Comments and Corrections

Comments on "An Enhanced Detection Technique for Spectral Amplitude Coding Optical CDMA Systems"

Hossam M. H. Shalaby, *Senior Member, IEEE*

***Abstract*— It has been shown in the above letter that the use of multiphotodiode balanced detection (MPBD), in spectral-amplitude coding optical code-division multiple-access systems, reduces the effect of phase-induced intensity noise (PIIN) at a cost of added complexity. In this letter, we show that this claim is not true, and the MPBD scheme retains the effects of PIIN as the conventional balanced detector does.**

***Index Terms*— Multiphotodiode balanced detection (MPBD), optical code-division multiple-access (OCDMA), phase-induced intensity noise (PIIN), spectral-amplitude coding (SAC).**

I. Introduction

In the above letter [1], a multiphotodiode balanced detection (MPBD) scheme has been proposed for the detection of spectral-amplitude coding optical code-division multiple-access (SAC-OCDMA) signals. SAC-OCDMA is an attractive multiple-access technique because of its simplicity and its ability to eliminate the effect of the multiple-access interference [2]. Balanced detectors, shown in Fig. 1, are normally used at the receiver in order to be able to cancel the effect of the multiple-access interference [2]. The main source of performance degradation in this technique, however, is the phase-induced intensity noise (PIIN). This type of noise results from the incoherency of the broadband light sources of different users of the system [3]. Since the PIIN is proportional to the square of the received power, the authors in [1] tried to reduce its effect by splitting the received filtered optical power into two branches and sending their outputs to two photodiodes as shown in Fig. 2. Since the received power at each photodiode is reduced by a factor of 4, the authors in [1] thought that the resulting PIIN will be reduced by a factor of 2. The price is some added complexity of the system because of doubling the number of photodiodes. If their idea was true, then in fact one could completely cancel the effect of PIIN by using a star coupler along with an array of photodiodes. Unfortunately, this is not true and the MPBD cannot reduce the PIIN effect, even by the factor given above. In the next section we derive a mathematical analysis of the MPBD scheme and confirm our claim.

Manuscript received February 13, 2012; revised March 18, 2012; accepted March 19, 2012. Date of publication April 3, 2012; date of current version July 10, 2012.

The author is on sabbatical leave from the Electrical Engineering Department, Alexandria University, Alexandria 21544, Egypt. He is now with the Department of Electronics and Communications Engineering, Egypt-Japan University of Science and Technology, Alexandria 21934, Egypt (e-mail: shalaby@ieee.org).

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Digital Object Identifier 10.1109/LPT.2012.2192259

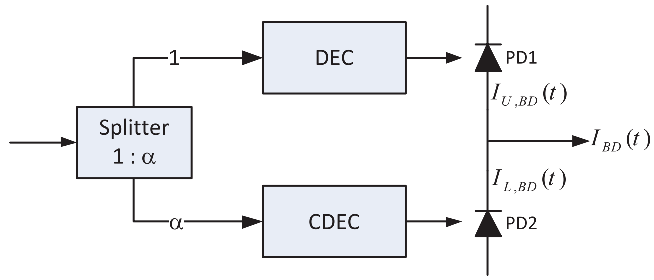

Fig. 1. Structure of a conventional balanced detector [1]. DEC: decoder filter. CDEC: complementary decoder filter.

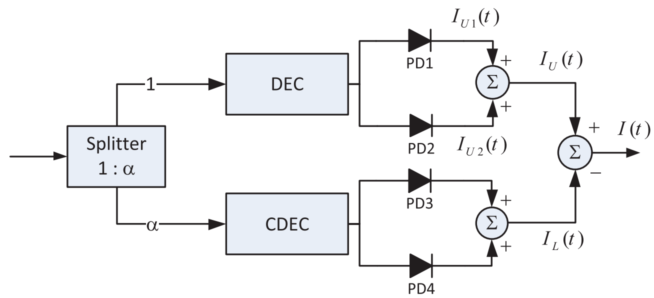

Fig. 2. Structure of a multiphotodiode balanced detector [1].

