Low Power IR-UWB Pulse Generator in 0.13um CMOS Technology

Jelena Radic[1], Alena Djugova[2] and Mirjana Videnovic-Misic[3]

***Abstract* – A low-power ultra-wideband (UWB) pulse generator is investigated in this paper. It consists of a glitch generator, a three-stage ring oscillator, an amplifier and a pulse shaping filter. The pulse oscillator is switched on by the glitch generator only for sub-nanosecond duration to produce a UWB signal. As impulse radio-based generator operates in burst mode with low duty cycle it has low power consumption with no static power dissipation. The circuit presented was designed in a 0.13µm UMC CMOS technology with 1.2V supply voltage. Simulation results showed spectrum that fully complies with the corresponding FCC spectral mask. The signal generator has been evaluated for the best performance supporting on-off keying modulation and 100 MHz pulse repetition frequency (PRF).**

***Keywords* – CMOS technology, impulse radio, low power, on-off keying (OOK), pulse generator, ultra-wideband (UWB).**

I. INTRODUCTION

During last decade ultra-wideband was becoming one of the most promising radio technologies in both academic and industrial circles within very high data rate short-range communication, and low data rate communication related to localization, targeting both low cost and low power consumption. Recently, UWB standard is highly used in short range wireless sensor networks, local and personal area networks, ground penetration radars, the position detection and inventory tracing systems, medical imaging system (remote cardiopulmonary monitoring) and many other medical applications [1-3].

The American Federal Communications Commission (FCC) defines a signal as ultra-wideband if it occupies more than 500 MHz of radio frequency spectrum or exhibits a fractional bandwidth of at least 25% [4]. Nowadays, two different approaches are used for the implementation of UWB communication system: the impulse radio (IR-UWB) technique where data are transmitted as a series of extremely short pulses modulated in time, polarity or amplitude [5], and the multi-band approach consisting in modulating several carriers by applying Orthogonal Frequency Division Multiplexing (MB OFDM). The main advantage of IR-UWB systems is their implementation that can lead to low complexity and low power architectures with increased battery lifetime. Additionally, IR-UWB technology offers wide bandwidth up to several GHz and high fading margin for communication systems in multipath environments [3].

Since the FCC allocated frequency spectrum for UWB technology is 3.1−10.6 GHz, the power level from the UWB transmitter should be small enough not to interfere with the already existing communication systems such as WiMax, Bluetooth and GSM. This requirement limits output power level of UWB TXs at −41.3 dBm/MHz [4]. In spite of these regulations, there have been many reports of interferences with wireless local area network (WLAN) systems operated in the 5-6 GHz band. Therefore, for practical reasons UWB spectrum is split in two sub-bands: 3-5 GHz (lower band) and 6-10.6 GHz (higher band).

There are many papers published about low-band UWB pulse generator due to its easier implementation. Although higher-band operation offers advantages like wider bandwidth, higher data rate, and immunity from interference with WiMax, this research is still at an early stage because of design difficulties (higher operation frequency and shorter pulse duration). In this paper pulse generator, with low power consumption and low complexity, designed for higher band UWB applications is proposed. The presented topology is analyzed in Section III. Simulated FOMs are given in Section IV followed by discussion of advantages and comparison with the other pulse generator designs found in literature. The Section V concludes the paper.

II. IR-UWB PULSE GENERATOR ARCHITECTURE

The pulse generator represents a key block in impulse UWB communications. As pulse shape determines the spectrum characteristic of the UWB signal and effectively dictates specific system requirements, its generation is one of the essential considerations in the UWB design. Fig. 1 shows the

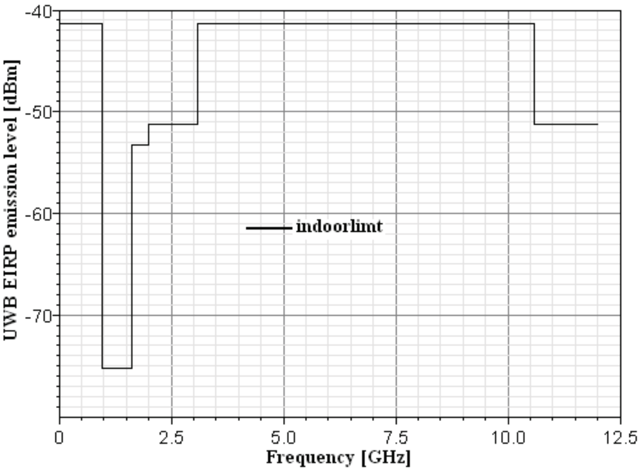

Fig. 1. FCC Indoor mask for UWB.

