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RESEARCH PAPER

A compact reconfigurable sub-nanosecond pulse generator with pulse-shape modulation

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A new design of reconfigurable sub-nanosecond pulse generator (PG) with pulse shape selection ability is presented in this paper. Step recovery diode is used as the pulse sharpening device and the pulse shaping circuit consists of a controllable RC differentiator in which a single PIN diode is embedded, which provides two different switchable pulse shaping performances. The realized PG has a compact (10 × 12 mm²) simple structure and is easy to implement while generating Gaussian and monocycle pulses with 510 and 660 ps pulse width, respectively. The proposed pulse shaping method is versatile and can be effectively modified and reconfigured to generate more complicated pulse shapes such as polycycle signals. The measured results reveal that the proposed reconfigurable PG is suitable to be used in systems with pulse shape modulation that require sub-nanosecond pulses at low pulse repetition rates.

Keywords: Monocycle pulse, Pulse shape modulation, Reconfigurable structure, Short pulse generator

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I. INTRODUCTION

An important component of any wideband system is the pulse generator (PG). An ultra-wideband (UWB) signal is defined by its bandwidth (>500 MHz) and limitations on the power-spectrum of UWB pulse shapes were imposed by FCC's reform in 2002 [1, 2]. The step, Gaussian, monocycle, and polycycle are the most commonly used pulse shapes for wideband systems. Although each of these pulse shapes has its unique merits, the monocycle is the most commonly used due to its simpler realization, wide spectrum, and more importantly because it does not contain low frequency spectrum including DC and therefore it can be transmitted through a practical antenna [3, 4].

Various techniques for short pulse generation have been proposed involving different impulse-like PG devices such as MESFET, step recovery diode (SRD), avalanche diode, and gallium arsenide photoconductive switches [5]. However, due to the increasing demand for low-power consuming handheld wideband devices it is desirable to have compact low cost PGs and other integrated RF modules [5–7]. The SRDs are the most promising devices for low power sub-nanosecond pulse generation. The SRD works as a charge controlled switch and its ability to change very rapidly from low impedance to a high impedance state can be used to sharpen the slow waveform edges. Transition time (T_t) and minority carrier life time (MCLT) are the most important characteristics of the SRD. The transition time of the SRD determines the minimum achievable pulse's transition time while the MCLT affects the storage time under reverse bias condition [4]. Moreover, many existing wideband PGs are capable of producing only a single type of pulse. However, modern wideband systems require transmitters with tuneable pulse width or multiple pulse shape generation capability. In addition multiple pulse shape generation can provide pulse shape modulation, which is desirable for encoding data in communication systems [8–10].

In this paper a novel design of reconfigurable wideband PG is presented. The designed PG output signal is able to switch between Gaussian and monocycle pulse shapes. The employed pulse shaping circuit consists of an RC differentiator, which can be effectively bypassed by a PIN diode leading to two different pulse shapes at the output port. Moreover, unlike many recently published wideband PGs, which employ input driving clock pulses with fast rise/fall times (few nanoseconds) [3, 4], the presented PG in this paper is driven by a 10 MHz sinusoidal signal. In the next sections the design procedure and the structure of the proposed reconfigurable wideband PG is illustrated in details.

II. DESIGN AND CONFIGURATION

The proposed reconfigurable SRD-based PG schematic is shown in Fig. 1, which consists of a Gaussian PG, a pulse shape selector, and the load section. The Gaussian PG section generates sharp pulses from a 10 MHz sinusoidal input signal using an SRD and a shunt short circuited transmission line (delay line). The input signal driving the series SRD creates a step-like pulse, which further divides into two equal pulses travelling toward the short circuited stub and pulse shape selector section. The reflected signal from the short circuit is 180° out of phase and combines with the next incident step-like pulse at the SRD-transmission line

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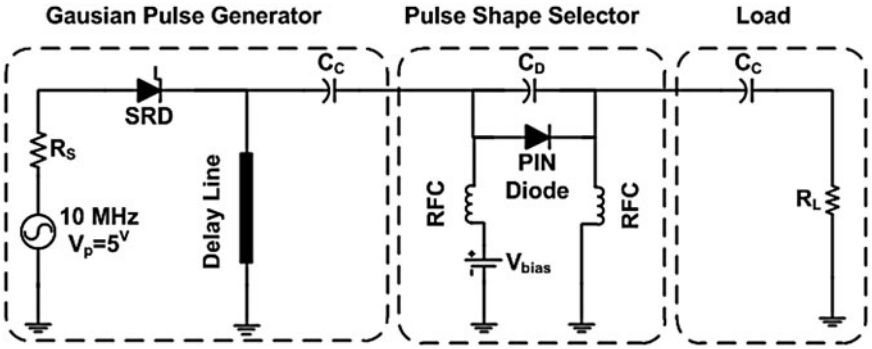


Fig. 1. The schematic of the proposed reconfigurable wideband PG.

