Ultra-Wideband Pulse Generator for Time-Encoding Wireless Transmission

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Abstract—The paper presents implementation of the Ultra-Wideband (UWB) pulse generator suitable for wireless transmission of time-encoded pulse train. Application of the UWB pulse generator enables direct pulsed triggering from the output of Time Encoding Machine (TEM). The pulse generator circuit is designed in IHP 0.24 μm SG25H3 technology. The paper presents simulation results for the pulse power spectral density and time domain results for the corresponding input and output signals. The pulse generator circuit is expected to consume 189 pJ energy per transmitted pulse and covers area of 0.132 mm². Expected output pulse width is equal to 301 ns and output voltage swing 502 mV.

Keywords—Ultra-Wideband; pulse generator; Time-Encoding Machine; Integral Pulse Frequency Modulator; Power Spectral Density.

I. INTRODUCTION

Due to low energy per transmitted pulse Ultra-Wideband systems are attractive solution for low power short range wireless applications [1-6]. Besides energy efficiency constraints, increasing number of Internet of Things (IoT) connected devices requires novel solutions for wireless connectivity, due to increased spectrum congestion in lower GHz frequency bands [7, 8]. Last 10 meters connectivity is becoming crucial problem in both spectrum management and data processing. Introduction of UWB provides alternative for Bluetooth and similar competing technologies, particularly in Body Area Networks [1, 5], with high number of sensors within low distance.

The most common UWB application areas are in wireless communication systems, particularly Personal Area Networks (PAN) [1, 3], localization [9] and radar imaging [10, 11]. This work is based on analog signal processing, time encoding and asynchronous transmission. Therefore, it cannot be compared in terms of bit rate and bit error rate performances to conventional UWB communication systems. Since it aims to transmit analog signal using asynchronous pulses, its application is considered as baseband modulation technique and is limited with pulse width and pulse repetition rate. The most recent and the most relevant publication proposes similar concept for wireless sensing application, using time constant measurement and UWB transmission [12].

Architecture of the Integral Pulse Frequency Modulator (IPFM) provides linear and energy efficient transformation of the analog input signal to time information encoded in output pulse distance. Therefore, triggering UWB pulse generator directly with TEM output signal enables extremely simple solution for wireless sensing, applicable in Internet of Things applications. To achieve multi-user analog signal acquisition, time delay-based coding is applied within IPFM feedback loop. According to that, the output pulse width depends on the user time delay ID value. Rectangular output pulse train is fed to the input of UWB generator to generate UWB pulse pairs, suitable for further wireless transmission.

Several recent papers present contributions in IC based Ultra-Wideband pulse generation and shaping [13-16]. Besides IC pulse generator implementations, the most common architectures of UWB pulse generators are based on step recovery diodes or avalanche transistors with application of micro-strip lines [17]. However, SRD and BJT implementations significantly increase power consumption of the circuit and cannot satisfy energy efficiency requirements. The proposed UWB generator, suitable for IC implementation in high frequency 0.24 μm process enables size and power efficient circuitry, suitable for wireless sensing applications.

Section II of the paper presents brief introduction to UWB transmitter architecture, followed by modulation principle explanation and UWB generator architecture. The simulation results of the UWB generator are presented in Section III, including the circuit performances analysis.

II. ULTRA-WIDEBAND TRANSMITTER

A. Integral pulse frequency modulator

The pulse generator is incorporated within IPFM wireless sensor node (Fig. 1). Feedback loop of the IPFM contains

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unique identifying delay cell used for multi-user-coding [18, 19]. Each sensor node has different corresponding time delay value, denoted as sensor ID. In that way, each sensor node exhibits different rectangular pulse width at the output.

Corresponding waveforms, for the IPFM DC input signal \( x(t) = 1 \) V (bottom line), are presented in the fig. 2. Corresponding integrator waveforms present input integrator \( I_{INF}(t) \) and user delay integrator \( I_{DD}(t) \) signals. Output of the IPFM modulator \( y(t) \) conveys information on analog input voltage \( x(t) \) within pulse distance and sensor ID information within pulse duration. Following rising and falling edges of the \( y(t) \) signal, UWB generator forms UWB pulses (top line).

