Novel Design and Implementation of Ultra-wideband Pulse Generator Based on Avalanche Transistor

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Abstract— Based on the avalanche multiplication effect of the avalanche transistor, a novel ultra-wideband (UWB) pulse generator has been designed. The UWB pulse technologies are described, and then different approaches for UWB pulse are analyzed and compared. The considered pulse generation technologies are based on logic gates, Step-Recovery Diodes (SRD), and avalanche transistors. The basis of the proposed generator is a precision oscillator, an avalanche transistor, and an unique pulse-shaping circuit composed of the SRD and Schottky diode, which is used to reduce the pulse width and maintain the pulse amplitude high. Every component in the UWB pulse generator should be picked out, and the radio-frequency (RF) characteristics of the circuit must be considered. Finally, the UWB pulse generator with pulse duration of 356 ps, pulse amplitude of 3.1 V and ringing level of −15.9 dB has been simulated and fabricated. The measured result agrees with the simulation. Besides, the measured result is analyzed and the expectation is presented. With the features such as simple structure, stable performance and low cost, the proposed design is ideal for the UWB wireless communication system.

1. INTRODUCTION

After the American Federal Communications Commission (FCC) announced the ruling for ultra-wideband (UWB) systems, the UWB technology has increasingly gained interest by many researchers and several applications of such systems have been developed. Notable applications are those in communications, through-wall radar and ground penetrating radar (GPR). To generate an impulse-based UWB signal for these applications, the UWB pulse generator circuit is critically needed.

In recent years, there are mainly three kinds of narrow pulse generation methods: logic gate pulse generator [1, 2], SRD pulse generator [3, 4] and avalanche transistor pulse generator [5, 6]. Choosing a suitable method is very important to complete the corresponding application [7].

Logic gate pulse generator is based on a fast logic component (an inverter and a NAND or XOR gate). The pulse width is determined by the inverter propagation delay, whereas, the pulse edge depends on the rise/fall time of the output stage. The pulse generated in this method is very narrow and the jitter is very weak. However, the pulse width is limited by the logic component, and the pulse amplitude is less than 1 V.

SRD pulse generator is based on the transition time of the minority carrier. Two important characteristics affecting the performance of the SRD pulse generator need to be identified. One is the transition time of the SRD that determines the minimum achievable pulse's transition time. The other is the minority carrier lifetime (MCLT) of the SRD, which affects the storage time under reverse-bias conditions. The pulse generated in this method is narrower than that in the logic gate method. However, the pulse amplitude is too small.

Avalanche transistor pulse generator is based on the multiplication effect of the avalanche transistor. This method is a traditional method to produce nanosecond pulses, which can be synchronous and have great voltage, so it is very suitable for the UWB wireless communication system. However, it requires a relatively high power supply, the pulse width is a little wide, and the pulse jitter is a little strong.

The pulse generated in the above method is too wide, or the pulse amplitude is too small, so it also can't meet the UWB pulse for the wireless communication system. This paper presents a novel UWB pulse generator composed of a precision oscillator, an avalanche transistor, SRDs and a Schottky diode, and it has been simulated and fabricated on an FR-4 glass epoxy substrate. The result is that the pulse width is greatly narrowed and the pulse amplitude is kept at a high level. The innovation of this paper is to design the edge sharpener and the pulse-shaping network, combine it well with the avalanche circuit, and avoid the strict demand for the input signal. Besides, the tunable pulse repetition frequency (PRF) is helpful to the different applications. The proposed design is clear and simple, so it is ideal to be used for the UWB wireless communication system.

2. DESIGN AND SIMULATION

In the UWB wireless communication system, the penetrability and resolution of the UWB pulse are a pair of contrary factors. The longer the wavelength is, which weakens the resolution of the UWB pulse, the better the penetrability will be. On the other hand, the shorter the wavelength is, which enhances the resolution of the UWB pulse, the more the attenuation will be, that is, the worse the penetrability is. The research shows that the signal has good resolution and penetration performance at about 1 gigahertz [8]. The approximate pulse width can be determined as $\tau \cong 350/B$ (ps), where B is the bandwidth (in gigahertz) [9].

So the UWB pulse signal will be spread well, if the pulse width is about 350 ps. With the attenuation of the spreading, the higher UWB pulse amplitude is, the farther the pulse spreads.

In order to design and implement a UWB pulse generator producing high-voltage and narrow pulses, we need to introduce a multi-stage circuit. For the amplitude of the UWB pulse is relatively high, the basic avalanche circuit is used to generate a high-amplitude pulse. Considering that the pulse width should be about 350 ps, it is necessary for the pulse-shaping network to narrow the pulse width of the avalanche pulse and maintain a high voltage. Besides, an internal signal source is important to drive the avalanche circuit, which has important role in defining the prominent characteristics of the UWB pulse, such as the PRF. However the rise time of the square pulse from the CMOS component is always long, the edge sharpener is very essential.

