

Sub-nanosecond Pulse Generator for Through-the-Wall Radar Application

Pavel Protiva ^{#1}, Jan Mrkvica ^{*2}, Jan Macháč ^{#3}

[#]*Dept. of Electromagnetic Field, Czech Technical University
Technická 2, 166 27 Praha 6, Czech Republic*

¹protipl@fel.cvut.cz

³machac@fel.cvut.cz

^{*}*RETIA, a.s.*

Pražská 341, Zelené Předměstí, 530 02 Pardubice, Czech Republic

²jmrkvica@retia.cz

Abstract—This paper presents a sub-nanosecond pulse generator intended for a transmitter of through-the-wall surveillance radar. The basis of the generator is a step recovery diode, which is used to sharpen the slow rise time edge of an input driving waveform. A unique pulse shaping technique is then applied to form an ultra-wideband Gaussian pulse. A simple transistor switching circuit was used to drive this Gaussian pulser, which transforms a TTL trigger signal to a driving pulse with the timing and amplitude parameters required by the step recovery diode. The maximum pulse repetition frequency of the generator is 20 MHz. High amplitude pulses are advantageous for obtaining a good radar range, especially when penetrating thick lossy walls. In order to increase the output power of the transmitter, the outputs of two identical generators were connected in parallel. The measurement results are presented, which show waveforms of the generated Gaussian pulses approximately 180 ps in width and over 32 V in amplitude.

I. INTRODUCTION

An Ultra-Wideband (UWB) short pulse generator is the fundamental part of any UWB radar transmitter. The wide bandwidth of UWB pulses ensures fine range resolution and high penetration capability. Lower microwave frequencies up to about 5 GHz are preferred for through-the-wall surveillance radars, since the losses of common building materials rise to unacceptable levels in higher frequency bands. The corresponding pulse width of the generated baseband pulses is approximately 100–200 ps. Various techniques are used to generate these pulses. The basis of a conventional UWB pulse generator is a pulse sharpener, which converts a slow rise time square waveform edge to a faster one. After sharpening, the step-like waveforms are usually converted to Gaussian, monocycle or some higher-order derivative pulses [1] by an additional pulse-forming circuit. These pulses are more convenient than the step-like pulses for transmitting. Special solid-state components are utilized as pulse sharpeners [2]. Avalanche transistors, Step Recovery Diodes (SRD), tunnel diodes [3], FETs [4] or bipolar transistors [5] are used. Avalanche transistors are advantageous as high power sharpeners, but the maximum 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 times at moderate power levels without additional amplification and with high repetition rates. This makes them most appropriate for current radar transmitters.

In this paper we describe a UWB Gaussian pulse generator. The generator consists of a simple transistor driver and an SRD sharpener with a novel pulse forming network. Unlike the generators described in the literature [6], our pulse forming network is located in the input section of the SRD sharpener. This unconventional circuit solution produces only low ringing levels and reasonably high output amplitudes without excessive requirements regarding the driver section of the generator. A bipolar transistor switching circuit with a power transistor operating in saturated mode was used to drive the SRD. Our objective was to generate high amplitude pulses capable of penetrating thick and lossy building walls. To fulfill this task, the outputs of two identical pulse generators were connected in parallel. However, direct connection of the outputs introduces pulse distortion and ringing into the output waveform, and an additional ringing suppression technique was therefore applied. The output waveforms of both independent pulse generators and the complete transmitter consisting of these generators connected in parallel were measured using an Agilent 86100C sampling oscilloscope.

II. PULSE GENERATION WITH STEP RECOVERY DIODES

A. Circuit Description and Design

A block diagram of the pulse generator is shown in Fig. 1. An edge-triggered driver generates a well-defined pulse with sufficient power and speed to drive an SRD. This pulse is independent of the input TTL waveform amplitude and duty-cycle, and the pulse width is set to a few nanoseconds in order to minimize the current consumption of the circuit.

The following 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.

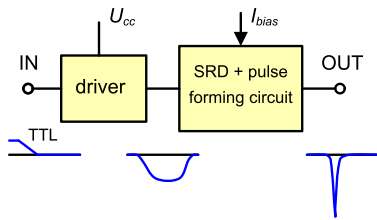


Figure 1. Block diagram of the Gaussian pulse generator.