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FCC mask for indoor UWB communications [4] that pulse spectrum has to comply.

The FCC rules only define the frequency bands and radiated power spectral density but there are no requirements on the time-domain shapes. Pulse shapes usually used in impulse radio technology are based on the Gaussian pulse and its derivatives. For indoor systems, the 5th or higher order derivative of the Gaussian pulse should be used to comply with allocated indoor spectrum mask [6].

Implementation of the pulse generator in standard CMOS process with low power and small area constraints is very challenging. Furthermore, assuming a single band operation, the sub-nanosecond pulse length is required to use the band efficiently. The requirements are even more demanding when higher band is used. The all-digital pulse generator architectures usually require power amplifier at the output to provide sufficient signal strength [7]. Although digital circuits have minimal power dissipation, the total power consumption of the mostly digital UWB transmitter is significantly increased due to power amplifier dissipation. Moreover, IR-UWB low system complexity is further degraded introducing additional PA design constraints. The approach, where the UWB pulse is generated using LC resonant circuits, requires considerable die area, making these architectures less suitable for area constrained applications. The slow transient response of the LC pulsed oscillators restricts the bandwidth and the pulse amplitude, as the oscillation is not able to settle sufficiently in a short duration. To use the high sub-band efficiently a pulse generating oscillator with a fast transient response is needed. One such approach is ring oscillator-based pulse generator whereby the central frequency of transmitted spectrum is defined by the oscillator frequency, and signal bandwidth is determined by the gate pulse duration. This architecture is analyzed in this paper.

III. PROPOSED UWB PULSE GENERATOR

The ring oscillator-based pulse generator is shown in Fig.2. It consists of a glitch generator, a pulsed oscillator and a pulse shaping filter.

The proposed pulsed oscillator is composed of a three-stage ring oscillator, (M_1-M_3), an oscillation-enabling switch (M_4), and a buffer (M_5). The ring oscillator has been chosen for its simplicity and short start-up time. It has small resistance at each feedback nod which allows fast transient response.

The buffer isolates the ring oscillator from pulse shaping filter, and simultaneously provides the current driving capability of the pulsed oscillator.

The oscillation-enabling switch, as its name says, controls the oscillation process. When the control switch turns off, each transistor goes into a sub-threshold region and no signal is generated at the output of the oscillator. At the same time, the output signals of the inverters M_1-M_3 go close to V_{dd} effectively shutting down the buffer. When the oscillation-enabling switch turns on, the inverters M_1-M_3 outputs have voltage values determined by the size ratio of the corresponding pMOS and nMOS transistors. Due to the small inverter reactance, the oscillation can start immediately. Also, during oscillation period voltage values at the output of the ring oscillator are ‘low’ enough to keep the buffer turned on.

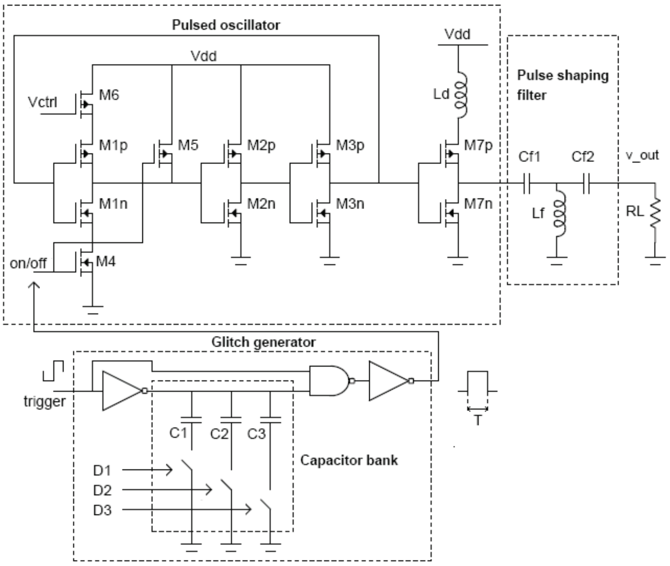

Fig. 2. Proposed UWB pulse generator.

Again, when the control switch turns off, the oscillation can stop immediately due to small reactance at the output node of each inverter. The duration of the control signal *T* (at the input of oscillation-enabling switch) determines the length of the signal generated at the ring oscillator output and thus its bandwidth. If the control signal is shorter, the output signal bandwidth gets wider.

