A CMOS UWB Pulse Generator for 6–10 GHz Applications

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***Abstract*—A CMOS ultra wideband (UWB) pulse generator with low energy dissipation and high peak amplitude is presented for 6–10 GHz applications. The pulse generator complies with the FCC spectral mask for indoor UWB systems. It consists of a glitch generator, a pulsed oscillator, and a pulse shaping filter. The pulsed oscillator is switched on by the glitch signal only for a short duration, so as to make a UWB pulse. For sub-nanosecond pulse generation, a pulsed oscillator with fast transient response is proposed. A pulse shaping filter makes the oscillator output fall into the FCC spectral mask. The pulse generator is fabricated using a 0.18 μm CMOS process. The core chip has a size of 0.11 mm^2. It shows pulse duration of about 500 ps with -10 dB bandwidth of 4.5 GHz from 5.9 to 10.4 GHz. The energy consumption is 27.6 pJ per pulse with a peak-to-peak amplitude of 673 mV on a 50 Ω output load. The generated pulses are very coherent with 1.8 ps RMS jitter.**

***Index Terms*—Coherent, CMOS, pulse generator, pulsed oscillator, pulse shaping filter, ultra wideband (UWB).**

I. Introduction

In recent years, Ultra-Wide-Band Impulse Radio (UWB-IR) technology has drawn much attention for short range radars, short distance communication systems, and wireless sensor networks. It transmits extremely short pulses on the order of a nanosecond or less, which occupy a bandwidth up to several GHz. This leads to many advantages such as high spatial resolution for radar systems, high fading margin for communication systems in multipath environments, and ranging capability for wireless sensor network terminals [1], [2]. The low duty cycle enables low power dissipation as well, which increases battery lifetime of radio systems.

However, there are several difficulties in using impulses in radio systems. The power spectral density (PSD) of a transmitted pulse must be limited so as not to interfere with already existing narrow band radio systems. This leads Federal Communication Commission (FCC) regulation of UWB devices [3]. The FCC allocated 3.1–10.6 GHz bands with a PSD of less than -41.3 dBm/MHz. In the GPS band (0.96–1.61 GHz), there is more stringent regulation: less than -75.3 dBm/MHz is enforced to avoid interference problems. This requires a high-level pulse shaping network for a UWB pulse generator.

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In spite of these regulations, there have been many reports of interference problems with narrow band radio systems such as WLANs in the 5–6 GHz band. The problems originally stem from spectrum sharing and usage in close proximity to similar applications [4]. To avoid such problems, the band is subdivided into two bands: 3–5 GHz (low-band) and 6–10 GHz (high-band).

Up to now, many researchers have concentrated on low-band UWB pulse generation because of its easy implementation. High-band operation allows a higher data rate, higher spatial resolution due to the wider bandwidth, and immunity from interference with WiMax at 3.5 GHz band [5]. Considering these advantages, high-band operation is highly desirable. However, research on a high-band UWB pulse generator is still at an early stage. It requires a higher operation frequency and shorter pulse length than a low-band UWB pulse generator. These factors make it difficult to design a high-band UWB pulse generator.

In [5], the high-band UWB pulse generator is presented in CMOS technology. However, the peak-to-peak amplitude of the output pulse is limited to 120 mV_{pp} even though a power amplifier is used. The small amplitude reduces the transmitted pulse energy per bit. This either increases bit error rate or reduces the operating range.

In this letter, we propose a high-band CMOS UWB pulse generator with low energy dissipation, high peak amplitude, and FCC compliant spectral mask.

II. Proposed UWB Pulse Generator

Pulse generation using oscillator switching for 24 GHz band [6] and for 3–5 GHz band [7] is a good candidate for low power dissipation and high frequency operation. But, these could not be directly applied to a 6–10 GHz UWB pulse generator, because the slow transient response of the LC pulsed oscillators restricts the bandwidth, and the 6–10 GHz band cannot be utilized efficiently. To use the band efficiently, the pulse length is required to be on the order of a sub-nanosecond, assuming a single band operation. The slow transient response also restricts the pulse amplitude, because the oscillation is not able to be sufficiently settled in a short duration. This is obviated using a pulsed oscillator with a fast transient response.

