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Picosecond Pulse Shaping Circuits with Inverse Gaussian Monocycle Waveform

Ji-Chyun Liu*, Ching-Yang Wu, Der-Chyuan Lou**, and Chin-Yen Liu*****

* *Department of Electrical Engineering, Ching Yun University*

***Department of Electrical Engineering, Chung Cheng Institute of Technology, National Defense University*

****Department of Electronics Engineering, Ta Hwa Institute of Technology*

ABSTRACT

A novel picosecond pulse shaping circuit with inverse Gaussian monocycle waveform is proposed in this paper. Firstly, the pulse shaping circuit utilizes the step recovery diode (SRD, Schottky diode) and RC differentiator to construct the monocycle pulse. Secondly, using the discontinuity in junction and load resistor for establishing the matching networks as well as to decide the inverse shape of pulse. Both simulation and measurement results are with good agreement in time-domain and frequency-domain responses. For UWB applications, an ultra-short inverse Gaussian monocycle pulse with duration 350ps, symmetry 37.03% and related ringing level 7.9% has been obtained.

Keywords: pulse shaping circuit, inverse Gaussian monocycle pulse

具反向高斯單脈波波形的微秒脈波整形電路之分析

劉智群*　吳清揚　婁德權** 劉錦燕*****

*清雲科技大學電機系

**國防大學中正理工學院電機工程學系

***大華技術學院電子系

摘　　要

本文提出具反向高斯單脈波波形的微微秒脈波整形電路之研究。首先，在脈波整形電路中，運用蕭基特二極體與 RC 微分電路，組成箝位電路，用以建構單脈波信號。其次，本電路利用微帶線於接面間不連續的特性，並結合負載電阻，用以建構匹配網路，調整輸出單脈波的反向波形。在分析上，時域與頻域的量測與模擬結果於文中呈現頗為一致的實驗結果。在實際量測上，所產生的反向高斯單脈波具有 350 微微秒持續時間，37.03%的波形對成性及 7.9%的鈴波位準。此電路可應用於微波通信系統中。

關鍵字：脈波整形器、反向高斯單脈波

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I. INTRODUCTION

Recently, Ultra wideband (UWB) communication has been developed as a good and cost-effective method for short range, especially in-building systems [1]. Basically, only the shaped pulse is transmitted and received between the terminals [2]. It is called "impulse radio" for applications [3, 4]. Thus, the picosecond pulse shaping circuit is a main research topic in UWB communication systems [5-13].

In General, step, Gaussian and monocycle pulses are usually applied in UWB systems due to the common characteristic of ultra wideband spectrums. Since the spectrum of Gaussian monocycle pulse dose not includes the dc portion and low-frequency part, it is available for UWB applications. Basically, Gaussian monocycle pulse shaping circuits consist of step-recovery diode (SRD), RC differentiator and time delay line [6-9, 13]. Therefore, the attractive features of these pulse shaping circuits are its simplicity, compact size, and low cost.

In this paper, modified the conventional Gaussian monocycle pulse shaping circuit, we propose a novel picosecond pulse shaping circuit with inverse Gaussian monocycle waveform for UWB applications. Firstly, this circuit utilizes the SRD Schottky diode and resistor-capacitor (RC) differentiator to construct the clamping circuit for rectifying the feeding Gaussian pulse and establishing the monocycle pulse. Then, using the discontinuity in junction and load resistor for constructing the matching networks and deciding the inverse shape of pulse. For measurements, testing set-up is realized by the pulse generator, time-domain reflectomery (TDR) digital oscilloscope and four channel test-set. And, both time-domain and frequency-domain results are presented and analyzed.