II. Mathematical Analysis of PIIN in Both Multiphotodiode and Conventional Balanced Detectors

Since our interest is to show that the effect of PIIN does not improve when using MPBD, in our analysis below we neglect both thermal and shot noises and focus only on the PIIN noise. In fact in [1], it has been shown that the effect of both shot and thermal noises does no improve when using MPBD.

A. Effect of PIIN in a Multiphotodiode Balanced Detector

The decision current $I(t)$ of the multiphotodiode balanced detector of Fig. 2 is given by

$$I(t) = I_U(t) - I_L(t), \tag{1}$$

where $I_U(t)$ and $I_L(t)$ are the detected currents of the upper and lower branches, respectively. In our analysis in this letter we focus only on the upper-branch current $I_U(t)$ since a similar analysis applies to the lower-branch current as well.

1) Means and Variances of Currents at the Upper-Branch: Consider a SAC-CDMA code, where each code sequence has a weight w and a length L. Assume (without loss of generality) that the desired user has its mark chips located at the first w positions of the code sequence, i.e., $\{1, 2, \ldots, w\}$. When incoherent light from ideal broadband light sources is incident on photodide PD1 of Fig. 2, the resultant incident field component, for spectral chip $n \in \{1, 2, \ldots, w\}$, can be written as:

$$r_{U1}^{n}(t) = \sum_{k=1}^{K_n} \frac{E_0}{\sqrt{2}} e^{j\phi_k(t)}, \tag{2}$$

where K_n is the number of users sending one in spectral chip n, E_0 is the envelope of a single-user light field that outputs from the decoder filter, and $\phi_k(t), k \in \{1, 2, \ldots, K_n\}$, is the phase of the kth optical signal, assumed to be a Wiener-Levy process [4], [5]. The division of $\sqrt{2}$ is due to the use of a 3-dB coupler immediately after the decoder filter. Notice that

$$\sum_{n=1}^{w} K_n = K, \tag{3}$$

where K is the total number of users sending one. If the photodiode responsivity is denoted by $\mathcal{R}$, then the detected current of PD1 is given by

$$\begin{aligned} I_{U1}(t) &= \mathcal{R} \sum_{n=1}^{w} |r_{U1}^{n}(t)|^2 = \mathcal{R} \sum_{n=1}^{w} \Big| \sum_{k=1}^{K_n} \frac{E_0}{\sqrt{2}} e^{j\phi_k(t)} \Big|^2 \\ &= \frac{\mathcal{R}|E_0|^2}{2} \sum_{n=1}^{w} \sum_{k=1}^{K_n} \sum_{l=1}^{K_n} e^{j[\phi_k(t) - \phi_l(t)]}. \end{aligned} \tag{4}$$

Let the average user power be denoted by P_0. Noticing that $|E_0|^2$ is the average user power per spectral chip, the last equation can be rewritten as follows.

$$\begin{aligned} I_{U1}(t) &= \frac{\mathcal{R}P_0}{2L} \sum_{n=1}^{w} \left[K_n + \sum_{k=1}^{K_n} \sum_{l=1, l \neq k}^{K_n} e^{j[\phi_k(t) - \phi_l(t)]} \right] \\ &= \frac{\mathcal{R}P_0}{2L} \left[K + 2 \sum_{n=1}^{w} \sum_{k=1}^{K_n - 1} \sum_{l=k+1}^{K_n} \cos\left(\phi_k(t) - \phi_l(t)\right) \right] \\ &= \frac{\mathcal{R}P_0}{2L} \left[K + X_U(t) \right], \end{aligned} \tag{5}$$

where $X_U(t)$ is a zero-mean random process, given by:

$$X_U(t) \stackrel{\text{def}}{=} 2 \sum_{n=1}^{w} \sum_{k=1}^{K_n - 1} \sum_{l=k+1}^{K_n} \cos\left[\phi_k(t) - \phi_l(t)\right]. \tag{6}$$

