4.7pJ/pulse 7^{th} Derivative Gaussian Pulse Generator for Impulse Radio UWB

Tuan-Anh Phan, *Student Member, IEEE*, Vladimir Krizhanovskii, Seok-Kyun Han, and Sang-Gug Lee, *Member, IEEE*
μ-Radio Lab, School of Engineering,
Information and Communications University (ICU),
119 Munjiro, Yuseong-gu, Daejeon 305- 714, Korea.
anh@icu.ac.kr

Hyun-seo Oh, and Nae-Soo Kim
Electronics and Telecommunication Research Institute (ETRI)
Daejeon 305- 350, Korea

***Abstract*—This paper presents a ultra low-power, low-complexity circuit to generate the monocycle pulse for Impulse Radio UWB (IR-UWB) applications. A 7th order derivative Gaussian pulse is generated using the edge combination technique plus an extra derivative circuitry. The proposed pulse generator is designed using TSMC 0.18 μm CMOS process. Simulation shows 500 mV of pulse amplitude and 800 ps of the pulse duration. Generated pulse spectrum fully complies with the FCC spectrum mask for out-door applications, especially in the range of 3.1–5.1 GHz. The pulse generator dissipates no static current with only dynamic energy consumption of around 4.7 pJ per pulse from 1.5 V supply.**

I. INTRODUCTION

Ultra-wideband (UWB) is regulated for commercial use the band from 3.1-10.6 GHz by Federal Communication Commission (FCC) with the constraints of spectral mask which determined the maximum average equivalent radiated isotropic power spectral density of –41.25dBm/MHz and a minimum bandwidth of 500 MHz [1]. According to FCC, the transmitted power should be under the mask shown in Fig. 1. There are two approaches for UWB applications, which are Multi-band OFDM UWB and Impulse-Radio UWB (IR-UWB).

Recently, low-cost, short-range wireless communication applications like radio frequency identification (RF-ID) and wireless sensor network have drawn much attention from the researcher as well as industries [2]. IR-UWB, without carrier signal, is one of the prominent candidates for those applications since circuit implementation is simpler, no up/down conversion or mixer is needed leading to substantial reduction in chip area and power consumption.

IR-UWB uses the nano-second monocycle pulses to transmit the data signal over much wider frequency band than any conventional carrier based wireless systems. Thus, pulse generator circuit is an indispensable part in the IR-UWB transceivers. The first UWB pulse generation utilizes the band below 5GHz because of the high interference by WLAN in the 5-6GHz ranges and technology limitation. Hence, the pulse generation is targeted for the band from 3.1-5.1 GHz in this paper.

The generation of monocycle pulses, which can satisfy the FCC spectral mask with low power and low complexity, is still a challenge at present. A several papers about pulse generator have been published. Several early works shows that pulse generation could be performed by direct synthesis, using step recovery diode and transmission line [4] or using BJT characteristic [5], which is not easy for integration, low cost, low complexity purposes. Recently, most of the papers are based on the analog technique since the digital technique circuitry [3] is complicated. In [6]-[9], analog based pulse generation circuits were presented.

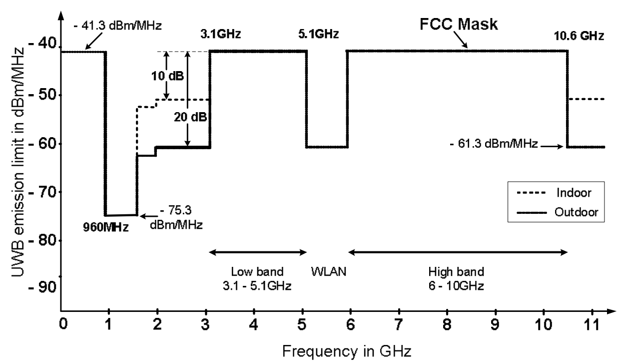

Figure 1. FCC spectrum mask

In those works, however, the pulses are often the first or second derivative Gaussian pulses, which can not satisfy the FCC mask according to theory analysis and require pulse shape filtering. Moreover, those previously published works consume much power. To satisfy the bandwidth, many types of pulses can be the candidates [10], but the Gaussian pulse is preferred since it has no side lobes and a sharp roll-off compared to other pulses. The theory analysis shows that, the higher order derivative of Gaussian pulse, the better roll-off we have and the pulse it self can satisfy the FCC spectral mask without using the filter.

