2009 International Conference on Future Computer and Communication

A Novel DS-UWB Pulses Design Using Genetic Algorithm

Shu-Han Liao
Department of Electrical Engineering
Tamkang University
Tamsui, Taipei, Taiwan, R.O.C.
shliao@ee.tku.edu.tw

Min-Hui Ho
Department of Electrical Engineering
Tamkang University
Tamsui, Taipei, Taiwan, R.O.C.
nancy_2002_168@yahoo.com.tw

Chien-Hung Chen
Department of Computer and Communication Engineering
Taipei College of Maritime Technology
Shilin, Taipei, Taiwan, R.O.C.
f1092@mail.tcmt.edu.tw

Chien-Ching Chiu
Department of Electrical Engineering
Tamkang University
Tamsui, Taipei, Taiwan, R.O.C.
chiu@ee.tku.edu.tw

Wei-Chun Chung
Department of Electrical Engineering
Tamkang University
Tamsui, Taipei, Taiwan, R.O.C.
mm7382@gmail.com

Abstract*—This paper proposes a new pulse design method to improve spectrum utilization rate and reduce the outage probability in Ultra Wide Band (UWB) system. Several third derivative Gaussian waveforms are employed to generate the pulse based on the bandwidth constraint set by the US Federal Communications Commission (FCC) mask. The genetic algorithm (GA) is used to find the optimal pulse parameter. This method is an easy way to achieve in practical circuit implementation compared to one pulse generator, since COMS circuit is hard to produce one pulse with short duration and complex pulse shape. Comparisons with the traditional Gaussian pulse, the synthesis pulse by GA not only satisfy the FCC emission mask but also have high spectrum utilization rate. Simulation results show that the performances in indoor UWB system using the synthesis pulse by GA is better than that using traditional Gaussian pulse. Numerical results show that the synthesis pulse by GA is higher 30 percent of spectrum utilization rate and lower 65 percent of outage probability for the same transmission power, as well as lower 21 percent of outage probability for fixed Signal-to-noise ratio (SNR)at the receiver comparing with traditional Gaussian pulse. This proposed method not only use in indoor UWB system but also can extend to different communication system just changing the system object function.

Keywords- pulse design;UWB;GA

I. INTRODUCTION

Ultra-Wideband (UWB) is short-range high data-rate indoor wireless communications and it is low spectral density, low power consumption, high immunity to multipath fading .UWB system not only use in indoor communications also apply to inter-vehicle communications [1]. Since the UWB occupies a large bandwidth, it introduces interference to the coexisting communication systems. In 2002, FCC approved the unlicensed use of the UWB spectrum from 3.1G to 10.6GHz, with a power spectral density (PSD) should be lower than -41.3 dBm/MHz. It is important to perform spectrum shaping to fit the PSD of UWB signal with the FCC mask[2].

Some papers use Hermite Gaussian Orthonormal Expansion to synthesize the pulse. However, the spectrum utilization rate is low [3]. Traditional standard Gaussian monocycles do not satisfy the FCC effective isotropic radiated power (EIRP) spectrum mask requirements [4],[5].In some researches of pulse design and pulse optimization as seen in [6]-[10] have proposed theoretical method from mathematics to produce one pulse directly without considering practical circuit implementation, since COMS circuit is hard to produce one pulse with short duration and complex pulse shape. Generating the high n-th derivative Gaussian pulses is extremely difficult and is not suitable for practical transceiver design using CMOS technology [11],[12].

We propose a simple pulse design method that linear combine several Gaussian pulses [13]. In UWB system, [14] is pulse shaping optimizer in UWB receivers by genetic algorithm. [15] propose a genetic algorithm based on finger selection scheme for UWB MMSE Rake receivers. In [16], the optimal finger selection problem is shown to be an NP-hard problem. Genetic algorithm is a technique for searching for the global optimum of an objective function and near-optimal solutions can be obtained in many cases with a degree of complexity that is much lower than that of the optimal exhaustive search algorithm. Genetic algorithm is using techniques inspired by evolutionary biology such as inheritance, mutation, selection, and crossover. We design UWB pulse by third Gaussian derivative base on genetic algorithm while satisfying the FCC emission. The optimal pulse by genetic algorithm is linear combination of several third Gaussian derivatives to meet the FCC spectral mask requirement.