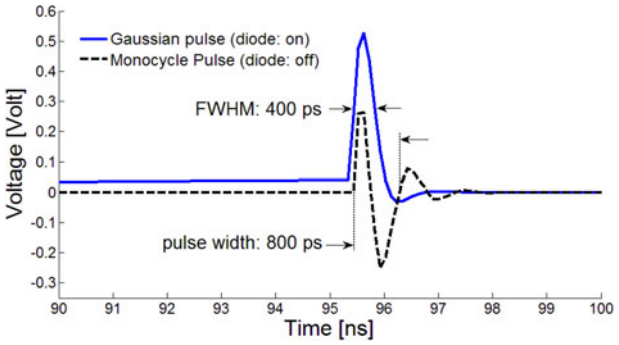


Fig. 2. Simulated output pulse shapes of the proposed PG.

junction forming a sharp Gaussian pulse [11]. The length of the short circuited stub is $L_d = \tau V_p/2$, in which τ is the pulse duration, and V_p is the speed of the wave. Other parameters especially the physical characteristics of the employed SRD such as the carrier life time of the SRD should also be considered during selection of the delay line length [12]. Agilent advanced design system simulation software (Agilent ADS) was used as the simulator [13] and the generated Gaussian pulse at the SRD-transmission line junction is shown in Fig. 2. A tuning practice has been performed during simulation in order to obtain the final value for the delay line length and the simulated results are depicted in Fig. 3. According to this figure, shorter stub can create shorter pulse duration but this will reduce the pulse amplitude significantly.

Same technique can be used in order to create monocycle pulse shape by combining two Gaussian pulses having 180° phase difference and certain time delay between them. However, the produced monocycle pulse will have a pulse duration about twice of that of the original Gaussian pulses [12]. Therefore in order to avoid pulse duration degradation, a first order RC differentiator (high pass filter) is employed to generate monocycle pulse shape. The RC differentiator consists of the load impedance R_L and the capacitance C_D, as shown in Fig. 1. The coupling capacitances named C_C in Fig. 1 are chosen very larger than the C_D and thus they can be ignored during differentiator calculations.

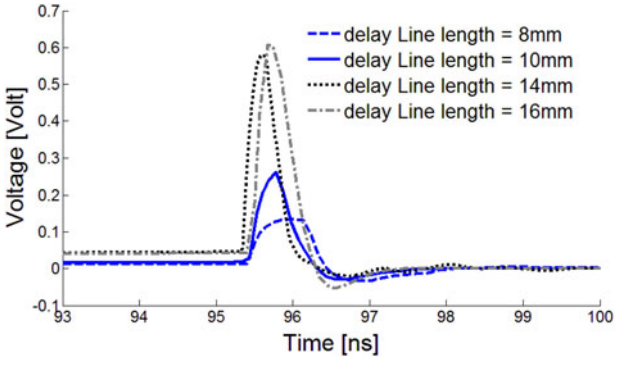


Fig. 3. The various simulated output Gaussian pulses with the delay line length as a parameter.

Assuming a Gaussian pulse, which is expressed as equation (1) in which A is the amplitude of the Gaussian pulse, f_c is the center frequency, and t is time, taking derivative of equation (1) gives the monocycle pulse shape as equation (2). Having $f_c = 1/2\pi R_L C$, by choosing the desirable frequency band of 0.5–1.5 GHz and $R_L = 50$, the C_D can be calculated in range of 2–3 pF.

$$V(A, t, f_c) = Ae^{-2(\pi f_c t)^2}, \tag{1}$$

$$V(A, t, f_c) = 2\sqrt{e}A\pi t f_c e^{-2(\pi f_c t)^2}. \tag{2}$$

In order to create a reconfigurable PG with pulse shape modulation (PSM) capability, a PIN diode is embedded parallel with the C_D as shown in Fig. 1. The PIN diode acts as a low impedance (usually 2–5 Ω) at its on state and thereby the C_D is bypassed and the effect of the differentiator is canceled and the output signal has a Gaussian shape. On the other hand, when the PIN diode is off it can be considered as a small capacitance ($C_P < 1$ pF), which is equal to a large impedance at high frequencies and therefore the effective capacitance of the differentiator becomes $C_{eff} = C_D + C_P$ and the output signal has a monocycle shape. After inserting the PIN diode a tuning process is done in order to obtain the final values of employed components. The final values of the components in Fig. 1 are: $R_S = R_L = 50\ \Omega$, $C_D = 2.2$ pF, $C_C = 100$ nF, *transmission line length* = 14 mm, $V_{bias} = 2$ V, *PIN diode junction capacitance* = 0.33 pF, *and PIN diode forward resistance* = 1 Ω. The SRD is assumed to have carrier life time of 50 ns, transition time of 120 ps and junction capacitance of 3 pF. The simulation results reveal that the generated Gaussian and monocycle pulses have 700 and 800 ps pulse widths, respectively and the full-width-at-half-maximum (FWHM) for the Gaussian pulse is 400 ps.

