High Power Monocycle Pulse Generator for Through-the-Wall Radar Transmitter

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***Abstract* — This paper presents a sub-nanosecond pulse transmitter of through-the-wall surveillance radar. The basis of the generator is a step recovery diode and a unique pulse-forming circuit, which forms an ultra-wideband Gaussian pulse. High amplitude pulses are advantageous for obtaining a good radar range, especially when penetrating thick and lossy building walls. In order to increase the output power of the transmitter, the outputs of two identical pulse generators were connected in parallel. A transmission line pulse forming network was then used to form an output monocycle pulse. The measurements show waveforms of the generated monocycle pulses over 33 V in amplitude.**

***Index Terms* — Pulse generation, radar transmitter, power combiners, pulse shaping circuits.**

I. INTRODUCTION

A sub-nanosecond pulse transmitter is the fundamental part of any ultra-wideband (UWB) through-the-wall radar. The wide bandwidth of UWB pulses ensures fine range resolution and high penetration capability. Lower microwave frequencies up to about 4 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. Sharpened step-like waveforms are then usually converted to Gaussian, monocycle or 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. However, high power SRDs are expensive, and the diode packages are in most cases not compatible with modern planar technology. Higher breakdown voltage diodes also show longer transition times, which results in increasing the output pulse width.

In this paper we describe a monocycle pulse transmitter. The basis of the transmitter is a Gaussian pulse generator, which consists of a simple transistor driver and an SRD sharpener with a novel pulse-forming circuit. Unlike the generators described in the literature [6], our pulse-forming circuit is located in the input section of the SRD sharpener. This unique circuit solution produces low ringing levels and reasonably high output amplitudes without excessive requirements regarding the driver section of the generator. Our primary 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 ringing into the output waveform, and an additional ringing suppression technique was therefore applied. The output waveforms of the Gaussian pulse generator and the complete transmitter including an additional output monocycle pulse forming network were measured using an Agilent 86100C sampling oscilloscope.

II. GENERAL STRUCTURE OF THE TRANSMITTER

A block diagram of the proposed monocycle pulse transmitter is shown in Fig. 1. The transmitter consists of two identical Gaussian pulse generators and a monocycle pulse forming network (PFN). Both generators are triggered by one timing source.

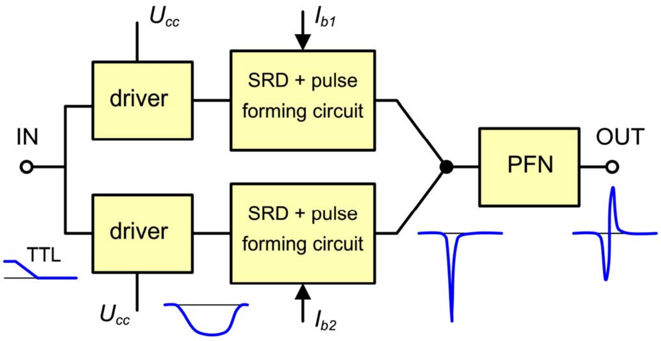

Fig. 1. Block diagram of the proposed radar transmitter.

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The main parts of the Gaussian pulse generator are a driver and a SRD pulser. The 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 I_b.

The outputs of two identical pulse generators are combined in order to obtain higher output pulse amplitude. The resulting Gaussian pulse is then converted to a monocycle pulse by an additional monocycle PFN. Monocycle pulses are of special interest, as their spectrum does not contain low frequency components and the PFN is simple to implement.

III. STEP RECOVERY DIODE PULSE GENERATOR

The pulse generator was designed and simulated by the AWR Microwave Office design suite and 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 C_3 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 are well described elsewhere [7].

