

# Universal Generator of Ultra-Wideband Pulses

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**Abstract.** *An Ultra-Wideband (UWB) subnanosecond pulse generator is described in this paper. High amplitude Gaussian pulses are generated by a Step Recovery Diode (SRD) included in a novel pulse forming circuit. The proposed circuit solution utilizes the performance of the SRD effectively, without excessive requirements regarding the driver section of the generator. Monocycle pulses are then generated by an additional pulse forming network. A simple transistor driver is also described, which transforms a TTL trigger signal to a driving pulse with the timing and amplitude parameters required by the SRD. Measurement results are presented, which show the proposed generator operating with stable output pulse parameters at arbitrary pulse repetition frequency up to 20 MHz. The generated monocycle pulses are 25 V in amplitude and approximately 500 ps in width.*

## Keywords

Ultra-Wideband, pulse generators, short pulses, step recovery diode, pulse shaping.

## 1. Introduction

An Ultra-Wideband (UWB) short pulse generator is the main part of any UWB system. The basis of a conventional UWB pulse generator is usually a pulse sharpener, which converts a slow rise time (or fall time) waveform edge to a faster one. Special solid-state components are utilized as the pulse sharpeners. Avalanche transistors, Step Recovery Diodes (SRD), tunnel diodes [1, 2], FETs [3] or bipolar transistors [4] are used. Avalanche transistors are advantageous as high power sharpeners, but the maximal usable pulse repetition frequency is limited, due to the power dissipation in the transistor. Tunnel diodes offer the fastest transition times at very small amplitudes. Step recovery diodes make it possible to generate approximately 50–100 ps rise or fall times at moderate power levels without additional amplification and with high repetition rates. This makes them most likely to be used in current UWB generators.

An SRD works as a charge controlled switch, which can change from a low impedance to a high impedance

state very rapidly. This ability of the SRD is used to sharpen the slow waveform edges. The time of the fast impedance change is called the transition rise time, which takes less than 100 ps for fast SRDs currently available on the market. The theory and application of SRDs as pulse sharpening and generating circuits is well described in [5].

After sharpening by the SRD, the step-like waveforms are usually converted to Gaussian, monocycle or some higher-order derivative pulses. Monocycle pulses are of special practical interest, as their spectrum does not contain low frequency components and the pulses are simple to realize. Transmission line pulse forming networks [6] or simple RC differentiators [2] are used to generate monocycle pulses. However, any pulse shaping circuits connected to the SRD sharpener output introduce pulse distortion and ringing into the output waveform. Therefore, additional circuits have to be employed to reduce the ringing [7].

A particular issue concerning SRD pulse generators is the design of driving circuits capable of driving the SRD with sufficient power and speed. SRDs were frequently driven by avalanche pulse generators in the past [8], [9]. The disadvantages of this solution are the low maximal pulse repetition frequency and the short avalanche transistor lifetime. The driver part of the UWB pulse generator is usually underrated in the literature, although the shape and power of the SRD driving waveform is crucial for the whole generator performance and output ringing level.

In this paper we present a UWB pulse generator of monocycle waveforms. A novel pulse forming circuit with an SRD is proposed. Compared to the generators described in the literature, this circuit is located in the input section of the SRD sharpener instead of the usual placement in the output. This circuit solution produces reasonably high output amplitudes with a low ringing level. Only a simple transistor switching circuit with a power transistor operating in a saturated mode is required to drive this SRD pulser. While the performance of SRD circuits is relatively independent on the pulse repetition frequency that is used, it is difficult to design a driver capable of providing well-defined driving pulses in a wider pulse repetition frequency range. Our objective was to design a compact UWB pulse generator with a stable performance at an arbitrary pulse repetition frequency from 0 to 20 MHz.

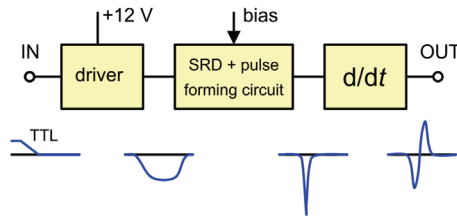


Fig. 1. Block diagram of the UWB pulse generator.

## 2. Circuit Description and Design

### 2.1 General Structure

A block diagram of the proposed UWB pulse generator is shown in Fig. 1. It consists of three main parts: a driver, an SRD pulser, and a monocycle forming network.

The edge-triggered driver generates a well-defined driving pulse, which is independent of the input TTL waveform amplitude, frequency and duty-cycle. The amplitude of the driver output determines the pulse generator output power. The driver output pulse width is set to a few nanoseconds in order to minimize the power loss.