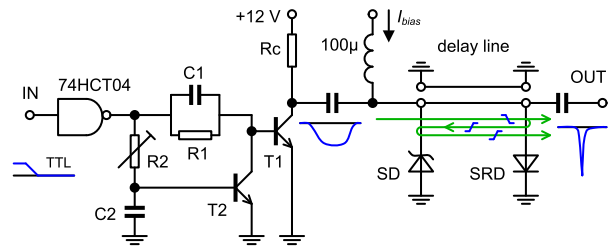


Figure 2. Circuit diagram of the proposed pulse generator.

The pulse generator was designed by the AWR Microwave Office design suite using the HSPICE transient simulator. A detailed circuit diagram is shown in Fig. 2. An essential part of the driver is the bipolar transistor T_1 connected as a switch. A TTL inverter drives the transistor into saturation, and a speedup capacitor C_1 effectively accelerates the switching. The pulse width is adjustable down to a few nanoseconds by a timing circuit consisting of R_2 , C_2 and T_2 . The driving waveform passes through a coupling capacitor to the SRD pulser.

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. After applying the negative driving pulse, the SRD switches very rapidly to the high impedance state. This ability of the SRD to change its impedance is used to sharpen the slow square waveform edges. The time of the fast impedance change is called the transition rise time, which takes less than 100 ps for the fast SRDs currently available on the market. The theory and application of SRDs as a pulse sharpening circuit is well described elsewhere [7].

After the SRD turns off, a fast fall time voltage step propagates in both directions away from the SRD. The first step propagates unchanged to the generator output, while the second propagates along the delay line back to the input of the pulser. A shunt-connected Schottky diode (SD) was reverse-biased and did not influence the circuit. 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 with an inverted polarity and propagates to the output again. Finally, the Gaussian-like pulse is formed by summing of the delayed inverted step with the waveform propagating unchanged from the SRD to the output.

B. Experimental Results

The pulse generator was implemented on an ARLON AD450 substrate 0.762 mm in thickness. Waveforms were measured using an Agilent 86100C sampling oscilloscope at a 50Ω load. The results are plotted in Fig. 3.

The driver provides driving pulses with a fall time of 800 ps. With the wideband transistor BFG235 used as T_1 and 12 V supply voltage, the pulses are -11.5 V high at a 50Ω load. An ASRD808D [8] step recovery diode was used. The

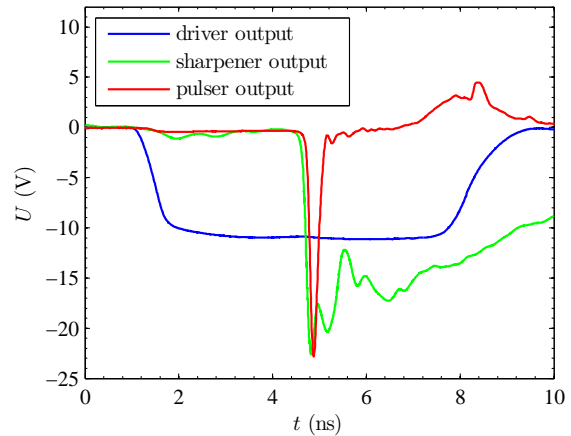


Figure 3. Waveforms measured in the pulse generator circuit using an Agilent 86100C sampling oscilloscope at a 50Ω load. The driver output was measured after the coupling capacitor, and the sharpener output was measured before the Schottky diode was soldered in.

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 (BAT15) on the delay line. The measured output pulses for two different lengths l are plotted in Fig. 4. The maximal observed amplitude of a generated Gaussian pulse is 23 V ($l = 8$ mm), and this pulse has a FWHM (Full-Width at Half-Maximum) of about 180 ps. The minimum achievable Gaussian pulse FWHM is approximately 100 ps for an ASRD808D diode, however, with lower output amplitude (see Fig. 4 for $l = 4$ mm).

Another advantage of the pulser configuration described here is the location of the pulse forming circuit. In the conventional SRD pulse generator concept [6], 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, which introduces loss and distortion to the output waveform. Our solution, where the pulse forming-network is implemented in the input section of the SRD sharpener instead of the usual placement in the output section, provides reasonably high amplitude pulses with a low ringing level. However, the measured waveforms show a distortion closely following the main pulse, which is caused by the driving pulse trailing edge. This overshoot can be removed by a series Schottky diode, if needed.