Moreover, various simulation studies have been performed in order to examine the robustness of the presented

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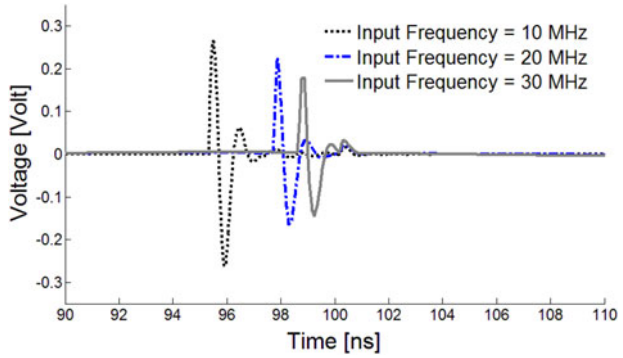


Fig. 4. The various simulated output monocycle pulses with the input excitation signal frequency as a parameter.

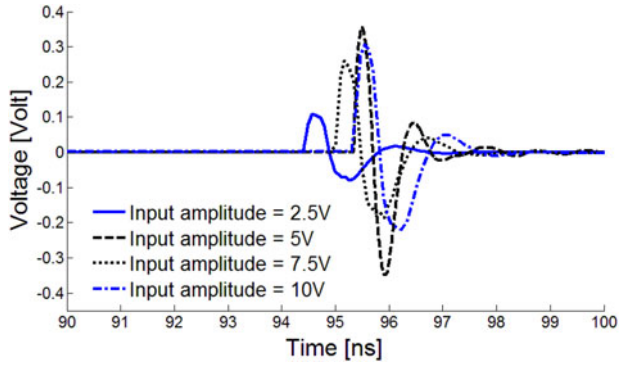


Fig. 5. The various simulated output monocycle pulses with the input excitation signal amplitude as a parameter.

reconfigurable PG against any changes in the input signal alteration. Various simulated output monocycle pulses with the input excitation signal frequency as a parameter are depicted in Fig. 4. As can be observed in this figure although the amplitude of the output pulses are decreased by changes in the excitation frequency, the monocycle pulse shape characteristic of the output pulse is well preserved, which is desirable. Also, various simulated output monocycle pulses with the input excitation signal amplitude as a parameter are depicted in Fig. 5. As can be observed in this figure, both amplitude and pulse width of the output pulse are influenced by the amplitude of the input excitation signal. However, the output monocycle pulse shape is again well preserved, which is a desirable characteristic in most applications with PSM [10].

III. RESULTS AND DISCUSSION

A prototype of the proposed reconfigurable wideband PG is realized on a RO4003 substrate ($\varepsilon_r = 3.38$, $h = 0.8$ mm) and its photograph is shown in Fig. 6. The employed SRD and PIN diode are HP 5082-0112 and BAR64-03W, respectively. As can be observed in Fig. 6 the components in the fabricated PG are tightly soldered together in order to avoid any unwanted performance alteration due to the distributed microstrip transmission lines effects [14, 15]. A pair of wires is used in order to apply the DC bias to the embedded PIN diode. Figure 7 shows the measured output signals for different biasing conditions of the PIN diode when it was driven by a

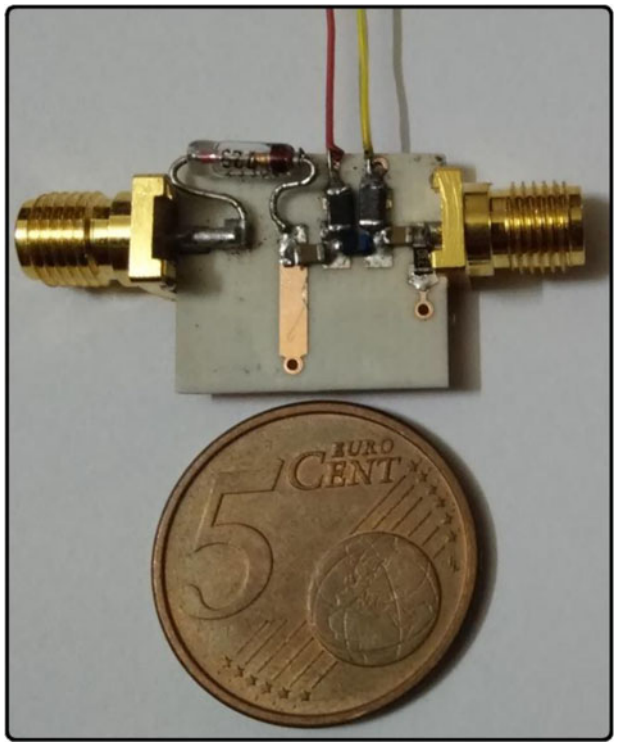


Fig. 6. The photograph of the realized reconfigurable PG.