The second stage of the pulse generator, the SRD pulser, consists of two main parts. The purpose of an SRD pulse sharpener is to sharpen the leading falling edge of the driving waveform. The sharpened step-like pulse is then processed in a pulse forming circuit to produce a Gaussian-like pulse. When no input driving pulse is present, the SRD is forward biased by an adjustable constant current source.

The third part of the generator is a monocycle forming network, which forms an output monocycle pulse. In general, the pulse forming network is a high-pass filter, which transforms the input Gaussian pulse into the monocycle pulse. Attention has to be paid to possible distortion and ringing at the generator output, which may arise as a consequence of repeated reflections in this pulse forming network.

### 2.2 Driver

A circuit diagram of the driver is shown in Fig. 2. An essential part of the driver is the bipolar transistor  $T_1$  connected as a switch. In a steady state,  $T_1$  is closed. After triggering the driver input with a TTL falling edge, the base voltage of  $T_1$  is inverted by a TTL inverter and it rises to a sufficient level to saturate the transistor. The speedup capacitor  $C_1$  (47 pF) effectively accelerates the switching. The output pulse width is controlled by a timing circuit consisting of  $R_2$ ,  $C_2$  and  $T_2$ . Switching of  $T_2$  (BFG410W) is delayed by an integrator ( $R_2$ ,  $C_2$ ).  $T_2$  turned on short-circuits the base of  $T_1$ , which turns off. The TTL inverter (74HCT04) output current is limited by  $R_1$  (470  $\Omega$ ) in this state.

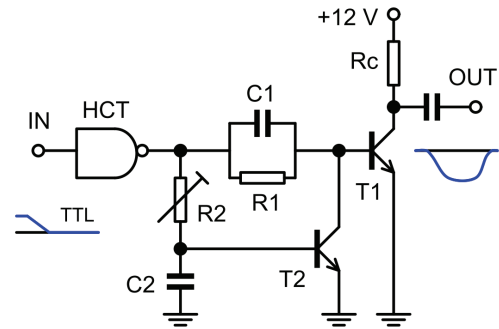


Fig. 2. Circuit diagram of the driver.

The circuit described here was analyzed using the SPICE simulator. The driver provides output pulses with fall times of 800 ps, maximal pulse repetition frequencies of about tens of MHz, and the pulse width is adjustable down to a few nanoseconds. With the wideband transistor BFG235 used as  $T_1$  and 12 V supply voltage, the pulses are -11.5 V high at a 50  $\Omega$  load. A simulated output waveform of the driver as the response of a TTL trigger edge provided by the input inverter is shown in Fig. 3.

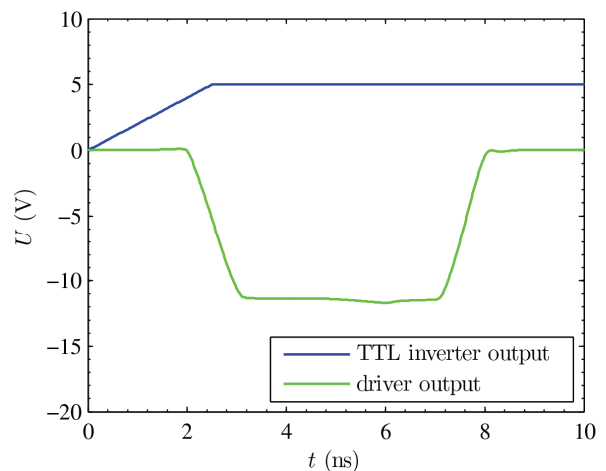


Fig. 3. Simulated output waveforms of the driver (green) as a response of a TTL trigger edge (blue).

### 2.3 SRD Pulser

The main parts of an SRD pulser are the SRD sharpener and the pulse forming circuit. In the conventional SRD pulse generator concept described in the literature [2], the pulse forming circuits are implemented as transmission line networks or simple RC differentiators. These circuits are connected in a cascade at the output of the SRD sharpener.

We introduce a different way of Gaussian pulse forming in our design, as shown in Fig. 4. The SRD, connected in parallel with a transmission line, operates as a falling edge sharpener. In a steady state, the diode is forward biased and appears as a low impedance. A driving waveform applied to the pulser input passes through a coupling capacitor and a delay line to the SRD. After the SRD turns off, a fast fall time step waveform propagates in

both directions away from the SRD. The first step propagates to the output, while the second propagates along the delay line back to the input. A shunt-connected Schottky diode (SD) was reverse-biased and did not influence the circuit before the driving waveform was applied. However, this diode is now opened by the negative driving pulse and represents a sufficiently low impedance to effectively short-circuit the transmission line. The step waveform propagating from the SRD to the input is reflected back inverted by this low impedance and propagates to the output again. Finally, the Gaussian-like pulse is formed by adding of the step waveform propagating unchanged from the SRD to the output with the delayed inverted step.