Fig. 1(a) shows the proposed UWB pulse generator. It consists of a glitch generator, a pulsed oscillator, and a pulse shaping filter. The proposed pulsed oscillator consists of a ring oscillator (M_1-M_3), an on/off-switch (M_4), and a buffer (M_5). The ring oscillator has small reactance at each feedback node (ⓐ,ⓑ,ⓒ). This allows a fast transient response. To increase the oscillation frequency (f_0) at a given DC current, a feedback resistor (R) is introduced between the input and the output of each stage. The buffer (M_5) not only isolates the ring oscillator (M_1-M_3)

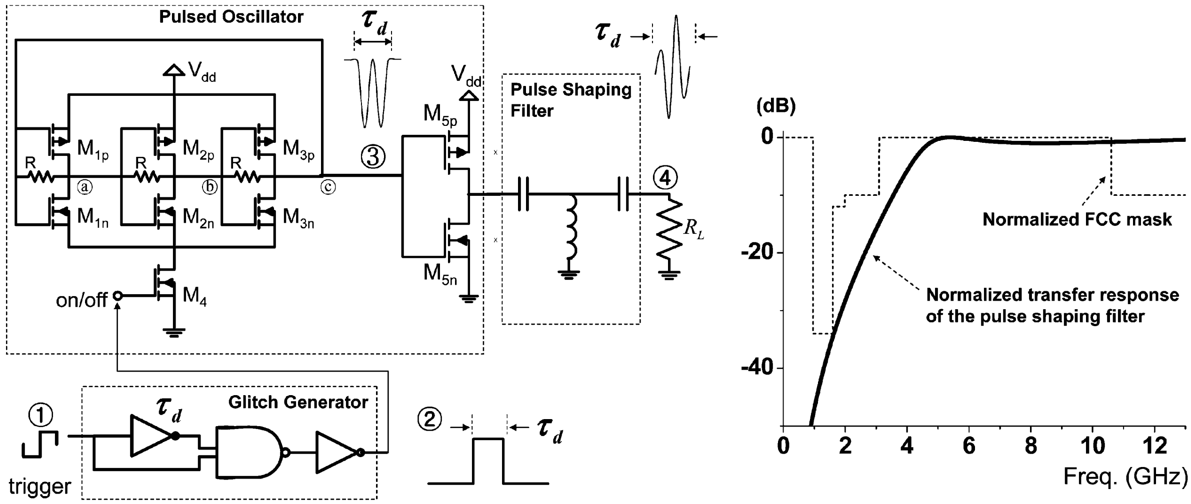

Fig. 1. Proposed UWB pulse generator. (a) Schematic of the proposed pulse generator, (b) Simulated frequency response of the pulse shaping filter.

from the loading of pulse shaping filter but also provides current driving capability for the pulsed oscillator.

When the control switch (M_4) turns off, each transistor goes into a sub-threshold region and no signal is generated at the output of the oscillator. In this case, the bias of each feedback node (ⓐ,ⓑ,ⓒ) goes to around V_{dd}. This also effectively turns off the buffer.

When the control switch (M_4) turns on, each node goes to specific bias voltages determined by the size ratio of pMOS and nMOS transistors in each gain stage (M_1-M_3). This bias-transition acts as a disturbance at the instance of oscillation startup. With this, the buffer effectively turns on as well. Because of the small reactance at each node, the oscillation can start immediately.

Again, when the control switch M_4 turns off, the oscillation can stop immediately because there is only a small reactance at each node. The control signal (②) is generated by the glitch generator in accordance with input trigger signal (①). This turns on the pulsed oscillator for the duration τ_d. This switching operation effectively up-converts the base-band signal (②) to the wideband RF signal (③) at f_0. The fast transient response of the pulsed oscillator generates sub-nanosecond pulse (③).

With proper filtering, the output pulse (④) complies with the FCC spectral mask. Fig. 1(b) shows the normalized frequency response of the pulse shaping filter and normalized FCC spectral mask for indoor UWB devices. The pulse shaping filter suppresses spectral components by more than 34 dB in the GPS band of 0.96–1.61 GHz. In addition, the side-lobe suppression makes the output signal fall into the FCC spectral mask. To maximize power efficiency, the oscillation frequency f_0 must be designed to be within the pass band of the pulse shaping filter, so as to concentrate the pulse energy within the pass band and to filter out only the side-lobes. This maximizes not only the efficiency but also the output amplitude, because the filtered-out components are only a small portion of the total generated spectral components.

The UWB pulse generator is fabricated using TSMC 0.18 μm CMOS process. Spiral inductor and MIM capacitors are used for the implementation of the pulse shaping filter. The size of buffer stage is optimized to make large amplitude on the output load. Fig. 2 shows the fabricated pulse generator. The chip size is 0.5×0.59 mm^2 including pads, and the core size is 0.11 mm^2.

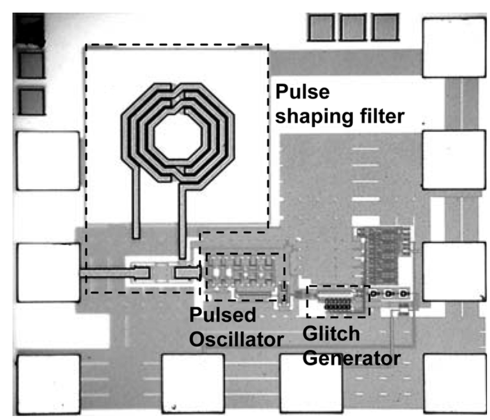

Fig. 2. Photograph of the fabricated UWB pulse generator.