1-4244-0921-7/07 $25.00 © 2007 IEEE.

In this paper, we proposed a simple but effective circuit to generate the 7^{th} derivative Gaussian pulse for IR-UWB. The pulse generator is designed based on TSMC 0.18 μm CMOS technology from 1.5 V supply. Output pulse spectrum fully satisfies the FCC mask with no static current consumption.

II. PULSE GENERATOR CIRCUIT DESIGN

A. *Pulse Type Selection*

The selection of monocycle pulse types is the primary consideration when designing pulse generator, because the impulse type will determine the spectral characteristics, system modulation and performance. Gaussian derivative pulse is the most commonly used and preferred in IR-UWB systems since it has wide bandwidth, no DC component and no side lobes in its spectrum. There are many types of monocycle pulses, which can have wide bandwidth spectrum like sinusoidal pulses, derivative form of Gaussian pulses and rectangular pulses. Their spectra were examined in [10], in order to meet the FCC mask, the filtering of DC component is needed for Gaussian and rectangular pulses, shifting the center frequency and shape filtering is required for n^{th} derivative form of Gaussian pulses. Also, for the sinusoidal and rectangular pulses, the sidelobe must be removed.

As mentioned above, the Gaussian derivative pulse is hard to meet the FCC mask. Theory analysis in [11] shows that, when the derivative orders get higher, the better roll-off the pulse has, also the center frequency is shifted to higher frequencies and low power spectrum distributed in low frequencies. Because of this reason, to satisfy FCC mask, the order of derivative should be increased. However, when the order of derivative increases, hardware becomes more complicated. From [11], 7^{th} derivative Gaussian pulse is the most effective and suitable pulse for IR-UWB outdoor applications. Its spectrum complies with FCC mask for outdoor applications without filtering or frequency shifting. Fig. 1 shows that the FCC spectral mask for outdoor applications is 10dB more stringent than the indoor one.

B. *Block Diagram*

In order to generate the 7^{th} derivative Gaussian pulse, at first Gaussian pulse is created then differentiated seven times. However, the process will be very complicated resulting complex circuit and not suitable for low power applications. A simpler implementation approach is shown in Fig. 2.

By observing the waveform of 5^{th} derivative of Gaussian pulse, which has a symmetric structure with four parts including two negative and two positive peaks with different magnitudes, a 5^{th} derivative of Gaussian pulse generator is proposed in [12]. However, this pulse is suitable only for short-range indoor application. The 5^{th} derivative Gaussian pulse generator includes a digital triangle pulse generator and a shaping stage. Because of the simplicity and power efficient scheme of the circuit in [12], these features will be taken advantage in this design.

In order to get the 7^{th} order of derivative, two more orders of derivation are needed. The block diagram of the proposed pulse generator is shown in Fig.2.

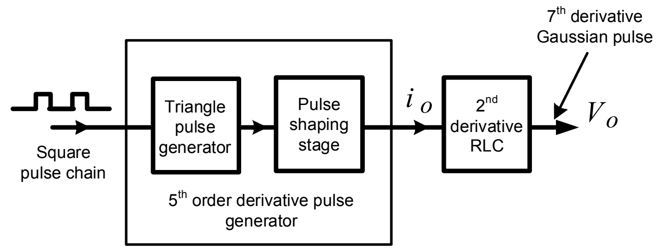

Figure 2. Block diagram of the proposed pulse generator

It consists of two cascaded stages, realizing the 5^{th} derivative Gaussian pulse and 2^{nd} order derivative function, respectively.

C. *2^{nd} Order Derivation Implementation*

The second order derivation is realized by the RLC circuit, shown in Fig. 3.