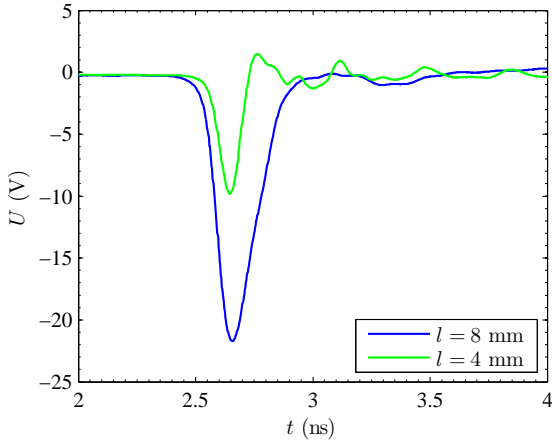


Figure 4. Dependence of the pulse shape on the delay line length l . Decreasing the length leads to narrowing of the pulse width and lowering of the pulse amplitude.

III. PULSE GENERATOR WITH ENHANCED OUTPUT POWER

A. Combining UWB pulses

When penetrating thick lossy obstacles, high amplitude pulses are very advantageous. However, high power UWB pulse generators are expensive, and are in most cases not compatible with modern planar technology and miniaturization efforts. A way to increase the transmitter's output power is to combine the output waveforms from multiple sources.

Combining ultra-wideband Gaussian pulses is a challenging task. Traditional power combining structures, e.g. the Wilkinson power divider, are fundamentally narrowband and distort UWB waveforms. Later modifications [9] have a wider bandwidth, but all these components require harmonic signals to work correctly. Applying a short UWB pulse – either to any port of the Wilkinson-based combiner or to both combiner inputs simultaneously – results in unwanted reflections and ringing at other ports. Some dividers/combiners using planar multilayer techniques, which show proper UWB performance, have also been described in the literature [10], [11]. Unfortunately, these designs are suitable primarily for the higher UWB band (3.1–10.6 GHz) and tend to differentiate Gaussian pulses.

B. Experimental transmitter with two generators

In our design we preferred to combine UWB pulses with a minimum insertion loss. This requirement is well accomplished by directly connecting the outputs of two or more identical generator units. To test this configuration, we assembled two identical pulse generators, as described above, on a single board, see Fig. 5. The measured output waveforms of this experimental transmitter are plotted in Fig. 6.

The transmitter output waveform generally contains a parasitic reflection, which is a consequence of a discontinuity formed by the parallel connection of the second unit and its output section. This distortion, which is located in the close vicinity of the main pulse, is unacceptable for most

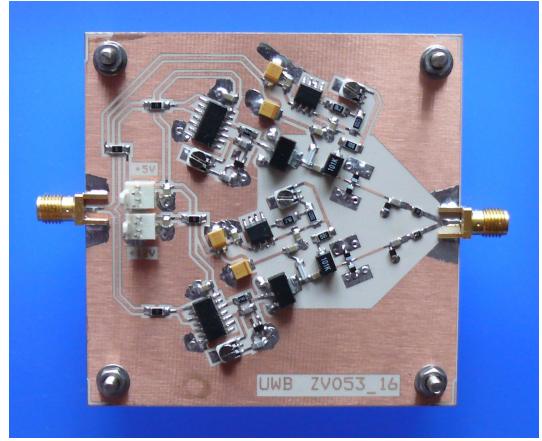


Figure 5. Experimental transmitter consisting of two identical generators. The connection of the units is similar to a reduced size Wilkinson power divider without any resistive elements.

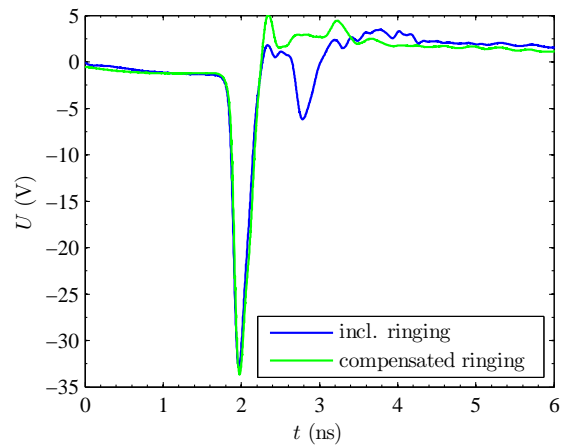


Figure 6. Measured output waveforms of the transmitter with uncompensated ringing and after compensation.

radar measurements. However, the circuit solution of the pulse generator presented in this paper offers a simple way to effectively suppress this waveform defect.