III. Measurement Results

The output waveform and the output spectrum were obtained by on-wafer measurement using a sampling oscilloscope (Agilent 86100C) and a spectrum analyzer (Agilent 8564E). The triggering signal was applied using a pulse pattern generator (Anritsu MP1763C).

The average power consumption including the buffer stage is 1.38 mW for a pulse repetition frequency (PRF) of 50 MHz and 2.1 V supply voltage. This corresponds to 27.6 pJ energy consumption per pulse. Fig. 3 shows the time domain measurement result of the output pulse. The peak-to-peak amplitude on a 50 Ω output load is 673 mV. The pulse width is about 500 ps. The pulse generator exhibits very coherent output pulses with 1.8 ps RMS jitter performance. The signal coherency is closely related with the signal to noise ratio in an impulse radio system which uses coherent detection. Fig. 4 shows the output pulse spectrum. The -10 dB bandwidth is 4.5 GHz from 5.9 to 10.4 GHz. The

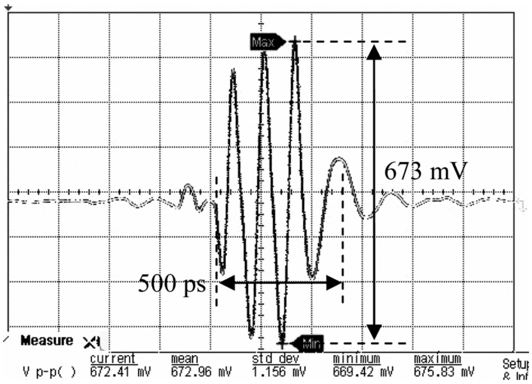

Fig. 3. Time domain measurement of the output pulse.

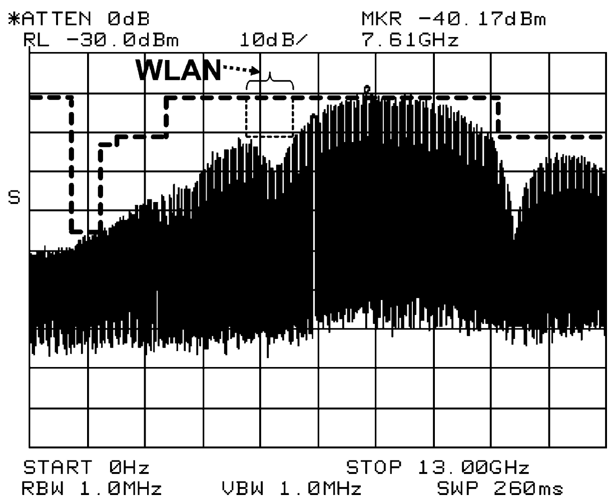

Fig. 4. Spectrum measurement of the output pulse.

spectral suppression in WLAN band (4.9–5.9 GHz) is more than 10 dB.

For a supply voltage of 1.8 V, the energy consumption per pulse reduces to 14 pJ. In this case, the peak-to-peak amplitude on a 50 Ω output load is 542 mV, the -10 dB bandwidth is 3.9 GHz from 5.1 to 9.0 GHz, and the pulse length is about 600 ps. Table I shows the performance comparison with previously reported UWB pulse generators. It shows that the proposed pulse generator is very suitable for high-band UWB pulse generation with high peak amplitude and low energy consumption. The fast transient response and tuned nature of the ring oscillator together with the current driving capability of the buffer stage contribute to these features. The intended application will be a radar system which receives its own signal reflected from targets or a communication system with non-coherent detection.

IV. Conclusion

A high-band (6–10 GHz) UWB pulse generator was presented. It used a pulsed oscillator with a fast transient response.

TABLE I
Comparison With Previously Reported Pulse Generators

Technology	Energy Consumption per Pulse (pJ/pulse)	Peak Amp. (mV_{pp})	Pulse Length (ns)	Band (GHz)
0.8 μm SiGe HBT [1]	190	~540*	~0.3*	3-10
0.13 μm CMOS [8]	125	450	0.6	3-5
0.18 μm CMOS [9]	50	200	1.1-4.5	3-5
0.18 μm CMOS [7]	18	180	3.5	3-5
0.18 μm CMOS [5]	41 (w/ PA) 12 (w/o PA)	120 -	0.5 -	6-10
0.18 μm CMOS [This work]	14 28	542 673	0.6 0.5	6-10

*Estimated from the measurement diagram in reference [1].

The proposed pulse generator was fabricated using a 0.18 μm CMOS process, with a core chip size of 0.11 mm^2. The measurement results demonstrated low energy dissipation, high-peak amplitude, and low jitter performance. To the best of our knowledge, this shows the lowest energy consumption per pulse with regard to output amplitude among previously reported high-band UWB pulse generators using CMOS technology. It is expected to be useful for low cost and low power high-band UWB radio systems.

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