II. DESIGN AND METHODOLOGYS

2.1 Pulse Waveform Bases

2.1.1 Gaussian pulse

In general, a Gaussian pulse is characterized in the following equation [2]:

$$f(t) = A \times e^{-(\frac{t-T_c}{T_{au}})^2} \qquad (1)$$

where A = amplitude, t = time, T_c =delay time (determine the pulse position), T_{au} =time decay constant (determine the pulse duration). While A = 1, T_c = 500 ps and T_{au} =100 ps, calculated results of Gaussian pulse with time and frequency responses are illustrated in Fig. 1(a). It is found that the shape of Gaussian pulse exhibits the DC voltage portion in time domain and presents the low-pass spectrum in frequency domain. Physically, there is a proportional relationship between the pulse's duration and cut-off frequency f_c, that is:

$$Tau \propto \left(\pi \times f_c\right)^{-1} \qquad (2)$$

2.1.2 Gaussian monocycle pulse

Mathematically, the Gaussian monocycle pulse is related to the first derivative of Gaussian pulse, which can be written as [4]:

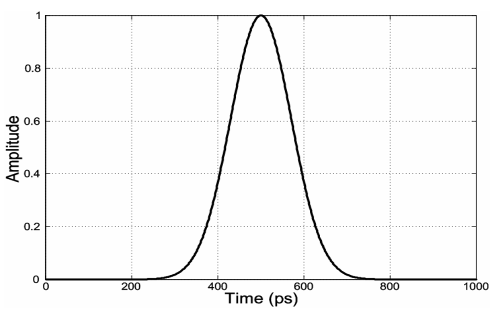
$$f(t) = 2A\pi f_c \sqrt{e}(t-T_c)\, e^{-2[\pi f_c (t-T_c)]^2} \qquad (3)$$

Similarly, as A = +1, T_c = 500 ps and T_{au}

=100 ps, the calculated results of Gaussian monocycle pulse are illustrated in Figure 1(b). Clearly, the shape of Gaussian monocycle pulse is presented the zero crossing in time domain and the high-pass spectrum in frequency domain.

2.1.3 Inverse Gaussian monocycle pulse

Practically, taking the negative amplitude ($A = -1$), the Gaussian monocycle pulse are inversed and plotted in Fig. 1(c) (solid curve). Therefore, the pulse is designated as the inverse Gaussian monocycle pulse or abbreviated as monocycle pulse [6, 8-9]. Especially, as T_{au} =318.3 ps, shown in Fig. 1(c) (dotted curve), the demonstrated waveform can be approximated to a sine monocycle pulse [2]. It is obvious that both inverse Gaussian monocycle pulse and sine monocycle pulse also presents the zero crossing in time domain, and exhibits the characteristic of band-pass spectrum.



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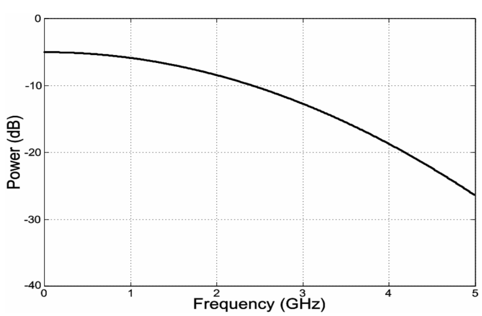

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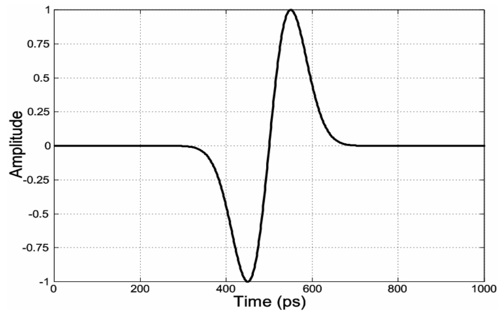

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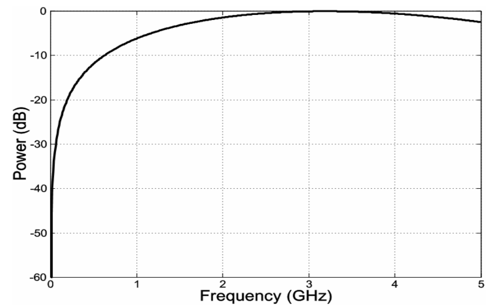