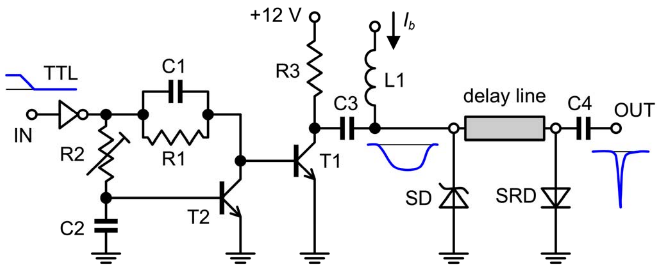

Fig. 2. Circuit diagram of the Gaussian pulse generator.

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.

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 50 Ω load. The results are plotted in Fig. 3.

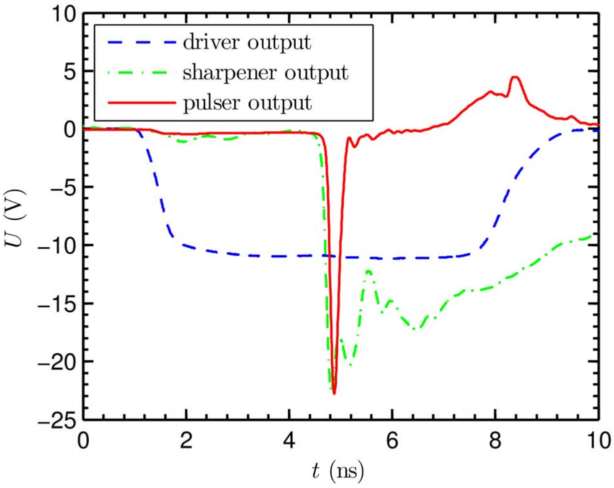

Fig. 3. Waveforms measured in the pulse generator circuit using an Agilent 86100C sampling oscilloscope at a 50 Ω load. The driver output was measured after the coupling capacitor C_3, and the sharpener output was measured before the Schottky diode SD was soldered in.

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 50 Ω load. An ASRD808D [8] step recovery diode was used. 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 (BAT15) on the delay line. The measured output pulse in Fig. 3 was formed by a delay line 8 mm in length with a characteristic impedance of about 90 Ω. The maximal observed amplitude of a generated Gaussian pulse is 23 V, and this pulse has a FWHM (full-width at half-maximum) of about 180 ps.

An 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 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.

IV. 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.

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. 4. The measured output waveform of this experimental transmitter is plotted in Fig. 5.

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 radar measurements and has to be suppressed.

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. 5.

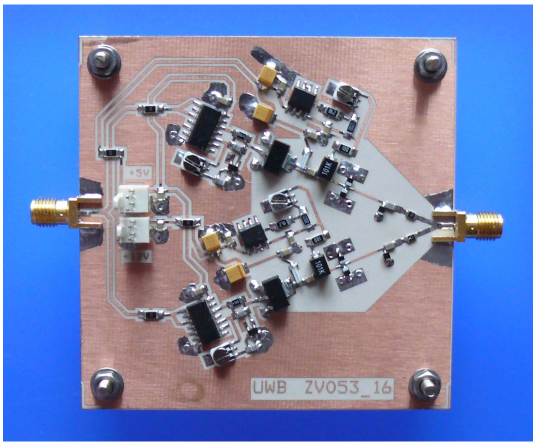

Fig. 4. Experimental Gaussian pulse transmitter consisting of two identical generators with their outputs connected in parallel.

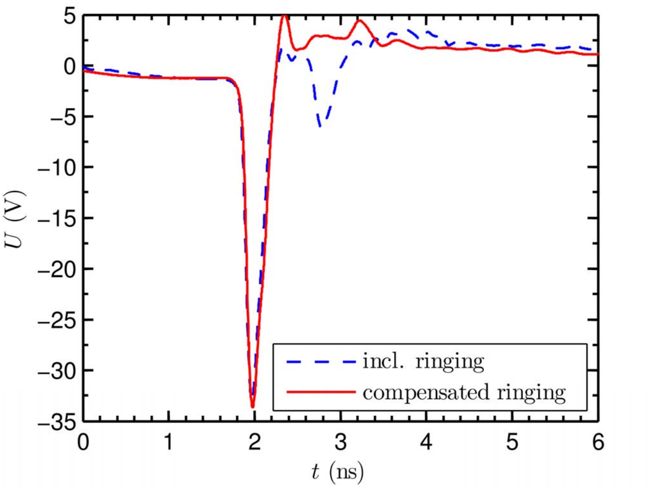

Fig. 5. Measured output waveforms of the Gaussian pulse transmitter with uncompensated ringing and after compensation.

