Enhancing the Power Spectral Density of PPM TH-IR UWB Signals Using Sub-Slots Technique

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Summary
The suppression of the spectral line is an issue of large interest in the design of compliant Time Hopping Impulse Radio (TH-IR) Ultra-Wide Band (UWB) systems. This issue has been previously addressed by randomizing the position of each pulse to make the period as large as possible. Our analysis suggests that randomizing the position of each pulse influences the overall shape of a signal's Power Spectral Density (PSD) in a way useful for spectral line suppression and diminishing the PSD maximum peak power. The method and system for generating a Dynamic Location Pulse Position Modulated (DLPPM) signal for transmission across an UWB communications channel are presented. An analytical derivation of the PSD of a DLPPM signal TH-IR UWB is introduced. Our proposal can be applied without affecting the users of other concurrent applications. The theoretical model for DPLM TH-IR is compared with the PSD for conventional Pulse Position Modulation (PPM) TH-IR. The results show that Fast Fourier Transform (FFT) based spectral estimation methods significantly overestimate the continuous part of the PSD for small and medium signal lengths, which have implications in assessing interference margins by means of simulation. Finally, the proposed system for DPLM TH-IR has been built inside Simulink/MATLAB to test its results via conventional PPM TH-IR system.
Key words:
FFT, PPM, PSD, Spectral Estimation, TH-IR, UWB.

1. Introduction

Impulse Radio (IR) based UWB systems are the leading candidate for low power, low complexity, low rate, long battery life communication systems, and immunity to multipath interference characteristics. The applications involving such systems range from collision avoidance automotive systems to sensor networks. IR-UWB technology (also referred to as impulse, baseband, and zero-carrier technology, uses very short pulses) which implies a large signal bandwidth, to convey information [1]. Different modulation techniques such as Pulse Amplitude Modulation (PAM), Pulse Interval Modulation (PIM), Pulse Shape Modulation (PSM), Pulse Position Modulation (PPM), On-Off Keying (OOK), and Bi-Phase Shift Keying (BPSK) are used to transmit the information in such systems [2, 3]. In PPM, the information is determined by the position of one pulse [4].

In order to deploy such applications, the interference from UWB based devices to already established narrowband deployments must be kept to satisfactory levels. As a consequence, the PSD of IR-UWB based devices must comply with regulatory spectral masks such as the one used by the Federal Communications Commission (FCC) [5]. In this context, simulation of the signals produced by UWB devices with their corresponding PSD estimation by FFT methods is a necessary step for the evaluation and improvement of such systems before actually building the physical prototype.

Conventional PPM TH-IR typically assumes a fixed timing offset between pulses in the signal set. This has several drawbacks for UWB systems. Therefore, there is a need for a modulation scheme that realizes the benefits of standard PPM while providing greater randomness. So, there is a need for a novel PPM scheme that is more robust to fixed timing offset effects while allowing for a greater throughput in UWB system than conventional PPM TH-IR scheme. Therefore, methods and systems for generating a Dynamic Location Pulse Position Modulation (DLPPM) have been introduced.

In previous researches [1, 6, 7], the behaviour of simulation FFT based PSD estimation of UWB signals was analysed by comparing the results with analytical and actual measurements. This paper is as an extension of such works where a comparison between the proposed system with existed system is introduced.

The use of FFT-periodogram estimation methods for spectrum analysis of random signals is well studied in literature [8]. However, some constraints must be observed when using these methods with the purpose assessing, via simulation, the PSD behaviour of a particular UWB system before implementation. In this work, the behaviour of such estimation methods for DLPPM TH-IR as a function of the sample length is analysed comparing the results with previous works, conventional PPM TH-IR, obtained with a swept spectrum analyser. This allows the identification of several issues that must be considered for enhancing the PSD of conventional PPM TH-IR UWB signals.

This paper is organized as follows: Section 2 describes the basic system properties and derivation of the conventional PPM and DLPPM TH-IR UWB schemes. Section 3 shows

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analytical and simulation results of the described system performance and the conclusions are given in Section 4.

2. Signal Representation and Analytical PSD of a DLPPM TH-IR Signal

2.1 Conventional PPM TH-IR System

Before discussing issues related to estimation of the spectrum power for DLPPM TH-IR, we introduce the signal considered for analysing conventional PPM TH-IR UWB system. The block diagram shown in Fig.1 consists of five stages and manages to diminish the problem of the spectral lines and obtains the smooth PSD for different probabilities by observing the output at spectrum analyzer [1].