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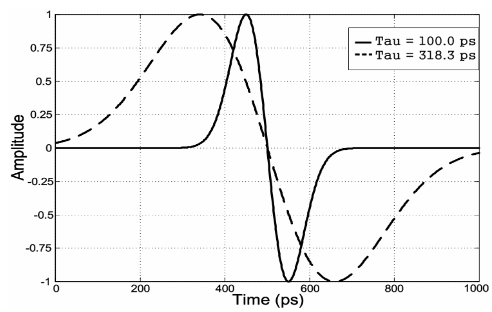

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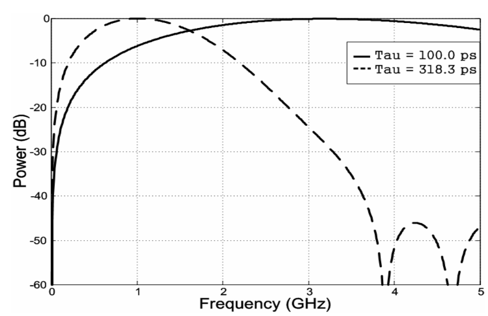
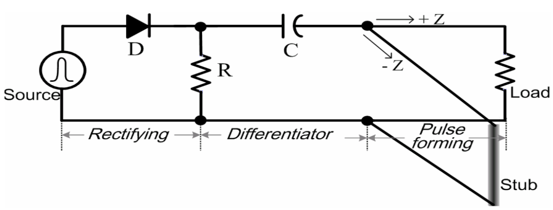


(c-2)

Fig. 1. Calculated results: (a) Gaussian pulse, (b) Gaussian monocycle pulse, (c) inverse Gaussian monocycle pulse.

2.2 Pulse Shaping Circuit Design

The picosecond pulse shaping circuit is usually used to produce the monocycle pulse. There are two types of pulse shaping circuit have been well developed and implemented as shown in Fig. 2(a) [6, 8] and (b) [9]. Conventionally, the Type I is constructed with three sections of rectifying (SRD), differentiator (R, C) and pulse forming (short-terminated stub). For reducing ringing, a tunable clipping diode (D_2) is designed in the Type II, which consists with four sections of rectifying (SRD), matching (50Ω stub and C), clipping (D_2 and V_R) and RC circuit. Therefore, a modified pulse shaping circuit is proposed.



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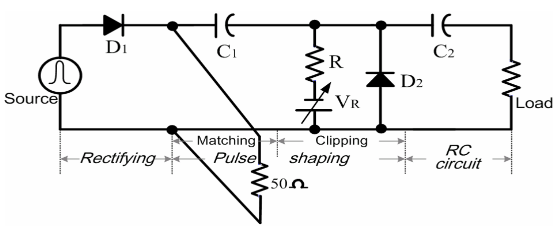

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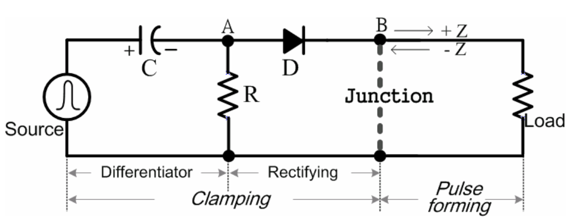
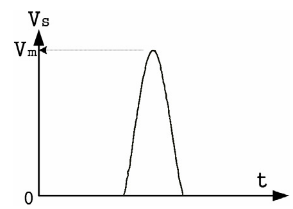


(c)

Fig. 2. Pulse shaping circuit: (a) Type-1, adapted from Lee, J. S., [6,8] (b) Type-2, adapted from Han, J., [9] (c) modified circuit.

The novel picosecond pulse shaping circuit is depicted in Fig. 2(c), which consists of three sections of differentiator, rectifying and pulse forming. At source termination, a Gaussian pulse is fed into the pulse shaping circuit shown in Fig. 3(a). The clamping circuit is distinguished into two paths: the charging path is composed of the SRD Schottky diode, capacitor C and load resistor R_L; the discharging path is composed of R and C. During the clamping process, the SRD Schottky diode is turned on and rectifies the Gaussian pulse and then the negative DC level is clamped and existed at point A of Fig. 2 shown in Fig. 3(b).