It is already noted that IR-UWB technology requires sub-nanosecond signal duration to generate wide bandwidth. As a single microcontroller can not give such a short signal, the control pulse is produced by the glitch generator. Signal is generated in accordance with input trigger signal which should be controlled by microcontroller. The glitch generator is composed of an inverter, a NAND gate, a digitally controlled capacitor bank and a buffer/inverter at the output of the circuit. In this work, the digitally controlled capacitor bank was added at the inverter output to allow adjustment of the control signal duration and thus the bandwidth of the output signal. Digital signals D_1, D_2 and D_3 switch off/on adequate capacitors determining the total capacitance of the capacitor bank which is directly proportional to the duration of the glitch generator output signal. In this way, the control signal duration and indirectly the output signal and its bandwidth

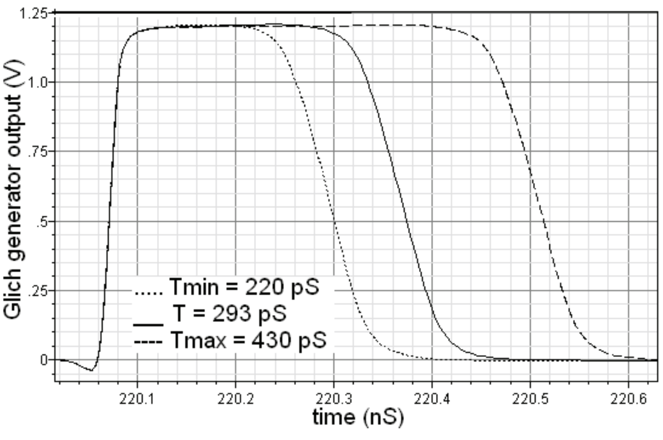

Fig. 3. The control signal at the glitch generator output.

could be digitally tuned. The smallest bank capacitance (D_1=1, D_2=D_3=0) gives the shortest control signal duration of T_{min}=220 pS, shown in Fig. 3. For the highest bank capacitance (D_1=D_2=D_3=1), the longest duration of the control signal (T_{max}=430 pS) has been achieved, depicted in Fig. 3. In this work, the control signal of T=293 pS (obtained for the digital signals combination of D_1=1, D_2= 1, D_3=0) turns on the pulsed oscillator. Due to its fast transient response, sub-nanosecond pulse with very wide bandwidth is generated at the output of the circuit. The buffer/inverter was inserted at the output of NAND gate to isolate the glitch generator from the pulse generator and provide the necessary logic.

The pulse shaping filter is high pass filter composed of inductor L_f and two capacitors C_{f1} and C_{f2}. Its main role is to shape the signal at the output of the pulsed oscillator so its spectrum complies with the FCC spectral mask. To enable the side-lobe suppression, the ring oscillator has to be designed in such a way that its oscillation frequency f_0 fall into the pass band of the pulse shaping filter. This maximizes the total power efficiency and the output amplitude as the filtered-out components are only the side-lobes that have small portion of the total generated spectral components.

IV. THE SIMULATIONS RESULTS AND DISCUSSIONS

The presented IR-UWB pulse generator has been designed and simulated in standard UMC 0.13 μm CMOS eight-metal technology. Supply voltage of this technology is 1.2V. Simulation has been performed using SpectreRF Simulator from Cadence Design System. Initially, the circuit was designed to generate pulse with central frequency in the middle of the higher UWB band (around 8 GHz) and optimized for frequency range from 6 GHz to 10.6 GHz, while driving a 50-Ω load and supporting on-off keying modulation. Even though the UWB antenna impedance is generally not restricted to 50 Ω, the value was chosen because it is used for most of models based on miniature commercial antennas. This type of modulation is adopted due to its simplicity. Next, the circuit was fine-tuned so that the output bandwidth could be pushed to the limits (the lower frequency limit) without degrading the other key circuit performance parameters.

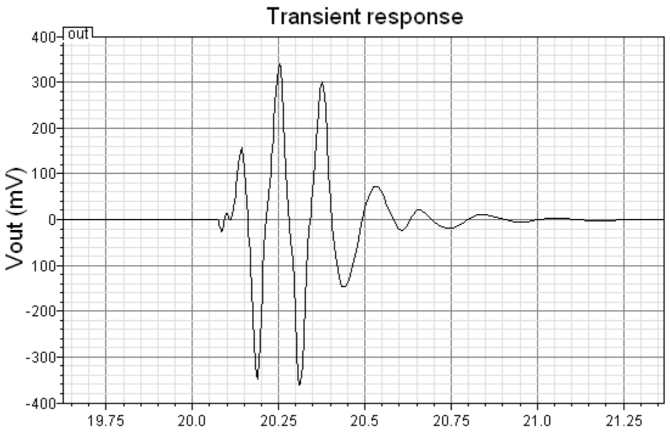

Fig. 4. Time response of the ring-oscillator based pulse generator.