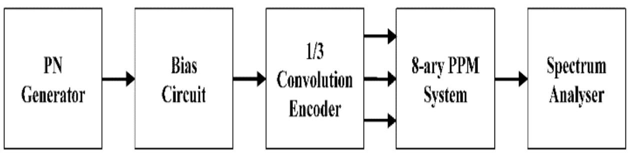


Fig. 1 Conventional PPM TH-IR system block diagram [1].

In the system presented in Fig. 1, the Pseudo Noise (PN) generator is 2^{18}-1 and is used to simulate a data source producing bits with equal probability. The output of the PN generator is fed to the second stage which is the bias circuit. The bias circuit changes the probability of one's and zero's and it functions better with very long sequence. The 1/3 convolutional encoder is used to control the code before applying it to the PPM system. However, the best code is to be observed in the model in order to achieve the maximum degree of randomness that is almost all the spectral lines will be eliminated or made very smooth. Convolutional codes are different from other codes. Usually, the purpose of coding is to provide higher levels of protection against channel noise and to support the system to be able to overcome a lossy transmission medium and a limited transmission bandwidth [9]. In general, encoders usually map the input bit into *n* length output bits [10], these *n* bits are not only determined by the present bit input but also the previous information bits [11]. The dependence on the previous information bits causes the encoder to be a finite state machine, this increases the capability of the communication systems to be able to overcome a lossy transmission medium and enhance the randomness [9, 11]. 8-ary PPM system is the modulation stage.

A generic TH-IR UWB signal with PPM, shown in Fig. 1 can be described by the formula [1]:

$$x(t)=\sum_m w\left(t - mT_r - \beta_m T_B\right) \qquad (1)$$

where $w(t)$ account for the pulse shape, T_r is the mean pulse repetition rate, β_m is the m^{th}symbol from rate 1⁄3 encoder taking values on the set {0,1,...,7}, and T_B is the PPM modulation shift (modulation index). The output of the PN generator is fed to a rate 1⁄3 convolutional encoder with generator code given in octal form. When connected in this way the output of the PN generator-convolutional encoder pair will resemble the data source that generates symbols uniformly and distributed on the set {0,1,...,7}. The PSD of $x(t)$ can be derived by using [1, 12]:

$$\overline{X}(f) = \frac{1}{T_r}|W(f)|^2 - \frac{1}{T_r}|W(f)|^2\left(\frac{1}{8} + \frac{2}{64}\sum_{n=1}^{8-1}(8 - |n|\cos(2\pi f n T_B))\right) + \frac{1}{T_r^2}\left(\frac{1}{8} + \frac{2}{64}\sum_{n=1}^{8-1}(8 - |n|\cos(2\pi f n T_B))\right) \qquad (2)$$

where $W(f)$ is the Fourier transform of $w(t)$. The value of T_B is chosen to eliminate as many spectral lines as possible [13].

2.2 DLPPM TH-IR System

Fig. 2 shows the proposed system. In order to perform comparisons between conventional PPM TH-IR and the proposed system based on DLPPM TH-IR technique. The proposed system differs than the one shown in Fig. 1 by introducing the extra sub-slots stage which divides each slot to a number of sub-slots.

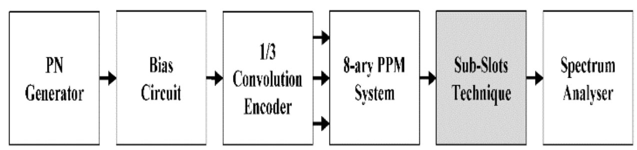


Fig. 2 Proposed system block diagram using DLPPM TH-IR technique.

The signal generated by the DLPPM TH-IR system, shown in Fig. 2, is described by the formula:

$$x(t) = \sum_m w\left(t - mT_r - \left(\beta_m + \frac{\alpha_m}{N_{ss}}\right)T_B\right) \qquad (3)$$

Where N_{ss} is number of time sub-slots and α_m accounts the position for the pulse inside the pulse repletion rate taking values on the set {0, 1, ..., N_{ss}-1}. Note that $x(t)$ is a random process.