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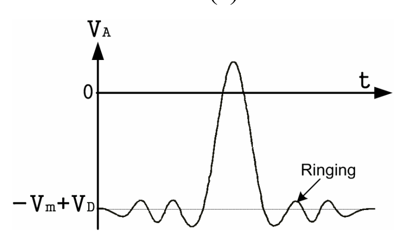

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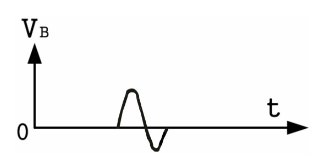
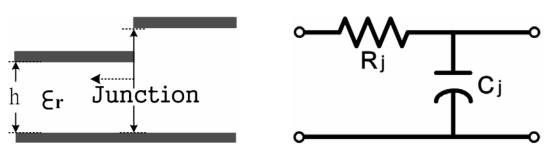


(c)

Fig. 3. Characteristic of pulse forming process: (a) Gaussian pulse waveform at source termination, (b) Clamped pulse waveform at point A of Fig. 2(c), (c) Inverse Gaussian monocycle pulse waveform at point B of Fig. 2(c).

Due to microstrip circuits are accompanied by discontinuity, the discontinuity occurs in the junction of pulse shaping circuit as shown in Fig. 4(a) [14]. And the equivalent circuit is composed of series resistor and parallel capacitor shown in Fig. 4(b). Consequently, the junction capacitor will associate with the parallel load resistor R_L to form the positive Z and negative Z pulses, thus the inverse Gaussian monocycle pulse is established at the load termination shown in Fig. 3(c). And, the characteristic of junction discontinuity effectively acts a low-pass circuit, which would adjust the shape of inverse Gaussian monocycle pulse.



(a) (b)

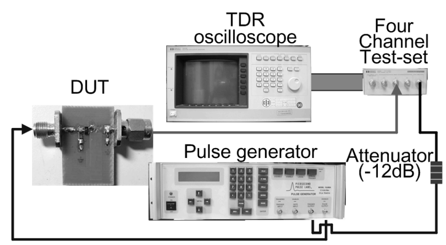
Fig. 4. (a) Microstrip junction discontinuity,
(b) equivalent circuit.
Adapted from Microstrip Line and Slotlines [13]

III. MEASUREMENTS AND SIMULATION RESULTS

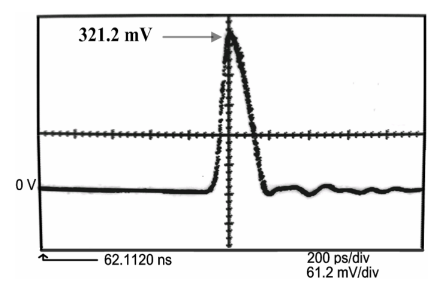
For implementation, the FR4 substrate with thickness h = 1.6mm, dielectric constant ε_r = 4.4 is used for fabricating the pulse shaping circuit. The Schottky diode adapts the HP-HSMS-2862 and load resistance R_L = 50Ω. In analyses, the time-domain responses are measured. And, with the aid of the simulation tool ADS (Advance Design System), both time-domain and frequency- domain responses are simulated and discussed.

3.1 Measurements

In measurement, the testing set-up is realized with the source generator (Picosecond Pulse Laboratories, Model- 10060A), digitizing TDR oscilloscope (HP- 54120B) and four channel test-set (HP- 54121A) as shown in Fig. 5(a). Initially, without the DUT (Device under test), the source generator directly feeds the Gaussian pulse with amplitude 500mV and PRF = 100kHz. The Gaussian pulse with duration 300ps and amplitude 321.2mV is displayed in TDR oscilloscope and shown in Fig. 5(b).



(a)



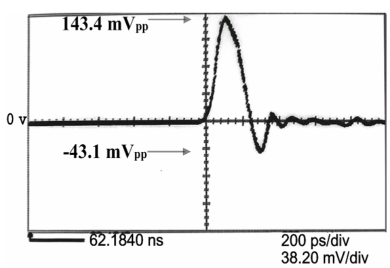
(b)

Fig. 5. (a) Measurement set-up, (b) Gaussian pulse with duration 300ps.

