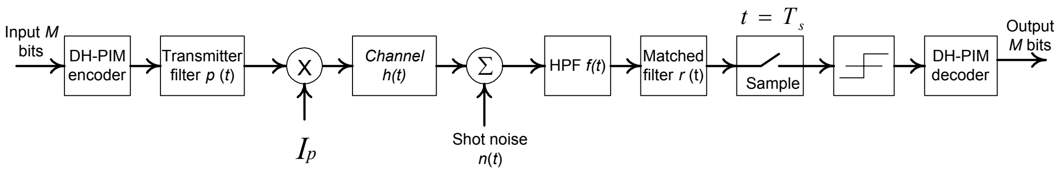

Fig. 1: Block diagram of the DH-PIM system.

The high pass filter can be modelled as a first order RC filter with cut-on frequency f_c and impulse response $f(t)$ given as [9]:

$$f(t)=\begin{cases}\left(\dfrac{\overline{L}-1}{\overline{L}}\right)Ve^{-t/RC} & 0\le t\le T_s \\ -\left(\dfrac{\overline{L}-1}{\overline{L}}\right)V\left(e^{T_s/RC}-1\right)e^{-t/RC} & t>T_s\end{cases} \quad (1)$$

where V is the pulse amplitude, RC is the filter time constant and $\overline{L}$ is the average symbol duration of a DH-PIM signal which can be given as $\overline{L}=\left(2^{M-1}+2\alpha+1\right)/2$ [7].

The simulation has been carried out using Matlab for different values for L, α, and bit rate. The ambient light has been modelled as an additive white Gaussian shot noise and independent of the received signal. The simulation assumed the ISI caused by fluorescent light spans over 9 slots and therefore random sequences of pulse trains with duration of 9 slots have been generated and only the valid DH-PIM sequences were considered in the simulation. The probabilities of occurrence for these sequences have been calculated. For different values of HPF cut-on frequencies, the optical power required to achieve a slot error rate of 10^{-9} have been calculated.

The probability of slot error for each sequence $P_{se,i}$ has been multiplied by the probability of occurrence of that sequence $P_{occ,i}$ and summing up of the results for all the valid sequences gives the average probability of slot error [7]:

$$P_{se}=\sum_{\text{all } i}P_{occ,i}P_{se,i}\,. \quad (2)$$

The power penalty is the difference in power requirements between the cases of not taking baseline wander effect in account and when it is taken into account. For the cases of multipath dispersion, different values of normalised delay spread have been taken in account in order to show the effect of HPF cut-on frequency on the DH-PIM signal when multipath propagation is used. In all the results, the HPF cut on frequency f_c is normalised to the bit rate R_b and the maximum power requirement was limited to 10 dB in the simulation to reduce the computational time.

3. Results

Figure 2 shows the optical power penalty against f_c/R_b ratio for the OOK, 8-PPM, 8-DPIM, 8-DH-PIM$_1$ and 8-DH-PIM$_2$ for a bit rate of 1Mbps and no multipath dispersion. The power penalty of DH-PIM signal starts to increase at lower values of f_c compared with PPM and DPIM and at higher frequency compared with OOK. For f_c/R_b > 0.5, the power penalty of DH-PIM is similar to those of PPM and DPIM and is much lower than that of OOK. This is due to the presence of higher power low frequency components for the case of DH-PIM compared with DPIM and PPM.

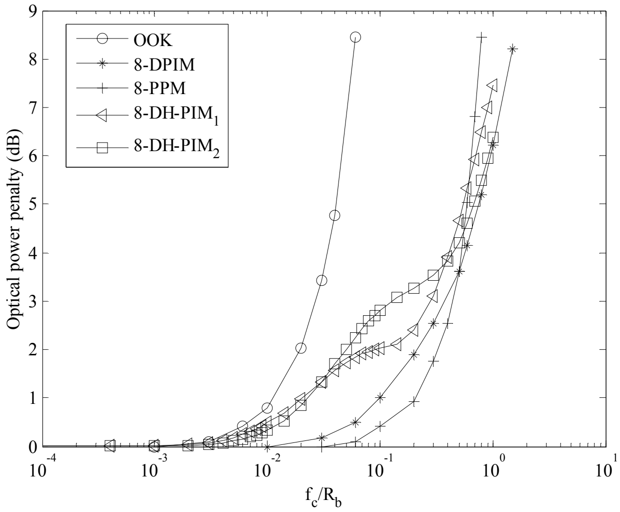

Fig. 2: Optical power penalty versus f_c/R_b for OOK, 8-PPM, 8-DPIM, 8-DH-PIM$_1$ and 8-DH-PIM$_2$.