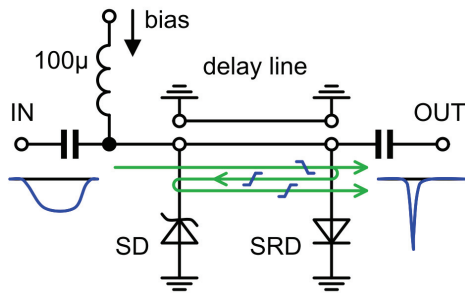


Fig. 4. Circuit diagram of the SRD pulser.

The pulse width of the output Gaussian pulse is proportional to the delay line length and can be flexibly adjusted by changing the position of the Schottky diode on the delay line. Another advantage of the pulser configuration described here is the location of the pulse forming circuit in the input section of the SRD sharpener instead of the usual placement in the output section. This makes it possible to maintain a low ringing level.

Computer simulation of an SRD is a challenging issue. As the SRD differs considerably from a traditional P-N junction diode, SPICE diode models provide inaccurate results. In most cases, SRD circuits are therefore fine-tuned experimentally. Advanced SRD models [10] are usually not implemented in conventional time domain simulators. Our simulations were performed in the HSPICE transient simulator included in the AWR Microwave Office design suite. We used a basic SRD model provided by AWR in the simulator with the parameters adopted from the data-sheet [11] of the selected diode ASRD808D.

The simulation results are shown in Fig. 5. The SRD sharpener output waveform corresponds to the circuit in Fig. 4 without the Schottky diode present. The Gaussian pulse that is shown is then generated by the SRD pulser with the Schottky diode (BAT15) connected at the input of the microstrip delay line 8 mm in length with a characteristic impedance of about 90  $\Omega$ . The length of the delay line was chosen with respect to the highest possible output amplitude. The generated Gaussian pulses are 25 V in amplitude and approx. 180 ps FWHM (Full-Width at Half-Maximum) in width.

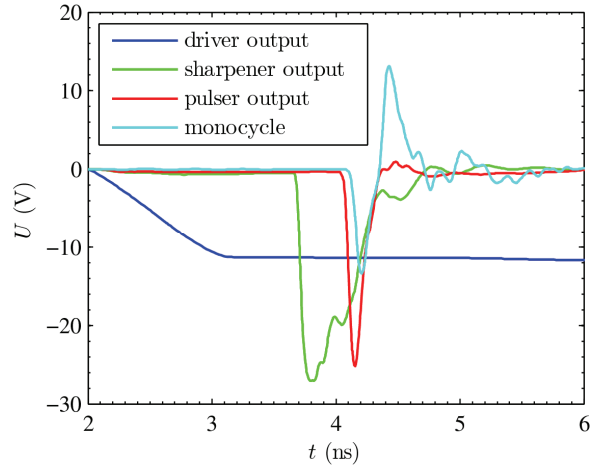


Fig. 5. Simulated output waveforms of the driver (blue), SRD sharpener (green), SRD pulser (red) and of the monocycle forming network (cyan).

## 2.4 Monocycle Forming Network

A pulse forming network may be connected to the output of the Gaussian pulser in order to form monocycle pulses. It can be implemented as a lumped RC differentiator (Fig. 6a) or as a distributed transmission line pulse forming network (Fig. 6b). Both circuits include a Schottky diode to reduce output ringing, which is a consequence of multiple reflections between the pulser output and the monocycle forming network input. In our design, we prefer the distributed structure, since the simulation showed higher output amplitude, a lower ringing level and lower dependence on the pulse repetition frequency than the lumped differentiator. However, the distributed structure generates wider pulse width monocycles than the lumped differentiator [7].

AWR Microwave Office was used to design a layout of the network. The length of the shortened shunt-stub was optimized to 18 mm in order to generate a symmetrical monocycle with the maximum possible output amplitude. The impedance of all the microstrip lines is 50  $\Omega$ . The simulated output waveform of the suggested network as a response of the input Gaussian pulse is shown in Fig. 5. The full width of these monocycles is 500 ps.

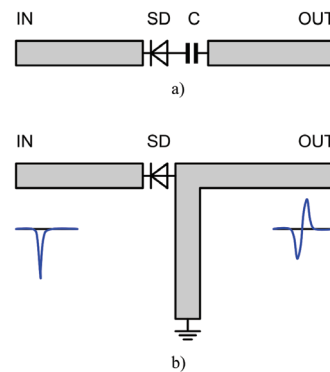


Fig. 6. Lumped (a) and distributed (b) pulse forming network.