This paper is organized as follows: Pulses parameters optimized by genetic algorithm have been explained in Section II. In Section III, Channel modeling and system description and system block diagram and Bit Error Rate performance for the indoor UWB system are briefly

978-0-7695-3591-3/09 $25.00 © 2009 IEEE
DOI 10.1109/ICFCC.2009.128

described. In Section IV, the simulation results and performance analysis of our proposed method is discussed. The conclusions are given in Section V.

II. PULSE PARAMETER SELECTION VIA THE GENETIC ALGORITHM

A genetic algorithm is a search technique that use in computing to find approximate or exact solutions of the problems. Genetic algorithms are categorized as global search heuristics that use techniques inspired by evolutionary biology. We use genetic algorithm must represent a solution to our problem as a genome and definition of the objective function by the following expression：

$$fitness = 1/[FCC_{mask} - P(f)] \tag{1}$$

The fitness function is evaluated for each individual, providing fitness values, We select higher fitness value to survive. Where FCC_{mask} is FCC spectral mask and $P(f)$ is a Fourier transform of $p(t)$ given by：

$$P(f) = \int_{-\infty}^{\infty} p(t)e^{-i2\pi ft}dt \tag{2}$$

$p(t)$ is the synthesis pulse waveform with ultra-short duration at nanosecond scale. The third derivative Gaussian waveform $p(t)$ can be described by the following expression：

$$p(t)=\sum_{i=1}^{N} A_i \cdot 16\pi^2 (t-Td_i)\cdot \exp(-2\pi(t-Td_i)^2/Tp_i^2)\cdot \left(-3Tp_i^2+4\pi(t-Td_i)^2\right)/Tp_i^6 \tag{3}$$

Where N is number of pulse and A_i is amplitude of the i-th pulse parameter which can adjust amplitude by genetic algorithm. Tp_i is pulse width of the i-th pulse parameter. Td_i is delay time of the i-th pulse parameter. Note that the pulse delay time zero was taken at the signal peak position of pulse.

Differentiation of the Gaussian pulse influences the spectrum as well; both peak frequency and bandwidth of the pulse vary with increasing differentiation order. In particular, it is differentiation k , and the shape factor T_p by observing that the Fourier transform of the k-th derivative has property[17]：

$$X_k(f) \propto f^k e^{-\frac{\pi f^2 T_p^2}{2}} \tag{4}$$

Which leads to a peak frequency for the k-th derivatives：

$$f_{peak,k} = \sqrt{k}\frac{1}{T_p\sqrt{\pi}} \tag{5}$$

Equation (5) shows that Gaussian derivatives of higher order are characterized by higher peak frequencies. Differentiation is thus a way to move to high frequency band. We tradeoff peak frequency and achieve in practical circuit implementation thus choose third derivative Gaussian. In order to employ genetic algorithm to adjust parameter that amplitude and pulse delay time and pulse width of equation (3).

The genetic algorithm creates a population of solutions and applies genetic operators such as mutation and crossover to evolve the solutions in order to find the best genome. Genetic algorithm proceeds to initialize a population of solutions randomly, and then improve it through repetitive application of mutation, crossover, inversion and selection operators. We need to know how to represent the chromosomes, and how to implement the steps of the iterative optimization scheme.

1) Initialization：We randomly generate N individual solutions form an initial population. The population size depends of the pulse number. The population size is 40 times of the pulse number.

2) Code：A code representation of the solution is as an array of bits. We use binary code.

3) One-point crossover：A single crossover point on both parents' chromosomes strings is selected. All data beyond that point in either chromosomes string is swapped between the two parent chromosomes. The resulting chromosomes are the children chromosomes.

4) Mutation：Mutation is a genetic operator used to maintain genetic diversity from one generation of a population of chromosomes to the next. Our mutation operator involves a probability that an arbitrary bit in a genetic sequence will be changed from its original state.

5) Selection：After the crossover and mutation population size is more than population size N. We select population size is RankN that higher fitness value to next generation.