The pulse amplitude is now over 33 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.

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.

Finally, a transmission line PFN inspired by [12] was connected to the output of the transmitter in order to form monocycle pulses. The layout of this circuit is shown in Fig. 6. It consists of a shortened stub 25 mm in length and a Schottky diode (BAT15), which reduces output ringing. The impedance of all microstrip lines is 50 Ω.

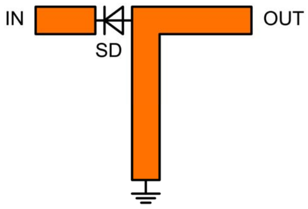

Fig. 6. Layout of the monocycle pulse-forming network.

The generated output monocycle is plotted in Fig. 7. The amplitude of this pulse is 32 V peak-to-peak, the total width is about 800 ps. The ringing level does not exceed 20 % of the output amplitude.

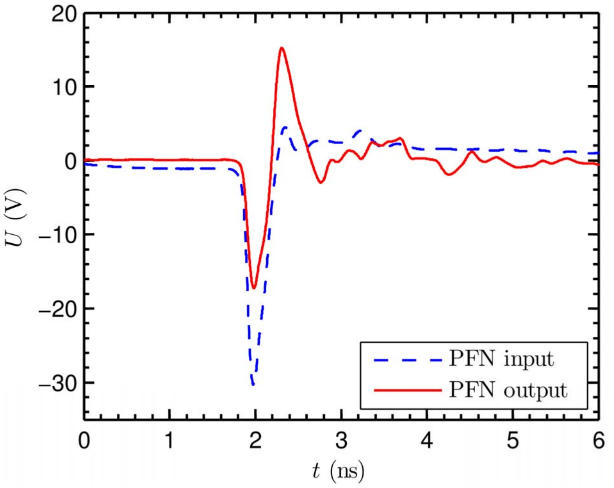

Fig. 7. Waveforms of the Gaussian and the monocycle pulses.

The power spectrum of the monocycle pulse calculated using the Fourier transform is shown in Fig. 8, normalized to the peak value. The 20 dB pulse bandwidth is 2.6 GHz.

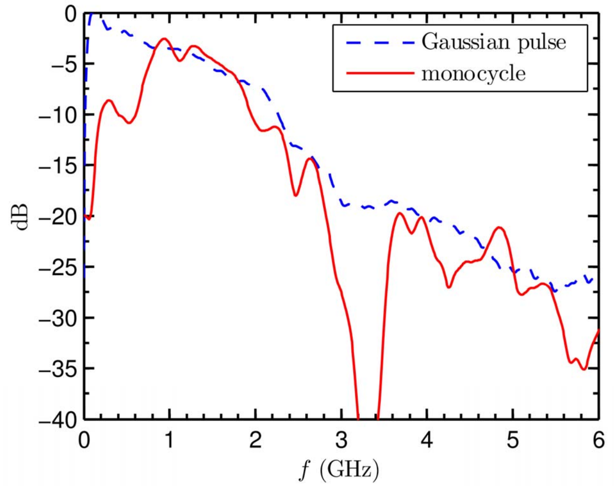

Fig. 8. Calculated power spectrum of the Gaussian and the monocycle pulses.

VI. CONCLUSION

This paper presents a new circuit solution of an ultra-wideband monocycle pulse transmitter. The transmitter consists of two identical generator units. 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. With an additional output pulse-forming network, monocycle pulses 32 V in amplitude and 800 ps in total width were measured.

ACKNOWLEDGEMENT

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