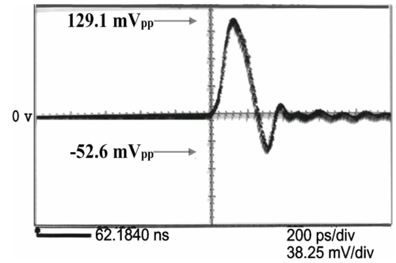
For analyzing the performance of picosecond pulse shaping circuit, four practical examples with various RC time constant are designed and examined. The details of chip parameters are listed in Table 1. Experimentally, feeding the Gaussian pulse with duration 300ps, measured results with time response are presented in Fig. 6

respectively. As can be seen, the inverse Gaussian monocycle pulses have been established correctly. Specifically, the performances of time response with four examples are also summarized in Table 1. In which, tabulated values of the symmetry specifies the percentage of magnitude about positive and negative portion, and the ringing level characterizes the peak-to-peak voltage of monocycle pulse and ring.

Accordingly, while the time constant RC=10ns, as shown in Fig. 6(c), the inverse Gaussian monocycle pulse with duration 350ps and amplitude 176.9mV$_{p\text{-}p}$ is obtained, and related symmetry is 37.03%, ringing level is 7.9%. It is clearly that the pulse shaping circuit could transfer Gaussian pulse to the inverse Gaussian monocycle pulse, and their time responses appear ultra-short pulse duration with correct symmetry and low ringing level.



(a)



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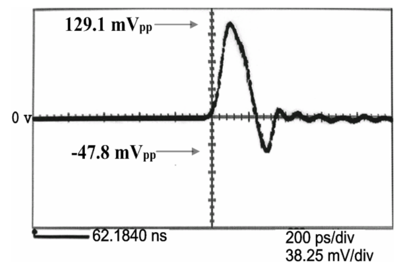

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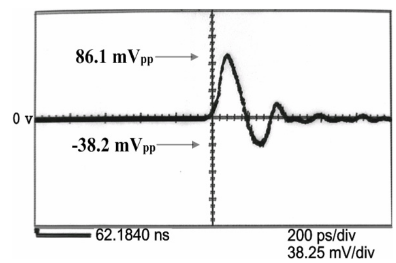


(d)

Fig. 6. Measurement results for time-domain response: (a) RC = 1000 ns, (b) RC = 100 ns, (c) RC = 10 ns, (c) RC = 1 ns

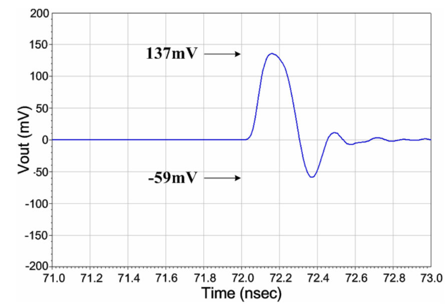
Table 1. Performances of time response with various RC time constant

RC Time Constant (ns)	Chip Resistor (Ω)	Chip Capacitor (pF)	Pulse Duration (ps)	Amplitude (mV$_{p\text{-}p}$)	Symmetry (%)	Ringing Level (%)
1000	10000	100	350	186.5	30.06	9.7
100	1000	100	360	181.7	40.74	7.5
10	500	20	350	176.9	37.03	7.9
1	50	20	320	124.3	44.38	14.3

3.2 Simulation Results

For comparison with experimental results and examining the circuit performance, two examples with RC=1000ns and RC=10ns are applied to demonstrate the phenomenon of this pulse shaping circuit. For simulations, taking a good matching condition on this circuit, the junction capacitor and junction resistor are chosen as C_j = 0.5pF and R_j = 30Ω. Consequently, as feeding the Gaussian pulse with duration 300 ps and amplitude 500mV, the simulation results of time-domain and frequency-domain responses are presented in Fig. 7. It is apparent that the obtained inverse Gaussian monocycle pulses present ultra-short duration with correct symmetry and low ringing level in time domain, and band-pass spectrum in frequency domain.