6) Termination：Genetic algorithm is repeated until a termination condition has been reached. The highest ranking solution's fitness is reaching or has reached a

plateau such that successive iterations no longer produce better results.

III. Channel Modeling and System Description

A. Calculation of the Channel Characteristics

UWB system statistical channel models for transmission have already been developed and standardized by the IEEE in the 802.15.3a standard. SBR/Image method is a ray optical method that assumes quasi-optical propagation of radio waves. In [18] simulation results statistics are extracted and compared to standardized UWB channel models. We employ the ray/image (SBR/Image) techniques to simulation three dimensional environments over the entire frequency range of UWB applications from 3.1 to 10.6 GHz. The equation used to model the multipath radio channel is a linear filter with an equivalent baseband impulse given by [18] :

$$h(t)=\sum_{n=1}^{N}a_n\delta(t-\tau_n) \tag{6}$$

Where N is the number of paths observed at time. $\delta(.)$ is the Dirac delta function. a_n and τ_n are the channel gain and time delay for n-th path respectively. The notation is according to IEEE 802.15.3a standard. The impulse response function of the environment for any transmitter-receiver location is computed by modified shooting and bouncing ray/image (SBR/Image) techniques [19],[20].

B. System Black Diagram

In this paper, we employ a direct sequence UWB (DS-UWB) system model and Binary Pulse Amplitude Modulation (BPAM) is applied. In Fig. 1 the information source is the random binary sequence generator that through the BPAM modulator obtain $d(t)$ given by (6). $p(t)$ is the transmitted waveform optimal by genetic algorithm. The received signal into 3.1-10.6 GHz band-pass filter allows UWB signals to obtain that is $r(t)$. We get the results after the decision device.

In Fig. 1 $d(t)$ input data can be described by the following expression. $d_n \in \{\pm 1\}$ is a BPAM symbol and is assumed to be independent and identically distributed (i.i.d.). Finally, the average BER for BPAM IR UWB system can be expressed as :

$$BER=\sum_{n=1}^{N}P(\vec{d})\cdot\frac{1}{2}erfc\left[\frac{V(n)}{\sqrt{2}\sigma}\cdot(d_N)\right] \tag{7}$$

IV. Simulation Results and Performance Analysis

The impulse response for channel was calculated from 3.1 to 10.6GHz by SBR/Image. The home network environment is with the dimension of 6.1m (long) ×10.20m (wide) ×3m (high). This home network has five rooms with the bedroom 1, office room, bedroom 2, living room and kitchen. Here we will show the simulation results of the effect of the pulse design phenomenon in this home network environment.

In our simulation, the transmitting antenna is located at Tx (3.5, 0.5, 0.01) m in the living room with the height of 0.01m. 256 receiving points with a fixed height of 1m are uniform distribution in bedroom 1, office room, bedroom 2 and kitchen, as shown in Figure 2. Tx denotes the transmitting antenna and the other points denote the receiving antenna. Transmitting and receiving antennas are modeled as a UWB antenna with simple omni-directional radiation pattern. Tx denotes the transmitting antenna and the other points denote the receiving antenna.

In our simulation the BPAM is applied in DS-UWB communication system. Every third derivative Gaussian pulse has three parameters: Td_i is pulse delay time and Tp_i is the pulse duration and A_i is amplitude parameter. GA population size is 40 times of pulses parameters and Binary string length is set to be 10, the probability of crossover and mutation are 0.5 and 0.025 respectively.
Since initial population is randomly generated by genetic algorithm. All parameter values and spectrum utilization rates are averaged for ten experiment results.

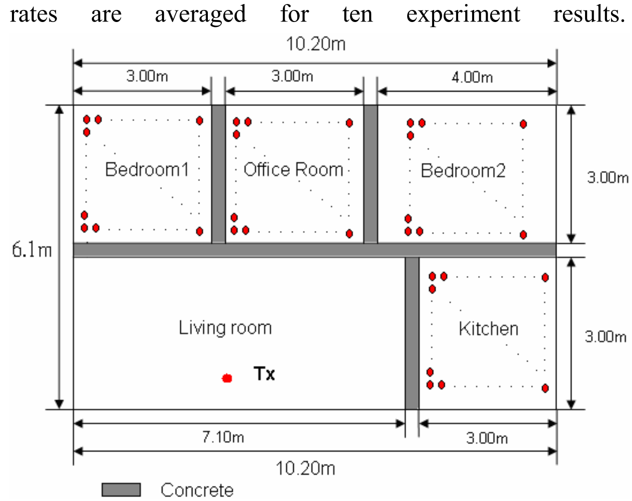

Figure 2. Layout of the simulated environment.