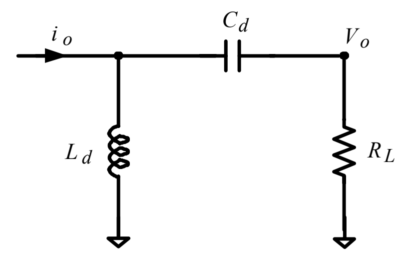

Figure 3. 2^{nd} order derivation circuitry

The trans-impedance of the RLC circuit in s ($j\omega$) domain is given by:

$$T(s) = \frac{V_o(s)}{i_o(s)} = (R_L + \frac{1}{Cs}) // Ls = \frac{RLs}{R_L + \frac{1}{Cs} + Ls} \qquad (1)$$

Since the frequency range is from 3-5GHz, the inductor L_d is in the range of a nH and the capacitor C_d is in the range of a pF, the following approximation is taken.

$$R_L + Ls << \frac{1}{Cs} \quad \text{with } R_L = 50 \text{ Ohms} \qquad (2)$$

From (1) and (2) the relation of V_o and i_o in s domain is obtained as:

$$\frac{V_o(s)}{i_o(s)} \simeq RLs \times Cs \Rightarrow V_o(s) \simeq RLCs^2 \times i_o(s) \qquad (3)$$

The relation (3) in s domain is translated into the time domain, the output V_o is the second derivative of the input current i_o. Thus, a simple RLC circuit can implement the 2nd order derivation.

D. Propose Pulse Generator Circuit

Combining the two circuit blocks, 5th order derivative Gaussian pulse generator and 2nd order derivative RLC circuit, by cascading, the proposed 7th order derivative Gaussian pulsed is implemented.

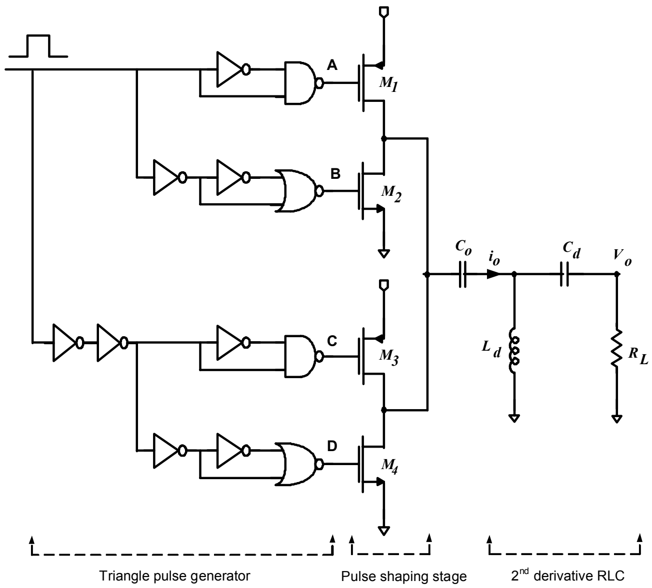

Figure 4. The proposed 7th derivative Gaussian pulse generator

Fig. 4 shows the detail circuit design of 7th order derivative Gaussian pulse generator. The 5th derivative Gaussian pulse is generated first. The input is driven by a square pulse train. After passing through digital components like inverter, NAND and NOR, triangle pulses are created at node A, B, C and D with the same amplitude, successive delays and 180 degree different in phase alternatively. Pulse shaping stage includes two pairs of PMOS and NMOS transistors with the inputs are the triangle pulses at node A, B, C and D. Pulse output currents are controlled and combined successively by these transistors, as a result, 5th derivative Gaussian pulse is generated. After the output current running through the 2nd order derivative RLC circuit, 7th derivative output pulse is obtained.

The inverter is adopted as a delay cell, whose delay time depends on the transistor size and the number of inverters in the signal path. The PMOS and NMOS transistor sizes in pulse shaping stages are chosen based on the needed amplification to shape the 5th derivative Gaussian waveform.

2nd order derivative RLC circuit consists of passive components, thus no current consumption at all. Moreover, since the frequency is in the range of GHz, the component size is small. During the simulation, the optimized value of inductor is 1.5nH and value of capacitor is 0.4pF. The inductor can be used as a bonding wire to save the chip space. Capacitor C_o is a DC blocking capacitor to blocks the static DC current from running from supply voltage through L_d to the ground. It does not affect the pulse spectrum at the frequency of interest. C_o also helps remove the low frequency spectrum near DC, its value can be as small as 0.5pF.

III. Simulation Results And Discussion

The proposed pulse generator is designed using TSMC 0.18 µm CMOS technology with 1.5 V supply.

A. Output Pulse Train

A square clock pulse train with pulse repetition rate (PRR) of 100 MHz is used to drives the pulse generator. The pulse generator output load (R_L) is 50 Ohm for antenna matching purpose.