In general, the PSD of the random TH-IR signal $\overline{X}(f)$ consists of continuous $x(t)$ as well as discrete components [1, 12] and is given by:

$$\overline{X}(f) = \frac{1}{T_r}|W(f)|^2 - \frac{1}{T_r}|W(f)|^2\left(\frac{1}{N_s * N_{ss}} + \frac{2}{(N_s * N_{ss})^2}\sum_{n=1}^{(N_s * N_{ss})-1}\left((N_s * N_{ss} - |n|)\cos(2\pi f n T_c)\right)\right) + \frac{1}{T_r^2}\left(\frac{1}{N_s * N_{ss}} + \frac{2}{(N_s * N_{ss})^2}\sum_{n=1}^{(N_s * N_{ss})-1}\left((N_s * N_{ss} - |n|)\cos(2\pi f n T_c)\right)\right)\sum_{-\infty}^{\infty}\delta\left(f - \frac{k}{T_r}\right) \qquad (4)$$

Where N_s is number of time slots. The proposed system is a new modulation technique, called DLPPM TH-IR, which reduces the risk of Inter-Pulse Interference (IPI) and guarantees high spectrum efficiency. The DLPPM TH-IR scheme maximizes the average separation between modulated pulses to achieve greater resistance to large delay spreads. In addition, DLPPM TH-IR randomizes the time offset between adjacent pulses to provide greater immunity to multiple access interference. Thus, the bandwidth efficiency of UWB communications systems is increased.

Fig. 3 is an illustration of an exemplary signal, in time domain, modulated using DLPPM technique. The signal consists of a number of symbols, having a symbol period T_r. Symbols are transmitted with very short pulses. Each symbol represents M bits of binary information and has a value in the range of (0 to 2^M-1). Each symbol is divided into a number of slots, each having a duration equal to T_B. Each slot contains sub-slots, each having a duration equal to T_B/N_{ss}. For instance, if N_S=8 and N_{ss}=4, there are 8 slots each containing 4 sub-slots, which correspond to the symbol values 0, 1, 2, and 3. Finally, each slot is divided into T_B ⁄4 time sub-slots, which correspond to the DLPPM TH-IR code sequence.

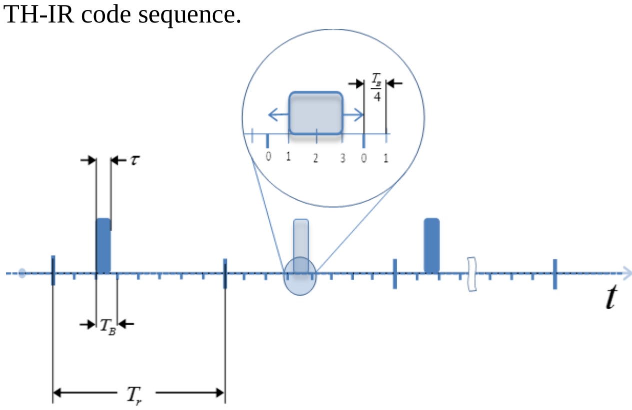


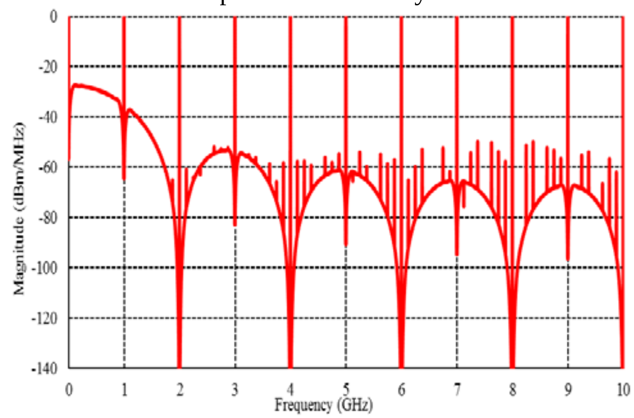
Fig. 3 An illustrative example of an exemplary DLPPM signal, where N_S=8 and N_{ss}=4.