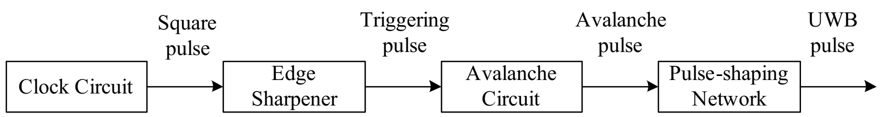

Figure 1: Block diagram of designed UWB pulse generator.

As can be seen from Figure 1, the square pulse from the clock circuit is converted to the triggering pulse after the edge sharpener, which can trigger the avalanche circuit for obtaining high-amplitude avalanche pulse, and then the pulse-shaping network will shape this pulse. Thus the UWB pulse circuit is composed of four parts: the clock circuit, the edge sharpener, the avalanche circuit and the pulse-shaping network, as shown in Figure 2.

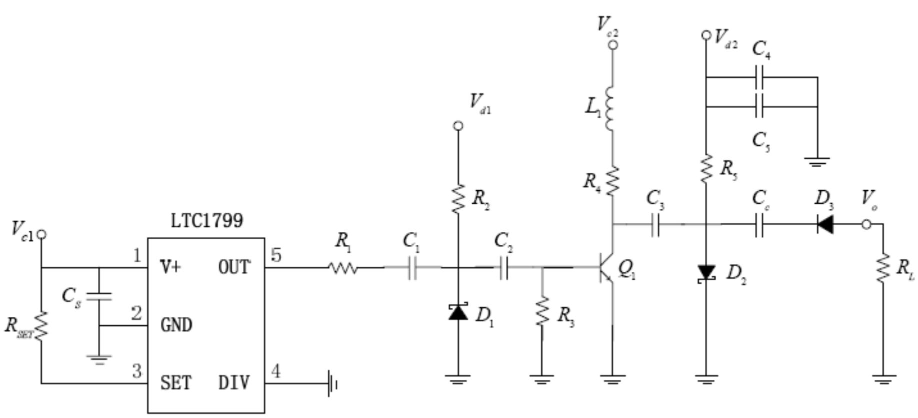

Figure 2: Circuit of designed UWB pulse generator.

The clock circuit is used to generate the square pulse, which can define the PRF of the UWB pulse. Because of the advantage of wide frequency range, low frequency error and low cost, the precision oscillator LTC1799 (Linear Technology) is picked out, which is easy to use and occupies very little PC board space. The oscillator frequency is programmed by a single external resistor (R_{SET}), and the frequency-setting resistor can vary from 3.32 kΩ to 1 MΩ to select a master oscillator frequency between 100 kHz and 30 MHz. If the supply V_{c1} is 5 V and C_S is 0.1 μF, the relationship between R_{SET} and frequency can be described in following formula:

$$f_{\mathrm{OSC}} = 10\,\mathrm{MHz} \cdot (10k/R_{\mathrm{SET}})$$

From the formula, it can be seen that the DIV PIN should set as GND and R_{SET} is 100 kΩ for PRF = 1 MHz, which is the ideal for lower power and better accuracy [10].

The edge sharpener is designed to sharp the rise time of the square pulse. The supply voltage V_{d1} and bias resistor R_2 forward bias the SRD D_1 and store a charge in the depletion region of the diode. As the rise edge of the square pulse appears, it tends to reverse bias the diode and deplete it of stored charge. During this charge depletion phase, the SRD continues to behave as a low impedance, shunting the rising input pulse to ground. When all the stored charge on the SRD is depleted, the diode snaps into its high impedance state, allowing the square pulse to return to ground through the resistor R_3. This switching action can occur in as little as 100 ps, forming a triggering pulse with high speed rise edge.

The avalanche circuit is used to generate an avalanche pulse with high amplitude. The supply voltage V_{c1} and bias resistor R_4 make the transistor Q_1 in a critical avalanche state. V_{c1} is used to charge up C_3 until the avalanche transistor is in the conduction state, and the time constant of charging process is $\tau = R_4C_3$. It is noted that this time constant is less than the pulse repetition frequency PRT $= 1/\text{PRF}$, that is, $\tau \leq 1/\text{PRF}$. In addition, the bias resistor should be suitable for the avalanche transistor, because the power consumption will be big if R_4 is too small, and the rise time will get long if R_4 is too big. The edge shaped triggering pulse can make the avalanche transistor generate a high speed down edge avalanche pulse.

The pulse-shaping network is designed to narrow the pulse width and suppress the pulse ringing. Due to the particular characteristics of the SRD D_2, the forward bias SRD allows the positive current to the ground, storing a charge in the depletion region of the diode, and the reverse bias SRD depletes the stored charge, sharping the negative avalanche pulse edge. The Schottky diode D_3 functions as a switch to suppress the overshoot of the pulse. Besides, the coupling capacitance C_3 and the load R_L form the high-pass filter naturally. Furthermore, the bypass capacitor C_4 and C_5 are used to filter out the noise of the power.

The circuit simulation was conducted using the Advanced System Design (ADS) platform, which is an accuracy simulation tool for RF and microwave circuits. The SRD used for shaping is MMD0840 manufactured by the Metelics Company, and the Schottky diode used for switching is MSS60,148-B10B manufactured by the Metelics Company. The simulation result of the designed UWB pulse generator is shown in Figure 3.

