22-29GHz CMOS Pulse Generator for Ultra-Wideband Radar Application

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Abstract—The pseudo-millimeter-wave ultra-wideband (UWB) is attractive for applications in short-range automotive radar systems using 22 to 29GHz in order to realize road safety and intelligent transportation. Although CMOS is suitable for the short-range radar since processing units can be implemented in the same chip with the UWB front-end building block, it is difficult to operate CMOS pulse generators at such a high frequency. To realize the pseudo-millimeter-wave band using CMOS, we have proposed a new pulse generator consisting of a series of delay cells and edge combiners with waveform shaping. As a result of measurement using 90nm CMOS technology, 1Gbps/bit pulses are successfully generated with a power consumption of 1.4mW at a supply voltage of 0.91V. This result will be the key technology for a one-chip short-range radar system.

I. INTRODUCTION

Short-range (SR) automotive radar is attractive for road safety and intelligent transportation systems such as car parking, blind spot detection, and reduction of traffic accidents. For such radar applications, the federal communication community (FCC) has established regulations for ultra-wideband (UWB) radar communication in the pseudo-millimeter wave band of 22 to 29GHz with a maximum output power of –41.3dBm/MHz [1]. In conventional pulse-radar systems, a pulse-train output is generated by controlling a continuous-wave (CW) input using a pulse-width control switch [1-6], where the output pulse envelope has a rectangular shape as shown in Fig. 1.

![Figure 1. Block diagram of conventional transmitter for SR radar](image1)

The power spectrum of the rectangular pulse results in a sinc (sin(x)/x) function, which inefficiently utilizes the FCC UWB transmission mask for short pulses. Additionally, using this method, it is necessary to turn on the oscillator throughout the data communication process, resulting in large power consumption. Furthermore, since the pulse generators mentioned above are realized using SiGe integrated circuits [1,2] or discrete components [3-5], 22-29GHz pulse generator using CMOS is still challenging.

To reduce the power consumption, direct pulse generation without using an oscillator is suitable as adopted in impulse radio (IR) communication in the 3.1-10.6GHz UWB band. It has attractive characteristics of low power and low cost since it can be fabricated using digital CMOS technologies [7-10]. Additionally, since the power consumption is linearly proportional to the input data rate, the average power consumption is reduced compared with that of oscillator-based UWB transmitters [3]. In the CMOS SR automotive radar system for the 22-29GHz UWB band shown in Fig. 2, a transmitter and a receiver will be integrated in the same chip. Here, an external power amplifier (PA) with high efficiency using a compound semiconductor will be useful to reduce total power consumption. Transmitting pulses are modulated with orthogonal pseudorandom number (PN) codes using a PN generator to prevent interference. It is noted that monopulses

![Figure 2. Block diagram of CMOS SR radar system](image2)
without PN modulation will interfere with each other so as to cause a probable misdetection when two different vehicles are traveling close to each other. By increasing the length of the PN codes, received signal-to-noise ratio can also be improved by $10 \log(N)$, where $N$ is the length of the PN codes.

In this work, the CMOS pulse generator circuit in Fig. 2 has been designed and implemented instead of a CW oscillator and a pulse-width control switch. The CMOS pulse generator circuit generates pulses with a pseudo-raised-cosine envelope having a better output spectrum with lower power consumption than those with the rectangular envelope.

II. CMOS PSEUDO-MILLIMETER-WAVE PULSE GENERATOR

A. High-Speed Pulse Generator

The block diagram of the pulse generator is shown in Fig. 3. Here, the rising edge of the input signal is passed through the delay-cell chain by contributing delays to form short pulses. Thereafter, the pulses are combined to create a complete waveform. To realize pseudo-millimeter wave frequencies using this technique, the pulse width should be narrowed, which is realized by making the rising and falling slopes steep. Since both slopes are proportional to the load capacitance in delay nodes, the load capacitances of the inverters in delay cells are equalized by merging a delay cell and a monopulse generator.

The monopulse generator consists of a delay cell and an edge combiner as shown in Fig. 4, where the delay cell is composed of two CMOS inverters and the edge combiner is composed of two NMOSFETs. After consecutive monopulses are generated, they are again combined by a wired OR to generate the spectrum-limited pulse. Here, no PMOSFETs are used in the edge combiner, since the insufficient high-frequency performance of the PMOSFETs will decrease both the center frequency and the output power because PMOSFETs will turn on before NMOSFETs are off in high-frequency operation.

Fig. 5 shows the transient waveforms of the internal signals and the output current in the pulse generator. The rising edge of the input signal is sent through the inverter chains, which form a delay line, to have a desired pulse width by shifting the delay. As shown in Fig. 5, a short pulse of several tens of picoseconds is formed since both the NMOSFETs in the edge combiners are on throughout the transient period of an inverter. Since both the rising edge and the falling edge in the delay cell are used by the edge combiner, extra capacitances in delay nodes are equalized. This circuit is suitable for realizing millimeter-wave frequencies since it can generate a narrow pulse width with low power consumption. Furthermore, its simple structure provides more stable pulse widths compared with complex digital pulse generators since delay time variation through a digital circuit is minimized. This characteristic is important for realizing pseudo-millimeter-wave frequencies using recent CMOS technologies.