Meanwhile, the details of performances are summarized in Table 2. In which, while the time constant RC=10ns, the inverse Gaussian monocycle pulse with duration 340ps, amplitude 202mV$_{p\text{-}p}$ is obtained, and related symmetry is 55.38%, ringing level is 4.95%. Correspondingly, the center frequency is 3.47GHz and related -3dB fractional BW is 160.2%. Obviously, this pulse shaping circuit could clearly transfer the Gaussian pulse into the inverse Gaussian monocycle pulse. The time response appears ultra-short pulse duration with correct symmetry and low ringing level, and the frequency response presents characteristic of band-pass spectrum. In addition, both simulations and measurements verify the time and frequency responses with good agreement.



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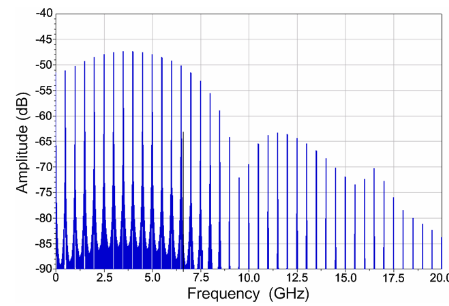

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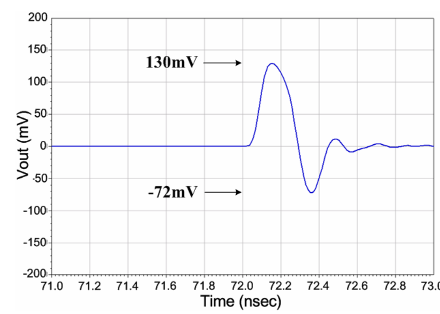

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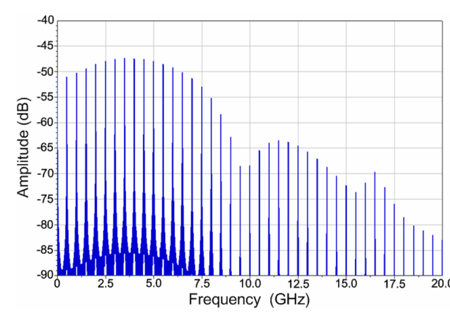

(b-2)

Fig. 7. Simulation results for time-domain and frequency-domain responses: (a) RC = 1000 ns, (b) RC = 10 ns

Table 2. Simulated results for the monocycle pulse

RC Time Constant (ns)	Time domain				Frequency domain	
	Pulse Duration (ps)	Amplitude (mV_{p-p})	Symmetry (%)	Ringing Level (%)	Center Frequency (GHz)	-3dB BW (GHz)
1000	350	196	43.07	4.59	3.75	144.5
10	340	202	55.38	4.95	3.47	160.2

IV. CONCLUSION

In this paper, a novel picosecond pulse shaping circuit with inverse Gaussian monocycle waveform is proposed and characterized. Essentially, the SRD Schottky diode and RC differentiator are utilized to construct the clamping circuit for rectifying the feeding Gaussian pulse and constructing the monocycle pulse. In addition, based on the junction discontinuity, the pulse forming and matching network are established as well as to decide the inverse shape and duration of the monocycle pulse. This is an alternative approach to improve the pulse performance of the conventional pulse shaping circuit. It is evident that the proposed pulse shaping circuit could clearly establish the inverse Gaussian monocycle pulse with ultra-short pulse duration, correct symmetry and low ringing level. Furthermore, the formed monocycle pulse presents ultra-wide bandwidth and band-pass characteristic in spectrum. Both time-domain and frequency- domain results with good agreement are verified by simulations and measurements.

In practice, the generated inverse Gaussian monocycle pulse presents 37.03% symmetry between the positive and negative portions with pulse duration 350ps and amplitude 176.9mV_{p-p}, and related ringing level is 7.9%. The simplicity, compact, low cost and its good performance of the developed pulse shaping circuit make it attractive for UWB systems. It also can be applied to the microwave communication systems.

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