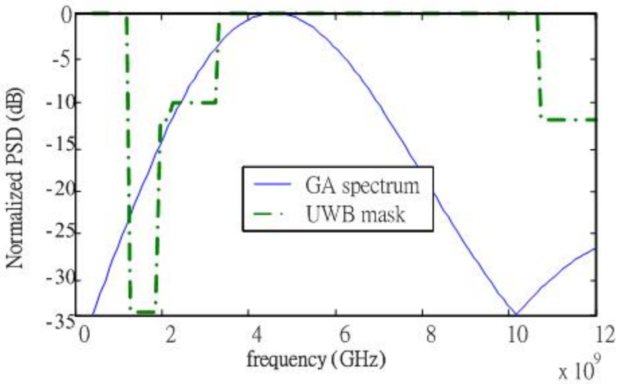

Figure 3. Traditional Gaussian pulse spectrum

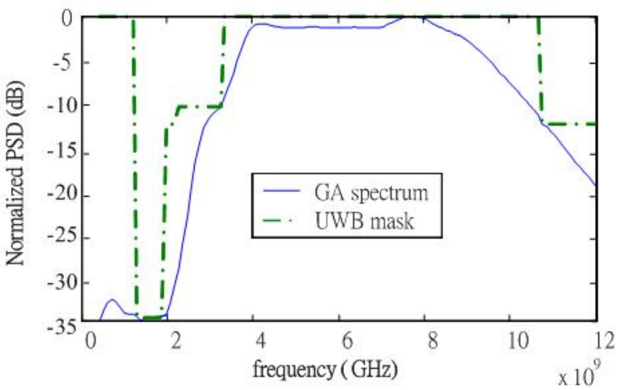

Figure 4. Spectrum of the synthesized pulse

Comparison with the traditional Gaussian pulse, the synthesis pulse by genetic algorithm not only has high peak amplitude but also have narrow pulse duration, thus synthesis pulse by genetic algorithm has high immunity to multipath fading.

The normalized power spectral density (PSD) of traditional Gaussian pulse spectrum is illustrated in Figure 3. It is seen that the spectrum utilization rate is 58% and the power spectrum violates FCC emission mask for the frequency range from 0 to 3GHz. Figure 4, shows the spectrum of the synthesis pulse by GA spectrum. It is found that the spectrum utilization rate is close to 90 percent and satisfy FCC emission mask.

Next, let us consider the BER performance for the home network environment. The BERs are used to calculate the outage probability for the BER requirement of BER<10^{-4}. Outage probability versus $(SNR)_t$ is shown in Figure 5. Here $(SNR)_t$ is defined as the ratio of the transmitter power to the noise power at the receiver. We can find that the synthesis pulse has lower outage probability than traditional Gaussian pulse, since the synthesis pulse has more received power than that of traditional Gaussian pulse. In Figure 5, the perfect pulse is the Fourier transform of FCC power spectral density. It is seen that the outage probability for the synthesized pulse is close to that for the perfect pulse. For