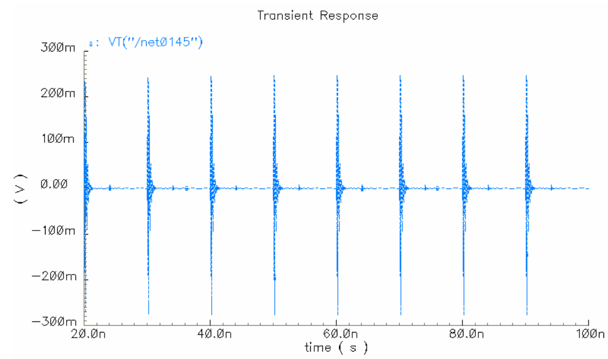

Figure 5. Output pulse chain at 100 MHz PRR

As the input clock trigger the circuit, a pulse train with period of 10ns is achieved and shown in Fig.5. The pulse is generated at the beginning of each period or input pulse edge. Thus, it is very robust to the change of repetition rate and pulse duty cycle.

To satisfy the bandwidth requirement, the pulse duration should be small enough. Pulse duration is determined by the delay time of the inverter, about 150ps each. Fig. 6 shows the waveform of a single 7th derivative Gaussian pulse.

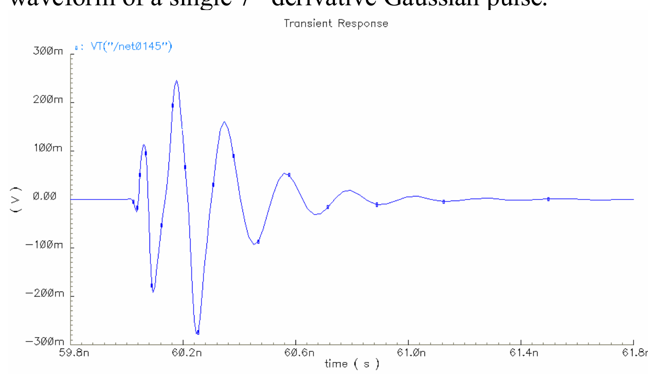

Figure 6. A single 7th Derivative Gaussian pulse

The peak-to-peak swing is more than 500mV, which is high enough to deliver the pulse to antenna without using any wide band amplificaiton. The pulse duration is 800ps resulting to the high spectral allocation in 3.1-5.1 GHz range, shown in Fig. 7.

B. Power Spectrum Density

Our interested frequency range is from 3.1 to 5.1 GHz, thus the spectrum is optimized to allocate in this range with high density. Fig. 7 shows the pulse power spectral density. The spectral shape allocates under the FCC mask for outdoor applications at entire UWB frequency ranges. From the spectral shape, it is clear that, the output impulse perfectly complies with FCC mask with high spectral efficiency.

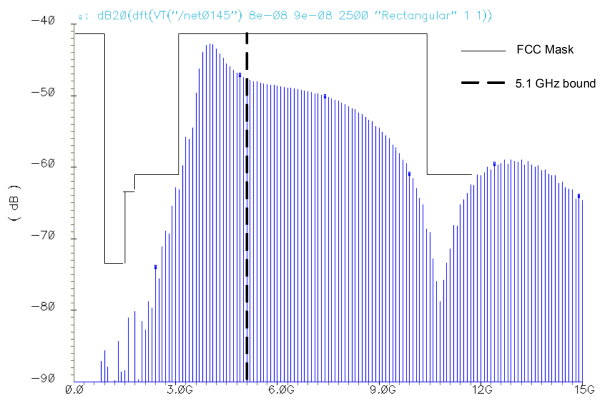

Figure 7. Pulse PSD in compliance with FCC mask

Another impressive characteristic of the proposed pulse generator is that the circuit shows no static (DC) current consumption. Because, only one transistor is turned ON at a specific time which results in no path for static current flows from supply voltage to ground. As a result, the circuit consumes only the dynamic current and it is proportional to the PRR. When PRR increases, higher current is consumed and vice versa. At PRR of 100 MHz, the dynamic current consumption is only 310 µA. For low data rate applications, the PRR is much lower leading to much smaller power consumption. At PRR of 1 and 200 MHz, the current consumptions are 3.2 and 650 µA, respectively. Thus, the dynamic energy consumption per pulse is calculated at around 4.7 pJ. The performance of the proposed pulse generator is summarized on Table I.