The output waveform of a single Gaussian pulse generator contains an overshoot caused by the driving pulse trailing edge, see Fig. 3 in the previous section. The polarity of this overshoot is opposite to the distortion observed at the connection of the generators. By properly setting the width of the driving pulse, it is possible to find a position where the overshoot and the distortion compensate each other. The result of the compensation, compared to an uncompensated state, is plotted in Fig. 6.

To obtain the sum of the pulses, both generators have to provide an output pulse exactly at the same time. Fine setting can be carried out by controlling the bias current of the SRD. The higher the forward bias current, the more electric charge is stored at the diode junction. Consequently, the storage time of the SRD [7] becomes longer and the delay between triggering TTL edge and generating the Gaussian pulse also increases.

The sensitivity of this delay control is relatively high, approx. 50 ps/1 mA, while the dependence of the pulse amplitude on the bias current is negligible.

The final output waveform of the transmitter compared to the outputs of both generator units measured separately is plotted in Fig. 7. The pulse amplitude is now over 32 V compared to 23 V of the stand-alone generator. The pulse peak power has risen to approx. 10 W, nearly double the previous value. The pulse width is now 200 ps FWHM. The power spectrum of this pulse calculated using the Fourier transform is shown in Fig. 8, normalized to the peak value.

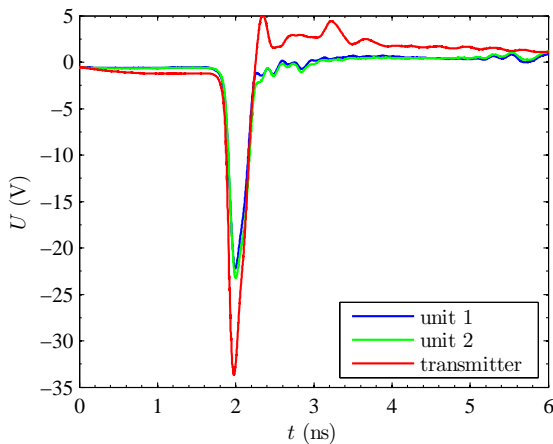


Figure 7. Measured output waveforms of the transmitter and of both generator units measured separately.

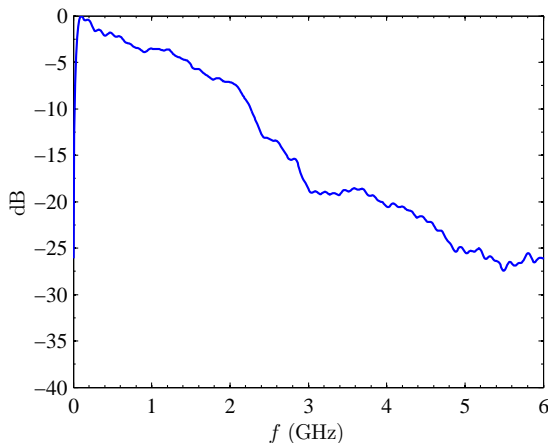


Figure 8. Calculated power spectrum of the output Gaussian pulse normalized to the peak value.

IV. CONCLUSIONS

This paper presents a new circuit solution of an ultra-wideband Gaussian pulse transmitter. The transmitter consists of two identical generator units. Each unit contains a Gaussian pulser with a step recovery diode, which is connected to a unique pulse-forming circuit composed of a delay line and a Schottky diode. This solution assures high obtainable

output amplitudes and low ringing levels. In addition, a simple transistor switching circuit is fully sufficient to drive this SRD pulser. The stand-alone generator unit provides 23 V high pulses at a 50 Ω load, having an FWHM of approx. 180 ps. In order to increase the output power of the transmitter, we assembled two of these units on a single board with their outputs connected in parallel. After balancing the delays in both units and suppressing unwanted reflections, we measured the output waveform of the transmitter. The peak power of the summed pulse is nearly double the peak power of the stand-alone generator.

ACKNOWLEDGMENT

The circuit design and simulation have been supported by the Grant Agency of the Czech Republic under project GD102/08/H018 “Modelling and simulation of fields”. The components for constructing, setting-up and measuring the transmitter have been supported by the Ministry of Industry and Trade of the Czech Republic under project FI-IM5/090 “Ultrawideband Radar and Positioning Systems”.

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