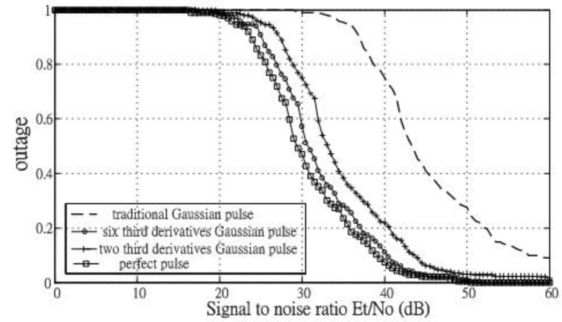

Figure 5. Outage probability versus (SNR)t at transmitter

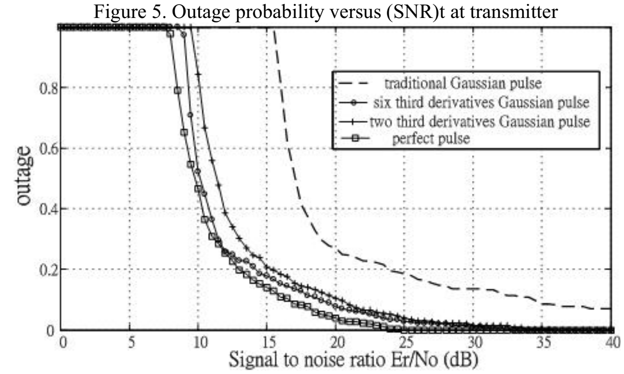

Figure 6. Outage probability versus $(SNR)_r$ at the receiver

comparisons with traditional Gaussian pulse can be reduced from 75 percent down to 10 percent.

The outage probability versus $(SNR)_r$ for the home network environment is depicted in Figure 6. Here $(SNR)_r$ is defined as the ratio of the receiver power to the noise power. In this case, we focus on pulse shape instead of the received power. For SNR = 20dB, it is seen that the outage probability of the synthesized pulse and traditional Gaussian pulse are 7 percent and 28 percent respectively. It is clear that the synthesized pulse has a better performance.

V. Conclusions

We propose a novel method to improve spectrum utilization rate and reduce the outage probability. Simulation results show that this method can maximize the emitted power under the bandwidth constraint set by FCC mask and mitigate inter-symbol interference and reduce the outage probability as well. Several third derivative Gaussian pulses are used to synthesize the optimal pulse. This method can be easily implemented with simple circuit by CMOS technology. Comparisons with the traditional Gaussian pulse, the synthesis pulse by GA not only satisfy the FCC emission mask but also have high spectrum utilization rate. Numerical results show that the synthesis pulse by GA is higher 30 percent of spectrum utilization rate and lower 65 percent of outage probability at $(SNR)_t$ = 40dB for the fixed transmission power, as well as lower 21 percent of outage probability at $(SNR)_r$ = 20dB for fixed receiving power comparing with traditional Gaussian pulse. In the future work, more detailed environment description at various operating frequencies will be considered to increase accuracy of simulating results.

REFERENCES

[1] F. Elbahhar, A. Rivenq, M. Heddebaut and J.M. Rouvaen, ‘‘Using UWB Gaussian pulses for inter-vehicle communications,’’ *IEE Proceedings-Communication,* Vol. 152, no.2 , pp. 229 – 234 , April 2005

[2] Federal Communications commission, ‘‘Revision of Part 15 of the commission`s rules regarding ultra-wideband transmission system, FIRST PEPORT AND ORDER,’’ *ET Docket 98-153,* FCC 02-48, pp. 1-118, February 14, 2002.

[3] R. Yang, C. Yu and Z. Zhou, ‘‘A Novel Algorithm for Designing Adaptive DS-UWB Pulses Using Hermite-Gaussian Orthonormal Expansion,’’ *2006. WiCOM 2006.International Conference* pp. 1-4 Sept. 2006

[4] B. Parr, B. L. Cho, K. allace and D. hi, ‘A novel ultra-wideband pulse design algorithm,’’ *Communications Letters, IEEE*, Vol 7, no. 5, pp. 219 - 221 May 2003

[5] A.B. Parr, B. L. Cho and Z. Ding, ‘‘A new UWB pulse generator for FCC spectral masks,’’ *Vehicular Technology Conference, 2003. VTC 2003-Spring. The 57th IEEE Semiannual*, Vol 3, pp. 1664 - 1666 April 2003

[6] M. P. David, “Waveform Optimizations for Ultrawideband Radio Systems,” *IEEE Transactions on Antennas and Propagation*, Vol. 51, No. 9, Sep., 2003

[7] X. Chen and S. Kiaei, “Monocycle shapes for ultra wideband system”, *IEEE ISCAS 2002.,* Vol.1 , 26-29 May 2002