3. Analytical and Simulation Results

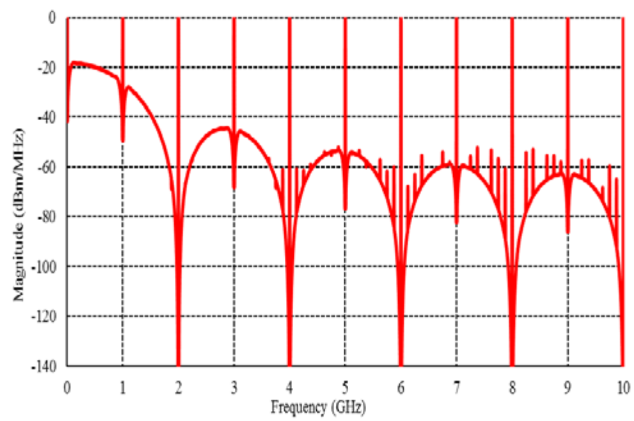
3.1 Analytical Results

In this section, we compare a conventional PPM TH-IR with DLPPM TH-IR where T_r=8x10^{-9} sec, N_s=8, and RWB=20 & 40 GHz have been applied and tested for both cases. Different N_{ss} have been selected for DLPPM TH-IR system to detect the effects on PSD.

Fig. 4 shows the theoretical PSD obtained by using the conventional PPM TH-IR system described in Section 2 and depicted in Fig. 1 for Resolution Bandwidth (RBW) equals to 20 and 40 GHz. It is evident that the signal tested in Section 2 has both random like and harmonic like components. Fig. 4 shows the PSD section consists of 10 spectral lines. These spectral lines don't comply with regulatory spectral masks such as the one used by the FCC. When the RBW increases from 20 to 40 GHz, as shown in Fig. 4(b), it is clearly seen the displayed power of the spectral lines does not change. However, the level of the continuous like component increases by about 8 dBm/MHz.



(a) T_r=8x10^{-9} sec; N_s=8; RWB=20 GHz.

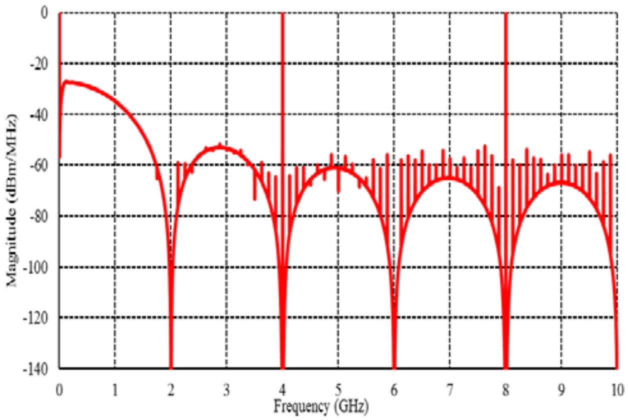


(b) T_r=8x10^{-9} sec; N_s=8; RWB=40 GHz.

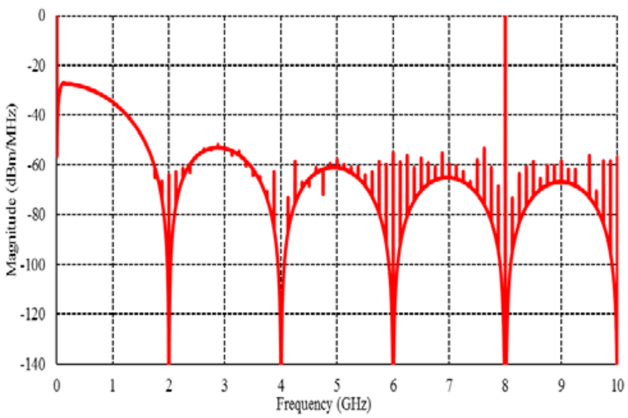
Fig. 4 Estimated PSD's performed with different Resolution Bandwidths (RBW's).

Fig. 5 shows theoretical PSD's obtained by using DLPPM TH-IR system described in Section 2 and depicted in Fig. 2. In Fig. 5(a), the DLPPM TH-IR system has 8 slots (N_s) and each slot has been divided into 4 sub-slots (N_{ss}). Fig. 5(a) consists of spectral lines repeated every 4 GHz in which the total number of spectral lines have been reduced and smooth harmonics components have been achieved compared to the conventional PPM TH-IR system, as shown in Fig. 4(a).