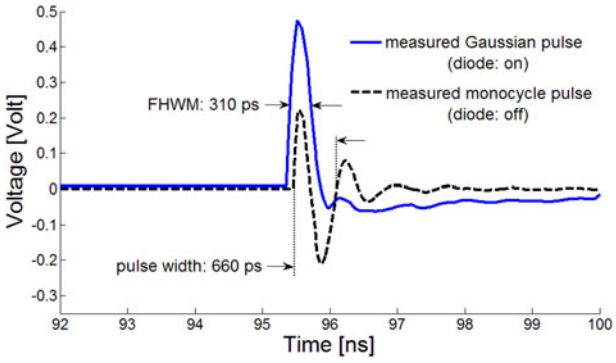


Fig. 7. The measured output pulse shapes for various biasing states of the embedded PIN diode.

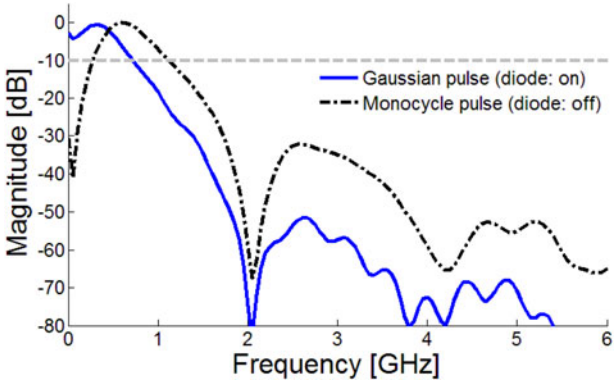


Fig. 8. Calculated power spectrum of the measured Gaussian and monocycle pulses generated by the designed reconfigurable pulse generator.

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Table 1. Comparison of this work with other pulse generators.

Reference	[10]	[11]	[14]	This work
Pulse shape	Gaussian & monocycle	Gaussian	Monocycle	Gaussian & monocycle
Pulse width	401, 550 ps	482 ps	1 ns	510, 660 ps
Ringing level	−16, −22 dB	−14 dB	−17.15 dB	−24.85, −11.5 dB
Number of SRDs	1	2	1 with an attenuator	1
Reconfigurable structure and employed element	Yes, Schottky diode	No	No	Yes, PIN diode

10 MHz 5 V_p sinusoidal signal. As can be observed in Fig. 7 the measured Gaussian waveform has 510 ps pulse duration, amplitude of 470 mV, and FWHM of 310 ps. The ringing level for the measured Gaussian pulse is −24.85 dB. Moreover, the measured monocycle pulse has pulse duration of 660 ps, 430 mV peak-to-peak amplitude, and ringing level of −11.5 dB. Good symmetry for both amplitude and shape exists between the positive and negative portions of the generated monocycle pulse. Although, comparing the simulation results in Fig. 2 with the measured results in Fig. 7 shows that the fabricated PG has a better performance in case of pulse width, it should be noted that another important issue which must be considered is the damping time of the ringing effect, which is longer for the measured results. This could be due to a number of parameters such as the manufacturing accuracy, SMA connectors, and the soldering process. However, in an overall point of view fine agreement exists between the simulated and measured results.

Moreover, the frequency bandwidth of the generated Gaussian and monocycle pulses have also been calculated using fast Fourier transform and the obtained results are shown in Fig. 8. The available bandwidth (>−10 dB) for both Gaussian and monocycle pulses are more than 500 MHz and therefore the proposed reconfigurable PG can be categorized as UWB PG.

A comparison between the proposed reconfigurable wideband PG with other similar PGs, which are recently published in the literature is presented in Table 1. According to this table the proposed reconfigurable PG structure has suitable performance and can be a good candidate for various wideband applications.

IV. CONCLUSION

A novel compact reconfigurable UWB SRD PG with switchable pulse shaping performance has been designed, fabricated, and tested. A simple RC high-pass filter was used to directly generate the monocycle pulse from the sharpened Gaussian pulse. Only a single PIN diode is employed to create the switchable reconfigurable performance. The simplicity, low cost, and good performance of this circuit makes it attractive for various low rate UWB systems with pulse shape modulation.

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