The mean and variance of $I_{U1}(t)$ are thus given by:

$$\begin{aligned} \mu_{U1} &= \mathrm{E}\{I_{U1}(t)\} = \frac{\mathcal{R}P_0}{2L} K \\ \sigma_{U1}^2 &= \mathrm{var}\{I_{U1}(t)\} = \left(\frac{\mathcal{R}P_0}{2L} \right)^2 \sigma_{X_U}^2, \end{aligned} \tag{7}$$

respectively, where $\sigma_{X_U}^2$ is the variance of $X_U(t)$. Similarly, it can be shown that the detected current of PD2 is given by

$$I_{U2}(t) = \frac{\mathcal{R}P_0}{2L} \left[K + X_U(t) \right], \tag{8}$$

which is exactly the same as that of $I_{U1}(t)$ of (5), leading to same mean and variance as given in (7).

2) PIIN at the Upper-Branch: From Fig. 2, the total upper-branch currrent is given by:

$$I_U(t) = I_{U1}(t) + I_{U2}(t). \tag{9}$$

It is now clear that the authors of [1] have assumed that $I_{U1}(t)$ and $I_{U2}(t)$ are independent of each other and thus, they obtained

$$\begin{aligned} \sigma_{PIIN,U}^2 &= \mathrm{var}\{I_U(t)\} \\ &= \sigma_{U1}^2 + \sigma_{U2}^2 = \frac{1}{2} \left(\frac{\mathcal{R}P_0}{L} \right)^2 \sigma_{X_U}^2, \end{aligned} \tag{10}$$

which is half the true value. However, from (5) and (8), it is obvious that $I_{U1}(t)$ and $I_{U2}(t)$ are dependent on each other through $X_U(t)$, and hence from (5), (8), and (9), we get

$$I_U(t) = I_{U1}(t) + I_{U2}(t) = \frac{\mathcal{R}P_0}{L} \left[K + X_U(t) \right], \tag{11}$$

leading to

$$\sigma_{PIIN,U}^2 = \left(\frac{\mathcal{R}P_0}{L} \right)^2 \sigma_{X_U}^2, \tag{12}$$

which is exactly the same as that of the upper-branch of the conventional balanced detector, Fig. 1. The latter can be obtained using a similar analysis to that given above, leading to

$$I_{U,BD}(t) = \frac{\mathcal{R}P_0}{L} \left[K + X_U(t) \right]. \tag{13}$$

III. Conclusion

The effect of PIIN on the performance of SAC-CDMA systems, adopting multiphotodiode balanced detectors, has been mathematically analyzed. It turned out that the MPBD scheme retains the effect of PIIN as the conventional balanced detector does. There is no advantage of multiphotodiode balanced detector over conventional balanced detector, rather it is more complex and encompasses excess insertion loss than the conventional one.

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[1] A. M. Alhassan, N. M. Saad, and N. Badruddin, "An enhanced detection technique for spectral amplitude coding optical CDMA systems," *IEEE Photon. Technol. Lett.*, vol. 23, no. 13, pp. 875–877, Jul. 1, 2011.

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Author's Reply

Ahmed M. Alhassan, N. M. Saad, and Nasreen Badruddin

I. Introduction

The point highlighted by Shalaby is an important point that we didn't take into consideration. In the original paper we considered that when an optical signal from a broadband source is split into two, the two signals can be considered as independent. Since the paper was accepted in this journal, and none of the three reviewers gave any comments regarding the correlation between the two split signals, we considered that our work was correct. In the next section we show why we assumed that the two split signals were independent.

II. Intensity Noise

In spontaneous emission sources such as Light Emitting Diode (LED) or Amplified Spontaneous Emission (ASE), the number of atoms contributing to the light emitted by the source is very large. Moreover, all the different atoms have different propagation direction with different phases. The light emitted by such sources can be modeled as thermal light [1].