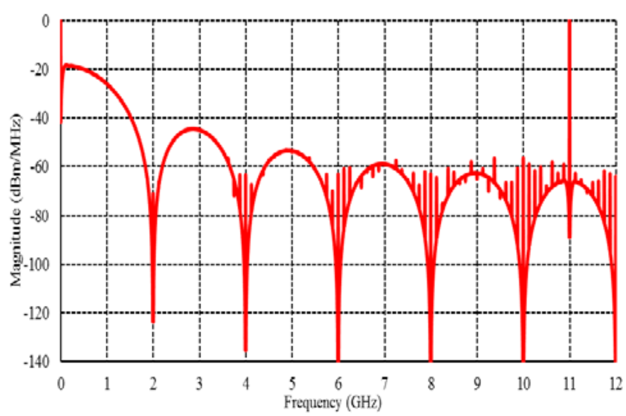
Fig. 5(b) shows the PSD section consists spectral lines repeated every 8 GHz. Fig. 5(c) shows the PSD section consisting of spectral lines repeated every 11 GHz in which the total number of spectral lines have been reduced and more smoother harmonics components have been achieved. In the last case, Fig. 5(c), the spectral line is out the UWB legalizing spectrum across 7.5 GHz between 3.1 and 10.6 GHz [14] which provides free-interference system.



(a) T_r=8x10^{-9} sec; N_s=8; N_{ss}=4; RWB=20 GHz.



(b) T_r=8x10^{-9} sec; N_s=8; N_{ss}=8; RWB=20 GHz.



(c) T_r=8x10^{-9} sec; N_s=8; N_{ss}=11; RWB=40 GHz.

Fig. 5 Estimated PSD's obtained by analytical model with different RWB's and N_{ss}.

3.2 Simulation Model Results

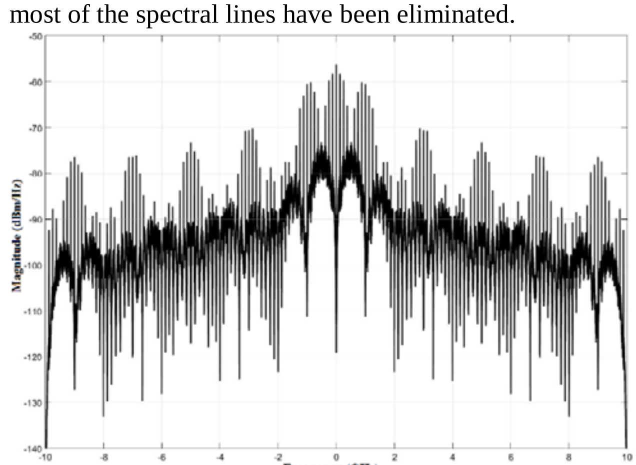
In this section, some code sets of systematic and non-systematic convolutional codes with rate 1/3 have been applied and tested with equal probability [15]. The same process has been repeated to detect the difference between the conventional PPM and DLPPM TH-IR systems which provides better PSD. The conventional PPM and DLPPM TH-IR systems, shown in Fig. 1 and Fig. 2 respectively, have been built inside Simulink/MATLAB in order to compare the two systems and test codes for eliminating the spectral lines or making it smoother to reduce interference problem on other users.

The results for both systems are compared for the same metrics; PN length, convolutional encoder codes, data rate, pulse shape (0.5 ns), and with equal probability. In DLPPM TH-IR system, each slot (N_s) is divided into 8 sub-slots (N_{ss}). The pulse position in both systems will be the same, the only different is the location of the pulse inside the slot. In conventional PPM TH-IR system, the pulse position will be always in the beginning of the slots. In DLPPM TH-IR system, another convolutional encoder is used to decide the sub-slot pulse position.

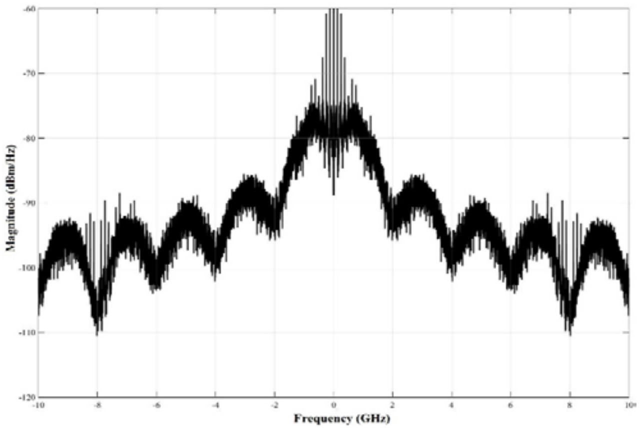
In other words, in the case of a stream of only zeros or only ones of data applied to a conventional PPM TH-IR system, the pulse position will be in the same slot for each symbol, which make the period equal to 8 ns producing harmonics every 125 MHz. For such a case in DLPPM TH-IR system, the pulse position will be in the same slot in each symbol but with different sub-slot which makes the period very large comparing with 8 ns in conventional PPM TH-IR system.