[8] C. A. Corral, S. Sibecas, S. Emami, and G. Stratis, “Pulse spectrum optimization for ultra-wideband communication,” *IEEE Conference on UWBST 2002, Digest of Papers*, pp.31-35, 21-23 May 2002

[9] B. Parr, B. Cho, K. Wallace, and Z. Ding, “A Novel Ultra-Wideband Pulse Design Algorithm”, *IEEE Communication Letters*, Vol.7, No.5, May,2003

[10] R. S. Dilmaghani, M. Ghavami, B. Allen, and H. Aghvami, “Novel UWB pulse shaping using prolate spheroidal wave functions”, *IEEE Proceedings on PIMRC 2003*, Vol.1, Sep. 2003

[11] H. Xie, X. Wang, A. Wang, B. Qin, H. Chen, Y. Zhou and B. Zhao ‘‘A Varying Pulse Width Third Order Derivative. Gaussian Pulse Generator for UWB Transceivers in COMS,’’ *2007 IEEE Conference* pp. 2794-2797 2007

[12] R. Hidayat, K. Dejhan, P. Moungnoul and Y. Miyanaga, ‘‘A 0.18um CMOS Gaussian Monocycle Pulse Circuit Design for UWB ‘‘ *IEEE Asia Pacific Conference on Circuits and Systems, 2006. APCCAS 2006.* Dec. 2006 pp. 89 - 92

[13] H. Ray, N. Udar and R. Viswanathan, ‘‘A weighted sum of Gaussian-derived pulse design for UWB,’’ *IEEE Radio and Wireless Symposium*, pp.383 – 386, Jan. 2006

[14] D. Zeng, A.I. Zaghloul and A. Jr. Annamalai, ‘‘Pulse shaping optimizer in UWB receivers,’’ *Antennas and Propagation Society International Symposium, 2005 IEEE*, Vol 2A, pp.635 - 638 July 2005

[15] S. Gezici, C. Mung, H.V. Poor and H. Kobayashi, ‘‘A genetic algorithm based finger selection scheme for UWB MMSE rake receivers,’’ Ultra-Wideband, 2005. *ICU 2005. 2005 IEEE International Conference* pp.164 - 169 Sept. 2005

[16] S. Gezici, M. Chiang, H.V. Poor and H. Kobayashi, ‘‘Optimal and suboptimal finger selection algorithms for MMSE Rake receivers in impulse radio ultra-wideband systems,’’ *Proc. IEEE Wireless Communications and Networking Conference (WCNC 2005)*, vol. 2, pp. 861-866, New Orleans, LA, March 13-17, 2005.

[17] J.T. Conroy, J.L. LoCicero and D.R. Ucci, ‘‘Communication techniques using monopulse waveforms.’’ *IEEE Military Communications Conference Proceedings*, Volume: 2 (November 1999), 1181-1185.

[18] C. Sturm, W. Sorgel, T. Kayser and W. Wiesbeck, ‘‘Deterministic UWB Wave Propagation Modeling for Localization Applications based on 3D Ray Tracing,’’ *2006 IEEE MTT-S International Microwave Symposium Digest*, pp. 2003 – 2006, June 2006

[19] S. Chen and S. Jeng ‘‘An SBR/image approach for indoor radio propagation in a corridor.’’ *IEICE Transaction Electronics 1995*

[20] S. Chen and S. Jeng ‘‘An SBR/image approach for radio wave propagation in tunnels with and without traffic.’’ *IEEE Transactions in Vehicular Technology 1996*; 45:570-578

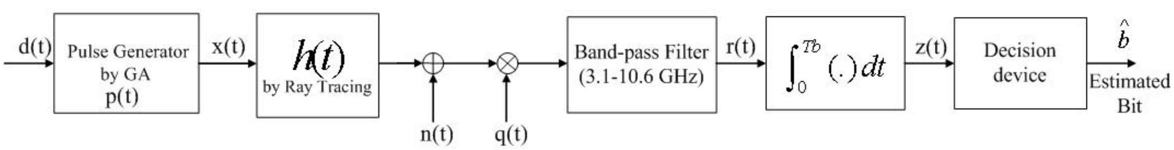

Figure 1. Block diagram of the DS-UWB communication system.