The consecutive pulse distance is proportional to the comparator threshold \( u_{TH}(t) = x(t) \) for ideal integrator \( L_{INF}(s) \) with time constant \( \tau_{INF} \). The input integrator output signal in time domain can be expressed by the following equation:

\[
I_{INF}(t_k) = \int_{t_{k-1}}^{t_k} \frac{V_{DD}}{R_{INF}} + C_{k-1}.
\]  

(1)

At the time \( t_k \) when integrator \( L_{INF}(s) \) triggers comparator, under consumption that at the beginning of the integration slope \( t_{k-1}, \) the integrator output was equal to 0 \( (I_{INF}(t_{k-1}) = C_{k-1} = 0) \) the following equation holds:
\[
I_{BF}(t_k) = \int_{t_{k-1}}^{t_k} \frac{V_{DD}}{t_{ID}} \, dt = x(t).
\]

The IPFM pulse width depends on input integrator switching on and switching off times \(T_{ON}\) and \(T_{OFF}\) and sensor ID time delay \(T_{ID}\), which is equal to:

\[
T_{ID} = \frac{\tau_{ID}}{2}.
\]

According to (2), the distance between consecutive output pulses \(T_k\) and \(T_{k-1}\) of the signal \(y(t)\), is equal to:

\[
T_k - T_{k-1} = \frac{\tau_{BF}}{V_{DD}} x(t_k) + \frac{\tau_{ID}}{2} + T_{ON} + T_{OFF}.
\]

B. Ultra-Wideband pulse generator

To keep information on particular user ID, UWB generator (Fig. 3) produces two UWB pulses per one rectangular IPFM pulse. Input to the pulse generator contains delay cell followed by XOR gate (Fig.4). One rectangular pulse is being transformed to two pulses, one for rising and the other for falling edge. Both pulses trigger the RF part of the UWB pulse generator and at the output form two wideband pulses (top line on Fig.2).

Delay line is implemented by two CMOS inverter cells and capacitor to adjust the time delay, required for the pulse period setting. Input and output of the delay line feed the XOR gate for two consecutive pulses formation. Output of the XOR gate is followed by the buffer which triggers the bipolar transistor coupled with capacitance and inductor for output pulse shaping. Proposed architecture enables direct application of the IPFM output pulse train to the input of the pulse generator, which is extremely important to maintain the circuit simplicity and to provide energy efficient wireless connectivity.

Resulting waveform at the output of the pulse generator is monocycle pulse in required frequency spectrum. Layout of the proposed UWB pulse generator is depicted on Fig. 5. It consumes only 0.132 mm\(^2\) mostly occupied by the planar inductor.

III. SIMULATION RESULTS

The UWB pulse generator circuit is designed and simulated in Cadence Virtuoso tools, using IHP’s PDK for SG25H3 0.24 μm BiCMOS technology, providing higher RF performances. Since the pulse generator requires high slew rate inputs for triggering, the technology is highly suitable for integration of time-encoding circuitry providing satisfying rising and falling pulse times suitable to trigger the pulse generator.

The resulting UWB pulse waveform is presented on Fig. 5. Achieved simulated pulse width is 301 ps and peak-to-peak amplitude over 500 mV. The power spectral density is provided on the Fig.6. The figure represents the PSD in dBW/MHz for pulse repetition rate equal 1.2 μs. Due to low pulse repetition rate, the power spectral density is far below the allowed limits according to the FCC requirements. Advantage of asynchronous transmission at low pulse frequency provides benefits in low power spectral density, which in turn enables

![Fig. 4. Block diagram of the UWB generator](image)

![Fig. 5. Layout of the proposed UWB pulse generator](image)

![Fig. 6. UWB pulse waveform](image)

![Fig. 7. Power spectral density of UWB pulse train](image)
application of output power amplifiers application and higher output voltage swing for longer range wireless transmission.

<table>
<thead>
<tr>
<th>Reference</th>
<th>Area [mm²]</th>
<th>Energy [pJ/pulse]</th>
<th>$V_p$ [mV]</th>
<th>Pulse width [ns]</th>
</tr>
</thead>
<tbody>
<tr>
<td>This work</td>
<td>0.132</td>
<td>0.189</td>
<td>502</td>
<td>0.301</td>
</tr>
<tr>
<td>[13]</td>
<td>0.123</td>
<td>0.54</td>
<td>365-583</td>
<td>0.28-7.5</td>
</tr>
<tr>
<td>[15]</td>
<td>0.182</td>
<td>30</td>
<td>400</td>
<td>-</td>
</tr>
</tbody>
</table>

IV. CONCLUSION

The paper presents the simple implementation of the Ultra-Wideband pulse generator in 0.24 μm technology. Architecture enables application within Time-Encoding based wireless sensor node applicable for wireless sensing applications. Since wireless sensor node operates in asynchronous manner, no need for clock signal is needed for signal acquisition and processing. Multi-user coding, achieved by simple time delay cell enables microprocessor-free coding which additionally reduces power consumption. Disadvantage of the proposed system is receiver architecture, suitable for asynchronous pulse detection. It can be implemented as a sliding correlator or simple level detector. Such architecture provides increased symbol error rate, but for application in slow varying signals, pulse repetition frequency can significantly be reduced, which enables potential error correction algorithms.

REFERENCES