As can be seen from Figure 3, the UWB pulse has the pulse duration of 356 ps, the pulse amplitude of 3.2 V, and the ringing level of −25.8 dB. Clearly, the pulse width meets the designed requirement. Compared to [11] and [12], the pulse width has improved largely, while the pulse amplitude has also been kept at a high level. However there are still some small overshoot, which is mainly caused by the limited state transition between the breaking and opening of the Schottky diode.

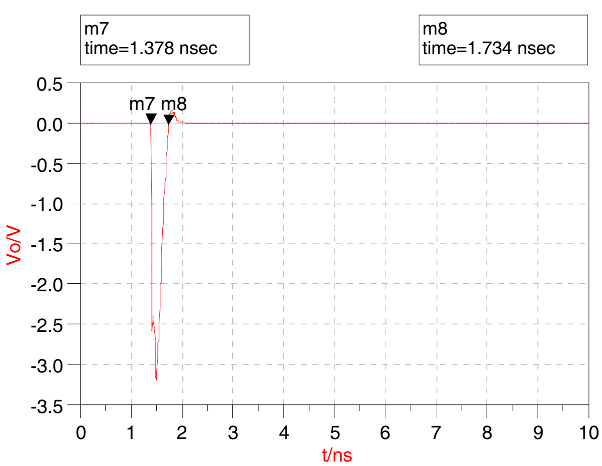

Figure 3: Simulation of designed UWB pulse generator.

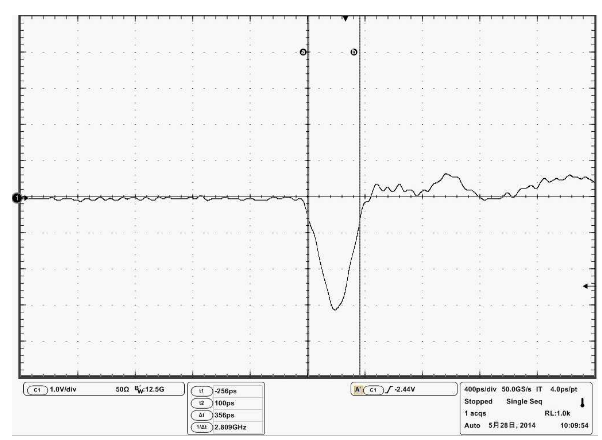

Figure 4: Measurement of designed UWB pulse generator.

3. FABRICATION AND MEASUREMENT

The novel UWB pulse generator has been fabricated on FR4 printed circuit board having a relative dielectric constant of 9.6, a thickness of 1.6 mm. The effect of the high frequency should be considered in the fabrication for avoiding the tail and the shock. The power supply used is a MOTECH LPS-305 (Linear Power Supply). For this pulse with 356-ps pulse width, the most sampling interval is 36 ps if it needs to sample at least ten points within the scope of the pulse width [10]. In other words, the sampling point frequency is at least 28 GS/s. As a result, we can use a Tektronix DPO-71254 (Digital Phosphor Oscilloscope) as the waveform testing instrument, because the sampling point frequency of this instrument reaches 50 GS/s.

As can be seen from Figure 4, a narrow pulse with the amplitude of 3.1 V and the pulse width of 356 ps is obtained. In other words, the measurement results agree with the theory analysis. At the same time, it is noted that the ringing level is below −15.9 dB, which may be caused by the high frequency crosstalk. From Table 1, the pulse generated in CMOS and SRD mode is narrower, but the pulse amplitude is very small, compared to the BJT mode. On the other hand, the pulse amplitude of the pulse in BJT mode is larger, meanwhile the pulse is wider. The pulse generated in this work has high amplitude, at the same time, the pulse width agrees with the design. The balance between the resolution and penetration performance is achieved.

Table 1: Comparison between this work and other proposed ones.

Ref.	PRF (MHz)	Supply (V)	Pulse width (ps)	Pulse Amplitude (V)	Technology
[1]	−−	1.2	142	0.5	CMOS
[4]	10	> 7	400	0.2	SRD
[11]	2.5	25	2071	9.08	BJT
[12]	1–8	5	1900	2.16	BJT&SRD
This work	1 (tunable)	15	356	3.1	BJT&SRD

4. CONCLUSION

A novel UWB pulse generator has been simulated on the RF software ADS and fabricated on FR4 printed circuit board. This pulse generator uses an avalanche transistor, SRDs and a Schottky diode to produce UWB pulses with the pulse width of 356 ps, the pulse amplitude of 3.1 V and the ringing level of −15.9 dB. Good agreement between the measured and simulation results is achieved. As a result, the proposed UWB pulse has good resolution and penetration performance. So this kind of simple and high-performance UWB pulse generator is very suitable for the design of UWB wireless communication system, pulse radar and so on. The ringing and jitter will be suppressed at a lower level in the future. Besides, the PRF of the UWB pulse is tunable by means of varying the external resistance of the precision oscillator.

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