### 3. Fabrication and Experiment

First, all circuit blocks described above were implemented and tested as separate modules on an FR4 substrate. A crystal oscillator was used as a TTL trigger source. Waveforms were measured using an Agilent 86100C sampling oscilloscope at a  $50\ \Omega$  load. After measuring the output of the sharpener, the circuit configuration was changed into a Gaussian pulser by soldering a pair of reflecting Schottky diodes. Two of these diodes were connected in parallel in order to enhance the reflection effect. The width of the driving pulse was set to about 6 ns and the bias current was set to 30 mA during all measurements.

After testing the separate modules, a complete monocycle pulse generator including a 5 V voltage stabilizer and a bias current source was assembled on a single board into a shielded box. The Arlon AD450 substrate was used. A photograph of the finalized monocycle generator is shown in Fig. 7.

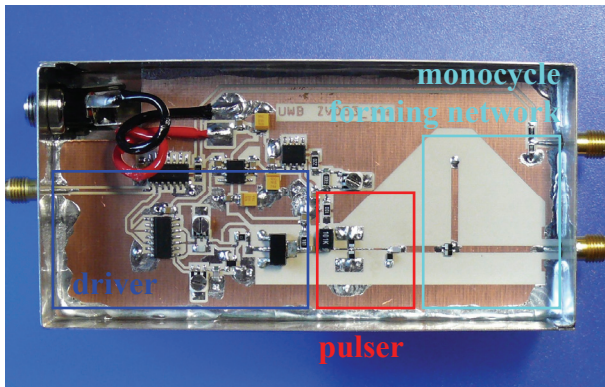


Fig. 7. Finalized monocycle generator.

### 4. Results and Discussion

Fig. 8 shows the measured output waveforms of the separate generator blocks. The pulse width and shape of the generated pulses show good agreement with the simulation in Fig. 5, although a simple SRD model was used. The pulse amplitude is lower than in the simulation, due to the loss of module interconnection cables and transitions. An additional source of loss is the series Schottky diode included in the monocycle forming network.

Fig. 9 and Fig. 10 show the output waveforms generated by the final circuit shown in Fig. 7, with the pulse repetition frequency as a parameter. The Gaussian pulses (Fig. 9) were measured at the output of the Gaussian pulser, with the monocycle forming network bypassed. Short interconnection paths and a high quality substrate result in an increased pulse amplitude, which reaches 27 V in the case of the Gaussian pulse and 25 V peak-to-peak (Fig. 10) in the case of the monocycle. The pulse width can be changed to some extent by repositioning the Schottky diodes. The minimal achievable Gaussian pulse width is

approximately 150 ps FWHM for an ASRD808D diode, however, with lower output amplitude.

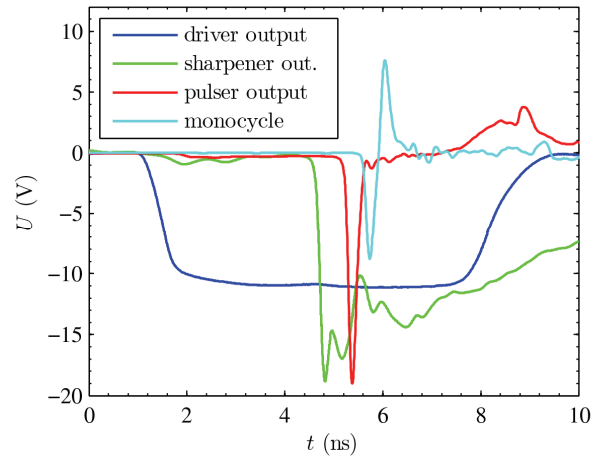


Fig. 8. Measured output waveforms of the separate generator blocks – driver (blue), SRD sharpener (green), SRD pulser (red) and monocycle forming network (cyan).

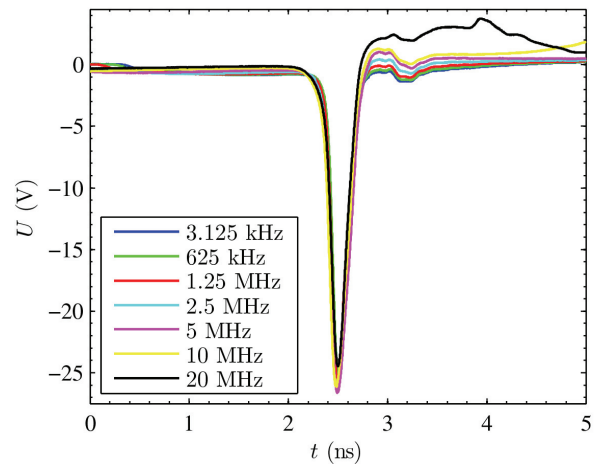


Fig. 9. Measured output waveforms of the Gaussian generator with the pulse repetition frequency as a parameter.