TABLE I. PROPOSED PULSE GENERATOR PERFORMANCE

Parameters	**Values**
Bandwidth	3.1-5.1 GHz
Pulse amplitude swing	500 mV
Pulse Duration	800 ps
Dynamic current consumption at PRR of 1, 100, and 200 MHz	3.2, 310, and 620 µA, respectively
Energy consumption per pulse/Supply voltage	4.7 pJ per pulse/1.5 V
Technology	TSMC 0.18 µm

IV. CONCLUSION

A ultra low-power, low-complexity circuitry to generate the monocycle pulses for IR-UWB system has been proposed. The pulse generator is designed in TSMC 0.18-μm technology. 7th derivative Gaussian pulse is generated, the pulse width is 800ps with an amplitude swing of 500mV. The proposed pulse generator is well suited for low-power solution, with no static current consumption. The energy consumption per pulse is only 4.7 pJ, which linearly depends on PRR. The pulse spectrum complies perfectly with FCC mask for outdoor applications without any filtering.

The proposed pulse generator has proved the feasible implementation of IR-UWB with the targets of low complexity, low power, for short-range, high data rate for applications like RFID, sensor network.

REFERENCE

[1] Federal Communications Commission, " Revision of part 15 of the commission's rules regarding ultra-wideband transmission systems: First report and order," Washington DC, *ET-docket 98-153*, *FCC 02-48*, pp. 1–118, Febuary 14, 2002.

[2] I. Oppermann, L. Stoica, A. Rabachin, Z. Shelby, and J. Haapola, " Uwb wireless sensor networks: Uwen - a practical example," *IEEE Commun. Mag.*, vol. 42, pp. S27.S32, Dec. 2004

[3] Brent Parr, ByungLok Cho, Kenneth Wallace, and Zhi Ding, "A Novel Ultra-Wideband Pulse Design Algorithm," *IEEE Comm Letters,* vol. 7, no. 5, pp. 219-221, May 2003.

[4] J. Han and C. Nguyen, "A new ultra-wideband, ultra-short monocycle pulse generator with rcduced ringing," *IEEE Microwave and Wireles Comonent Letters*, vol. 12, no. 6, pp. 206-208, June, 2002.

[5] Gerrits, J.F.M and Farserotu, J.R, **"** Wavelet generation circuit for UWB impulse radio applications**,"** *Electronics Letters*, vol. 38, no. 25, pp. 1737 – 1738, Dec. 2002.

[6] S. Bagga, W. A. Serdijn, and J. R. Long, "A PPM Gaussian monocycle transmitter for Ultra-wideband communications," *IEEE Conf. on Ultra Wideband Sys. and Tech*., Kyoto, Japan, pp. 130-134, May 2004.

[7] Youngkyun Jeong; Sungyong Jung; Jin Liu, " A CMOS impulse generator for UWB wireless communication systems," *IEEE Int. Symp. Circuits and Systems* (ISCAS), vol. 4, pp. 129-132, 23-26 May 2004.

[8] Byunghoo Jung, Yi-Hung Tseng, Harvey, J. and Harjani, R, " Pulse Generator Design For UWB IR\ Communication Systems," *IEEE Int. Symp. Circuits and Systems* (ISCAS), pp. 4381– 4384, 23-26 May 2005.

[9] Yuanjin Zheng, et al, " A low power Noncoherent CMOS UWB Transceiver Ics," *IEEE Radio Frequency integrated Circuits (RFIC) Symposium*, pp. 347 – 350, 12-14 June, 2005.

[10] X. Chen and S. Kiaei, "Monocycle shapes for ultra wideband system", *IEEE Int. Symp. Circuits And Syslems (ISCAS),* vol.1, pp.597-600, May 2002.

[11] Hongsan Sheng, et al, "On the spectral and power requirements for ultra-wideband transmission," *IEEE International Conference on Communications* (ICC), vol.1, pp.738 - 742, 11-15 May 2003.

[12] Hyunseok Kim and Youngjoong Joo," Fifth-derivative Gaussian pulse generator for UWB system," *IEEE Radio Frequency integrated Circuits (RFIC) Symposium*, pp.671- 674, 12-14 June 2005.