For multipath channel, additional ISI is introduced that increases with the normalised delay spread (NDS). NDS is defined as the RMS delay spread divided by the bit rate D_T/R_b. Figure 3 shows the optical power requirements against f_c/R_b for 8-DH-PIM$_1$ for NDS = 0.01, 0.05 and 0.1. For f_c/R_b < 0.01, the power requirements are almost constant for all values of NDS with DH-PIM requiring about 0.6 dB and 0.4 dB less power as NDS decreases from 0.1 to 0.05 to 0.01, respectively. However for f_c/R_b > 0.01, the power requirements shows an exponential increase for all values of NDS, requiring the same penalty beyond f_c/R_b > 0.5.

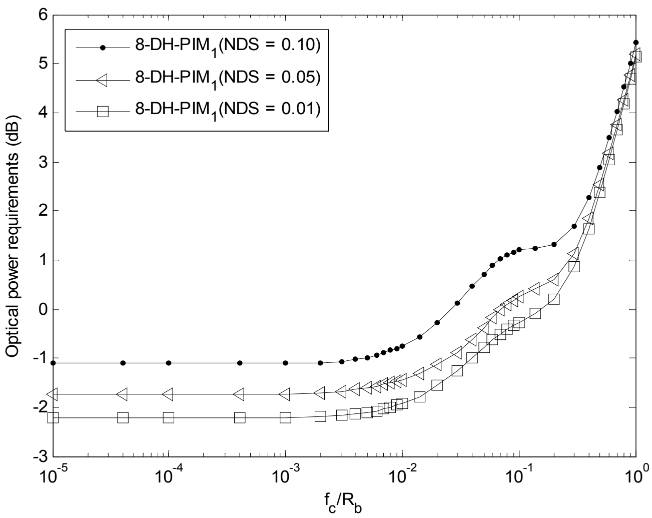

Fig. 3: Optical power requirements against f_c/R_b for 8-DH-PIM$_1$ for different normalised delay spread values.

To show the effects of the data bit rate on the system power penalty when multipath dispersion is high (i.e. NDS = 0.1), the optical power requirements versus f_c/R_b for 8-DH-PIM$_1$ for and bit rates of 1, 10 and 100 Mbps are shown in Fig. 4. Here for f_c/R_b < 0.01, DH-PIM requires about 5 dB more power as R_b increases from 1 Mbps to 10 Mbps and from 10 Mbps to 100 Mbps. However, as f_c/R_b increases above 0.01, the power requirements starts to increase more rapidly in the case of 1 Mbps than 10 Mbps and 100 Mbps.

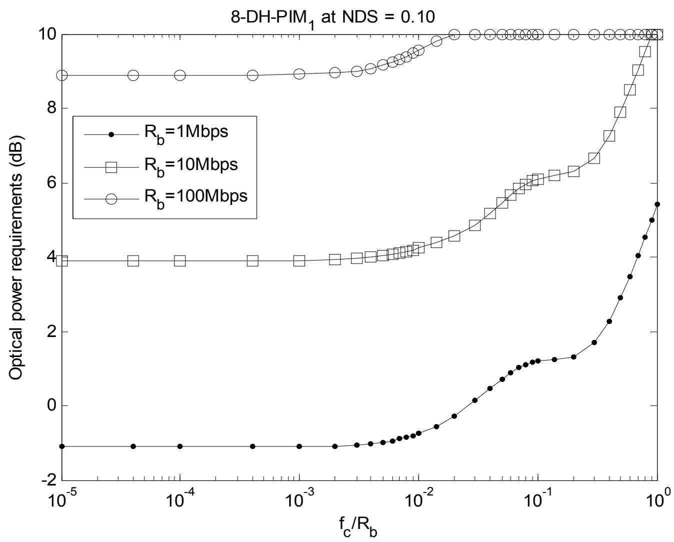

Fig. 4: Optical power requirements against f_c/R_b for 8-DH-PIM$_1$ for NDS = 0.1 and different bit rates.

4. Conclusions

We have studied the effects of artificial light interference on optical wireless systems operating DH-PIM technique. The use of HPF reduces the artificial light interference at the expense of introducing baseline wander whose severity depends on the HPF cut-on frequency. Thus there should be a trade off between the extent of fluorescent light interference rejection and the severity of baseline wander.

5. References

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