Many different convolutional codes [16] have been tested to achieve a smoother PSD. As an example, the codes [5 5 5] non-systematic and [4 2 1] systematic. The PSDs have been compared with each other's for conventional and DLPPM TH-IR systems.

Fig. 6 shows PSD section obtained by using conventional PPM vs DLPPM TH-IR systems with same conditions. For conventional PPM TH-IR system, Fig. 6(a) shows a continuous component of harmonics with some numerous spectral lines. This appearance may be explained by the lack of the randomness between consecutive pulses. However, when Fig. 6(b) is compared with Fig. 6(a), it can be observed that the PSD in the Fig. 6(b) is better as well as most of the spectral lines have been eliminated.



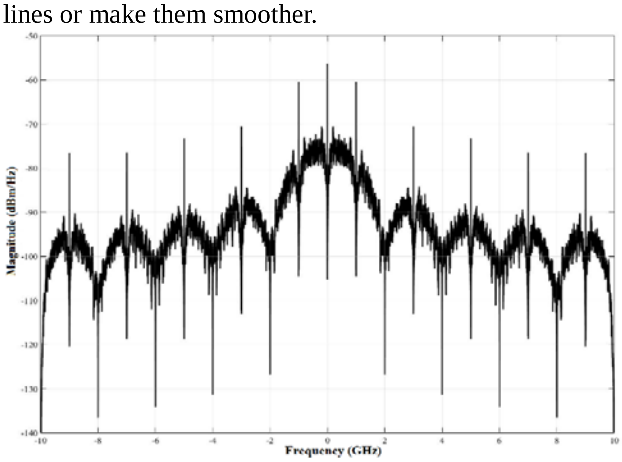
(a) Conventional PPM TH-IR system.



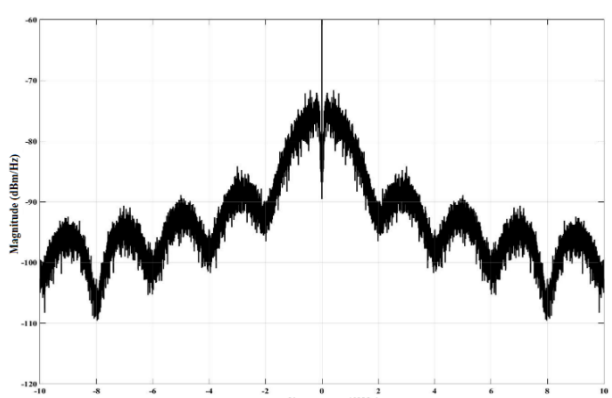
(b) Proposed system using DLPPM TH-IR technique.

Fig. 6 PSD with probability of 0.5 for non-systematic [5 5 5].

Fig. 7(b) shows that PSD has an excellent performance compared with Fig. 7(a) and Fig. 6. An excellent performance returns to the randomness between consecutive pulses. Furthermore, it can reduce the spectral lines or make them smoother.



(a) Conventional PPM TH-IR system.



(b) Proposed system using DLPPM TH-IR technique.

Fig. 7 PSD with probability of 0.5 for a systematic code [4 2 1].

The results also show that the systematic convolutional encoder codes enhance the PSD more than the non-systematic [15-17]. Therefore, the systematic convolutional codes should be used to achieve the best PSD performance.

4. Conclusion

The present method provides a novel technique which meets the requirements described earlier with the help of a DLPPM TH-IR scheme that allows for a greater throughput than conventional PPM TH-IR scheme. This can be achieved by maximizing the pulse separation and randomizing the time offset between pulses in a time efficient manner to ensure the period is as large as possible. A mathematical representation of the PSD of a DLPPM TH-IR UWB signal was derived. The analytical result was used to investigate the effect of the variable position of the pulse in a DLPPM TH-IR system in the PSD of the signal and it was found that it can be effectively used to eliminate some spectral lines or to diminish the peak value of the PSD. It has been observed that DLPPM TH-IR significantly outperforms conventional PPM TH-IR with respect to spectral efficiency when the location of the pulse being variable within each slot. The hardware complexity at receiver side does not need to be increased which makes the DLPPM scheme very attractive for TH IR-UWB communication systems.