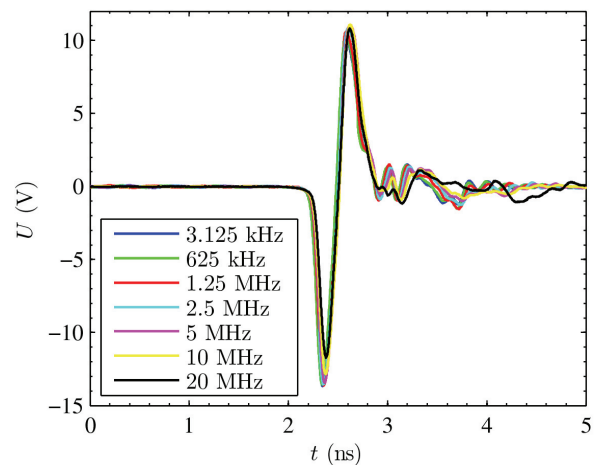


Fig. 10. Measured output waveforms of the monocycle generator with the pulse repetition frequency as a parameter.



The influence of the pulse repetition frequency on the shape of the main output pulse is negligible. The overshoot, following the main pulse, is a consequence of the driving pulse trailing edge. This overshoot is removed by the series Schottky diode included in the monocycle forming network.

## 5. Conclusion

In this paper, we have presented a new circuit solution of an ultra-wideband short pulse generator. The main circuit blocks of the pulse generator were described in detail: a simple transistor driver, a novel Gaussian pulser with a step recovery diode and an additional distributed monocycle forming network, which forms an output monocycle. All generator blocks were analyzed by a transient simulator, then implemented and tested as separate modules. Finally, a sample of the monocycle generator was implemented on a single board. Measurements performed by a sampling oscilloscope show good agreement with the simulations. The generated Gaussian pulses are up to 27 V in amplitude and 180 ps FWHM (Full-Width at Half-Maximum) in width. The amplitude of the generated monocycle pulses is up to 25 V, and the total width of the monocycles is about 500 ps. The influence of the pulse repetition frequency on the shape of the output waveforms is negligible up to 20 MHz.

Several ultra-wideband pulse generators based on the concept described above have now been successfully used in our ultra-wideband radar experiments, time-domain antenna measurements, and as a part of microwave sampling circuits.

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## References

- [1] MILLER, E. K. *Time-Domain Measurements in Electromagnetics*. Springer, 1986.
- [2] REED, J. H. *An Introduction to Ultra Wideband Communication Systems*. Prentice Hall PTR, 2005.
- [3] OUSLIMANI, A., VERNET, G., HARDALLAH, H., ADDE, R. Large amplitude picosecond step generation with FETs. *Electronics Letters*, 1990, vol. 26, no. 19, p. 1563 - 1564.
- [4] GERDING, M., MUSCH, T., SCHIEK, B. Generation of short electrical pulses based on bipolar transistors. *Advances in Radio Science*, 2004, no. 2, p. 7-12.
- [5] *Hewlett-Packard Application Note AN918: Pulse and Waveform Generation with Step Recovery Diodes*. Hewlett-Packard, 1984.
- [6] SMITH, P. W. *Transient Electronics: Pulsed Circuit Technology*. Wiley, 2002.
- [7] HAN, J., NGUYEN, C. A new ultra-wideband, ultra-short monocycle pulse generator with reduced ringing. *IEEE Microwave and Wireless Components Letters*, 2002, vol. 12, no. 6, p. 206 - 208.
- [8] TIELERT, R. Subnanosecond-pulse generator employing 2-stage pulse step sharpener. *Electronics Letters*, 1976, vol. 12, no. 3, p. 84 - 85.
- [9] EVANS, S., READER, H. C. An impulse generator for antenna measurements in the time domain. *Journal of Physics E: Scientific Instruments*, 1988, vol. 21, p. 657 - 660.
- [10] ZHANG, J., RAISANEN, A. A new model of step recovery diode for CAD. In *Proc. IEEE MTT-S International Microwave Symposium Digest*. Orlando (USA), 1995, vol. 3, p. 1459 - 1462.
- [11] *ASRD 800 Series Surface Mount Step Recovery Diode*. Advanced Semiconductor, Inc., 1999.

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