We assume that the flow of light as a sum of a very large number N of atoms. Where each atom is represented as a random phasor with random length of $\alpha_i/\sqrt{N}$ and a random phase of φ_i. The phasor of the sum with amplitude a and phase θcan be expressed as:

$$A = ae^{j\theta} = \frac{1}{\sqrt{N}}\sum_{i=1}^{N}\alpha_i e^{j\varphi_i}. \quad (1)$$

The following assumptions where made by Goodman on the statistical properties of the elementary phasors composing the sum [1].

1) The amplitude $(\alpha_i/\sqrt{N})$ and phase (φ_i) for the ith element is independent of each other, and of the amplitudes and phases of all other different elements.
2) The random variables α_i are all identically distributed for all values i, with an average of $\overline{\alpha}$ and second order moment denoted as $\overline{\alpha^2}$.
3) All the phases φ_i are uniformly distributed over $[-\pi, \pi]$ for all values of i.

Based on the above assumptions, we can consider the light from a broadband source as sum of independent atoms or photons. Thus when splitting the signal into two, we considered that the two signals are independent.

Manuscript received June 1, 2012; accepted June 1, 2012. Date of current version July 10, 2012.

The authors are with the Electrical and Electronic Engineering Department, Universiti Technologi Petronas (UTP), Perak 31750, Malaysia (e-mail: ahmed7060@yahoo.com; Naufal_saad@petronas.com.my; Nasreen.b@petronas.com.my).

Digital Object Identifier 10.1109/LPT.2012.2203209

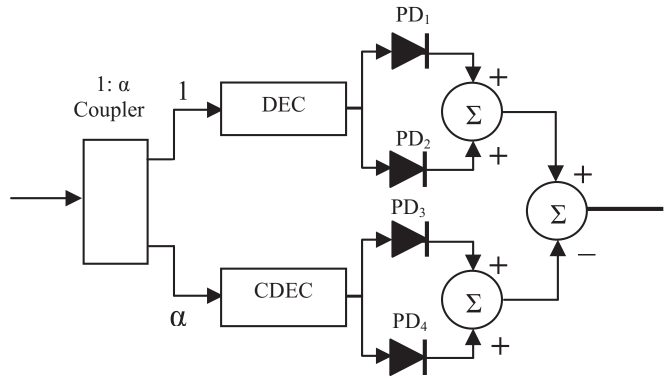

Fig. 1. Structure of the multi photodiode balanced detection technique [3].

For this reason we considered that the variance in the upper branch (the same applies on the lower branch) of the multi photodiode balanced detection (MPBD) in Fig. 1 is given by

$$\mathrm{var}(I_1 + I_2) = \mathrm{var}(I_1) + \mathrm{var}(I_2) \quad (2)$$

where I_1 and I_2 are current from the from PD_1 and PD_2.

It is obvious now that the assumption given above is highly optimistic and some correlation will always exist between the two split signals. However, the results given in [2] can be considered as an upper limit in the performance improvement if independence between the two split signals can be achieved.

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Erratum to "Design of Low-Threshold Photonic Crystal Surface-Emitting Lasers"

Chih-Tsang Hung, Yu-Cheng Syu, Tzeng-Tsong Wu, and Tien-Chang Lu

In [1], the second author's e-mail address was printed incorrectly. The correct e-mail address is rickson_519@yahoo.com.tw.

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[1] C.-T. Hung, Y.-C. Syu, T.-T. Wu, and T.-C. Lu, "Design of low-threshold photonic crystal surface-emitting lasers," *IEEE Photon. Technol. Lett.*, vol. 24, no. 10, pp. 866–868, May 15, 2012.

Manuscript received April 30, 2012. Date of current version July 10, 2012.

C.-T. Hung, T.-T. Wu, and T.-C. Lu are with the Department of Photonics, Institute of Electro-Optical Engineering, National Chiao Tung University, Hsinchu 30010, Taiwan (e-mail: dolphone01@gmail.com; mulderbob.eo98g@nctu.edu.tw; timtclu@mail.nctu.edu.tw).
Y.-C. Syu is with the Display Institute, National Chiao Tung University, Hsinchu 30010, Taiwan (e-mail: rickson_519@yahoo.com.tw).

Digital Object Identifier 10.1109/LPT.2012.2200159