B. Pulse Shaping

As described in the introduction, pulse shaping is effective in fully utilizing the spectrum regulation. In the circuit shown in Fig. 4, the falling slope of the output signal is determined by the gate widths of the edge combiner although the rising edge of the output signal is determined by the load impedance of 50 $\Omega$. To shape the pulse envelope, the
gate widths of the edge combiners should be adjusted. There are several candidates for generating the pulse envelope. Although it is easy to realize rectangular pulse, the rectangular pulse utilizes the bandwidth inefficiently and the power spectrum of the rectangular waveform with short pulse trains violates the FCC 22-29GHz UWB regulations by having a leakage to outside of the mask. On the other hand, although a raised-cosine pulse efficiently utilizes the output spectrum than rectangular pulse theoretically, it is difficult to adjust the gate width precisely to follow the envelope. To utilize the regulation mask efficiently and to implement the hardware easily, pseudo-raised cosine (PRC) pulse has been used in this work, where the gate widths of the edge combiners, which are connected to the output, are adjusted by changing the number of gate fingers. Since the maximum number of gate fingers is four in our work, gate widths are quantized into four levels from an original raised cosine. As a result of the symbolic and numerical computations on the output spectrum of the PRC, four-level approximation with 14 cycles a PRC pulse is adopted. Waveforms and corresponding output spectrums of the rectangular, raised cosine and PRC pulses are shown in Figs. 6 and 7 for comparison. According to the output spectrum shown in Fig. 7, it is found that the PRC pulse utilizes the whole UWB 22-29GHz band efficiently.

III. MEASUREMENT RESULTS

Fig. 8 shows a chip micrograph of the proposed pulse generator fabricated by 90nm CMOS technology. The time-domain response of the proposed pulse generator with a 100MHz input at a 0.91V supply voltage is shown in Fig. 9. The measurements were performed without any external filters at the output. As shown in Fig. 9, 14 pulses with a 39.2ps width have been realized using 14 monopulse generators. The envelope of the pulse train follows the pseudo raised cosine as expected in simulation, although the baseline of the 14 pulses varies since load impedance is fixed to 50 Ω while the driving current generated by the edge combiners changes. This pulse shape is maintained up to a high input data rate of 1Gbps at 0.91V supply voltage. The frequency-domain response at an input frequency of 20MHz is shown in Fig. 10(a), where the FCC spectrum mask is fulfilled. Since the measurement limitations, the spectrum below 27GHz can be shown in Fig. 10(a), whole spectrum shape is also shown in Fig. 10(b) by adjusting the center frequency down to 22GHz. Power consumption as a function of input bit rate is compared with [2] as shown in Fig. 11. The power consumption at an input bit rate of 1Gbps is 1.4mW using the proposed pulse generator, which is approximately 1/100 of the conventional work. It is noted that power consumption is proportional to the input bit rate down to 10Mbps, which is 1.4pJ per bit for an OOK modulation. This feature will be useful for reducing the average power of the SR radar. Finally, the performance of fabricated chip is summarized in Table I.

IV. CONCLUSION

A UWB pulse generator for the SR radar application in the 22-29GHz band was successfully fabricated using 90nm CMOS process. The power consumption is 1.4mW for an input bit rate of 1Gbps with a 0.91V supply voltage. Power consumption is proportional to the input bit rate down to 10Mbps, which corresponds to 2.8pJ per pulse and 1.4pJ per bit for an OOK modulation. The proposed pulse generator will open up a new application for the UWB SR radar system with low power and low cost.

ACKNOWLEDGEMENT

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REFERENCES


Figure 8. Micrograph of CMOS pulse generator for a UWB-IR SR radar.

Figure 9. Time-domain response of output of pulse generator.

Figure 10. Output spectrum of a pulse generator with the center frequencies of (a) 25.5GHz and (b) 22GHz. Due to measurement limitations, the spectrum up to 27GHz is measured. Dotted lines show the calculation results with PRC pulses.

Figure 11. Comparison of power consumptions as function of input bit rate.

TABLE I. PERFORMANCE SUMMARY OF THE FABRICATED CHIP

<table>
<thead>
<tr>
<th>Technology</th>
<th>90nm CMOS</th>
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</thead>
<tbody>
<tr>
<td>Frequency Band</td>
<td>22-29GHz</td>
</tr>
<tr>
<td>Modulation</td>
<td>OOK</td>
</tr>
<tr>
<td>Supply Voltage</td>
<td>0.91V</td>
</tr>
<tr>
<td>Maximum Input Data Rate</td>
<td>1 Gbps</td>
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<tr>
<td>Power Consumption</td>
<td>1.4 mW @ 1Gbps</td>
</tr>
<tr>
<td>Core Size</td>
<td>90µm × 15µm</td>
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