The pulse generator operates in burst mode with low duty cycle and pulse repetition frequency (PRF) of 100 MHz, and thus has very low power dissipation. The IR-UWB topology was optimized with the main aim to meet FCC spectrum demands and minimize power consumption while still keeping acceptable values for remaining Figures of Merits (FOMs).

The simulation results for the generated UWB pulse and its PSD (Power Spectral Density) are shown in Figs. 4 and 5. The center frequency was observed to be around 7.66 GHz and the -10 dB bandwidth was 5.6 GHz, from 5 GHz to 10.6 GHz. In fact, the upper cut-off frequency is slightly greater than 10.6 GHz, but the mentioned point represents the upper UWB limit.

As it could be noticed, the pulse duration is about 0.75 ns and spectrum fully complies with FCC spectrum mask with more than 20 dB of the side-lobe rejection. The peak-to-peak amplitude on a 50 Ω output load is around 700 mV. The average power consumption including the glitch generator, the buffer stage and the filter is 478 μW for PRF of 100 MHz. This corresponds to 4.78 pJ energy consumption per pulse.

Simulation results show that the presented design is very suitable for high-band IR-UWB pulse generation with extremely low power consumption. The possible application could be a radar system which receives its own signal reflected from targets or a communication system with non-coherent detection.

The comparisons of the obtained Figures of Merit with pulse generators performances found in literature [8-10] are summarized in Table I. Unfortunately, the simulation results for the same pulse repetition frequency (100 MHZ) and higher UWB sub-band in 0.13μm CMOS technology could not be found in the literature. Therefore, the pulse generators optimized for the whole UWB band in the same technology (except in Ref [9]) have been used for the performance comparison.

As it was already noted that the proposed design was initially optimized for the higher band and then fine-tuned at the expense of the lower frequency limit, bandwidth of the presented pulse generator is slightly narrower compared to the observed results. Furthermore, it can be seen that design proposed in this work has by far the lowest power consumption and significantly higher amplitude compared to values reported in published papers. Other Figures of Merits are comparable to the results given by other authors.

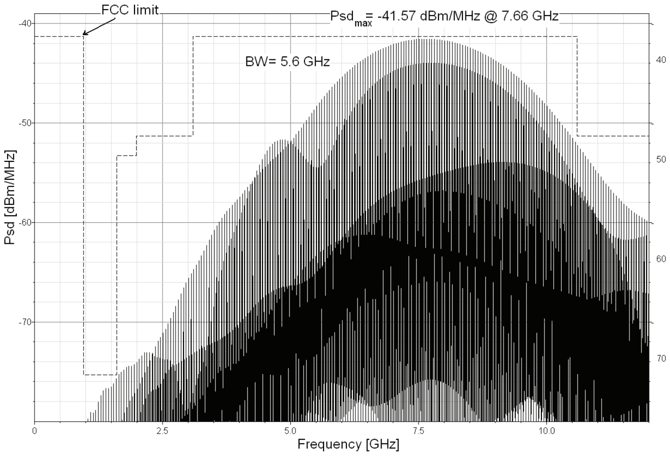

Fig. 5. Simulated spectrum of the output signal.

TABLE I
SIMULATION RESULTS SUMARY AND COMPARISON WITH REPORTED PULSE GENERATORS

Reference	This work	Ref [8]	Ref [9]*	Ref [10]
Ener. cons. [pJ/pulse]	4.78	21	380	5.6
PRF [MHz]	100	200	100	100
Amplitude (V_{pp}) [mV]	700	230	127	190
Pulse length [nS]	0.75	1	0.31	0.75
Band [GHz]	5–10.6	3.5–7.5	3.6–10.2	3.9–10.4
Technology	UMC 0.13µm CMOS	IBM 0.13µm CMOS	TSMC 0.18µm CMOS	0.13µm CMOS

*Simulation results are obtained using Advance Design System (ADS)

V. CONCLUSION

In this paper IR-UWB pulse generator for high-band applications is presented. The results demonstrated that proposed ring oscillator-based architecture has significantly lower power consumption and considerably higher peak to peak amplitude compared to the previously reported UWB pulse generators using CMOS technology. Moreover, it was shown that design has high signal bandwidth and very good side-lobe rejection performance. In addition, it should be noted that the bandwidth could be adjusted by tuning capacitance of the digitally controlled capacitor bank. The pulse generator is feasible for applications in a radar system which receives its own signal reflected from targets or in non-coherent detection communication systems.

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