Finally, the simulated results within Simulink/MATLAB were compared to conventional PPM TH-IR UWB. The results showed that when testing with a systematic code [4 2 1], a smoother PSD without spectral lines was achieved.

References

[1] Villarreal-Reyes, R. M. Edwards and B. Al-haj Moh'd, “On for the Comparison of Measurement and Simulation of the Power Spectral Density of PPM TH-IR UWB Signals,” Loughborough Antennas and Propagation Conference Proceedings, LAPC 2006, March 2006, pp.118-122.

[2] Win, M. Z., Scholtz, R. A.: Ultra-Wide Bandwidth Time Hopping Spread-Spectrum Impulse Radio Wireless Multiple Access Comm. IEEE Trans On Comm, vol. 48, pp. 679–691, (2000)

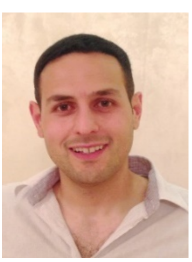
[3] Scholtz, R. A.: “Multiple Access with Time-Hopping Impulse Modulation,” In: Proc. MILCOM 1993, Bedford, MA, pp. 447–450, (1993).

[4] T. Ballal and T.Y. Al-Naffouri, “Low-sampling-rate ultra-wideband channel estimation using equivalent time sampling,” Signal Processing, IEEE Transactions on, vol. 62, no. 18, pp. 4882–4895, Sep. 2014.

[5] Das, B., G. K. Mishra, S. Kanungo, and B. K. kumar Sahu. "Performance improvement through interference mitigation techniques in Transmitted Reference UWB system used in WPAN overlay systems." (2015).

[6] S. Villarreal-Reyes and R. M. Edwards, “On the Behaviour of Simulation-DFT Based Analysis for Spectral Estimation of PPM TH-IR UWB Signals,” Loughborough Antennas and

Propagation Conference Proceedings, LAPC 2005, April 2005.
[7] Yajnanarayana, Vijaya, Satyam Dwivedi, Alessio De Angelis, and Peter Händel. "Spectral efficient IR-UWB communication design for low complexity transceivers." EURASIP Journal on Wireless Communications and Networking 2014, no. 1 (2014): 1-13.
[8] Marshall, Alan G., and Francis R. Verdun. Fourier transforms in NMR, optical, and mass spectrometry: a user's handbook. Elsevier, 2016.
[9] S.V.N.Reddy, C. K.K,and N. Koppala." Design of Convolutional Codes for varying Constraint Lengths". International Journal of Engineering Trends and Technology- Volume4Issue1- 2013.
[10] J. G. Proakis, M. Salehi, N.Zhou, and Li Xiaofeng." Communication systems engineering". (Vol. 2). Englewood Cliffs: Prentice-hall.
[11] Liu, Er. "Convolutional coding & Viterbi algorithm." IEEE S (2004): 11-16.
[12] M. Z. Win, “Spectral density of random UWB signals”, IEEE Communications Letters, Vol. 6, No. 12, pp. 526-528, Dec 2002.
[13] S. Villarreal-Reyes and R. M. Edwards, “Spectral Line Suppression in TH-IR Ultra Wideband Systems,” 5th IEE International Conference on Mobile Communications Technologies (3G 2004), Oct 2004.
[14] Federal Communications Commission. "Revision of part 15 of the commission’s rules regarding ultra-wideband transmission systems, first report and order (ET Docket 98-153)." Adopted Feb 14 (2002): 2002.
[15] Johannesson, Rolf. "Some rate 1/3 and 1/4 binary convolutional codes with an optimum distance profile (Corresp.)." IEEE Transactions on Information Theory 23, no. 2 (1977): 281-283.L.
[16] Hanzo, Lajos, Tong Hooi Liew, and Bee Leong Yeap. Turbo coding, turbo equalisation and space-time coding. John Wiley & Sons, 2002.
[17] Nail, Rana, and Nidal Qasem. "Enhancing the Power Spectral Density of PPM-IR for Ultra-Wide Band signals by using a convolutional encoder." In Internet Technologies and Applications (ITA), 2015, pp. 14-17. IEEE, 2015.



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