Low cost programmable pulse generator with very short rise/fall time

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ABSTRACT

The paper describes a design of a very short rise/fall time programmable pulse generator. The circuit is based on a Si-Ge comparator, resulting in the rise/fall time of 50 ps. Low component count makes the design relatively simple. As a result, in many applications the presented generator can be a low-cost alternative to sophisticated test and measurements equipment. Due to use of in-system-programmable microcontroller and RS-232 interface, firmware upgrades of the device are very easy, and the generator can be controlled by a PC computer and used in automated measurement applications.

Keywords: fast pulse, pulse generator, sub-nanosecond rise/fall time

1. INTRODUCTION

Pulse generator is a relatively common instrument that can be found in most of electronic laboratories, research companies, etc., however in different applications different features of such an equipment can be of primary importance. Some people will be using it mainly as a source of square waves of relatively high frequencies, some other will value its capability of producing short pulses, while for some other short rise/fall time of the pulse will be of primary concern. Design of a versatile instrument that would cover all three mentioned areas is a challenging task. It should be noted, however that in many applications the mentioned short or fast (short edge) pulses not necessarily have to be repeated with high frequencies. Hence, if the generator is optimized from the point of view of only one of the mentioned features (repetition frequency, pulse length or rise/fall time), its design can be much simpler end much less expensive. The paper presents such a design in which the main effort was concentrated on obtaining relatively simple equipment capable of producing fast pulses.

2. APPLICATIONS AND GENERATION OF FAST PULSES

Some of the most common applications of fast pulses are measurements of:

- fast semiconductor devices, [1]
- microwave amplifiers, [2, 3]
- connectors, microstrip lines, etc. (by means of time domain reflectometry), [4]
- wide bandwidth oscilloscopes.

A bit more sophisticated application examples may be identification of S-matrix coefficients (network analyzers) or picosecond spectroscopy. [5, 6, 7, 8]

Fast pulse generators can be implemented in a few ways, that can be divided into three main categories - electrooptical methods, superconducting methods, and methods based on standard electronic circuits. The most common solutions of fast pulse generators are based on:

- optical switch, [9, 10]
- Josephson junction, [11, 12]
- non-linear transmission line, [13, 14]

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- resonant tunneling diode, [15, 16]
- standard tunnel diode,[17]
- HEMT transistor, [1]
- step recovery diode, [18]
- Gunn diode,
- avalanche transistor,
- standard transistor circuits.

The fastest pulses (rise time shorter than 200 fs) can be produced by means of optical switches. The method uses a microstrip line with a small gap, placed on a semiconductor substrate (Si, GaAs, InP). When the area around the gap is illuminated with a laser light, concentration of the carriers rapidly increases. This results in increase of conductivity of the area, which means that both ends of the line become shorted. If one end of the line is connected to some voltage source, a fast pulse will be produced on the other end. Rise time of the pulse depends on number of factors, which in particular are: gap geometry, concentration, mobility and relaxation time of the carriers in the semiconductor, light absorption coefficient, etc.

Slightly bit slower pulses, but still with the edges shorter than 500 fs can be produced with Josephson junction, which consists of two superconductors separated with a dielectric layer. If the layer is thin enough, then in addition to standard electron tunneling, a phenomenon of Cooper electron pairs tunneling can be observed. Then, at first, current flowing through the junction results from the Cooper electron pairs, and it does not produce any voltage drop across the junction. But the mentioned current increases, and when reaching a given threshold level, a rapid voltage step across the junction appears. Then the Cooper electron pair current stops flowing, and being replaced by standard electron tunneling current. The mentioned voltage step is fast and its speed depends, among others, on junction characteristics, and relaxation time of the electrons in the superconductor.

Although both mentioned methods can be used for generation of impressively fast pulses, the resulting equipment is expensive, complex and definitely not compact. In case of other mentioned methods, many of them, although giving nice results in producing fast pulses, are difficult to implement or unprofitable. To give some examples, it can be stated, that resonant tunneling diodes are not commercially available, speed of commercially available tunnel diodes and step recovery diodes is around 100 ps, HEMT transistors are very expensive, etc. As a result low cost, fast pulse generators can be built mainly around non-linear transmission lines or standard transistor circuits. The design presented in this paper is based on the latter approach.

3. DESIGN OF THE GENERATOR

Block diagram of the generator is presented at Fig. 1. The two key components of the instrument are microcontroller and fast Si-Ge comparator. The microcontroller (AD:C814) performs three main tasks. The first one is a display and keyboard controller, so that user can change settings of the generator (e.g. repetition frequency, trigger delay) in a simple manner. The keyboard works in a matrix consisting of 4 rows with 4 keys each. Ten numerical keys and a dot key are used for numerical entry of the main generator settings. Escape / backspace, enter, up and down cursor keys are used for navigation throughout a menu displayed at an alphanumerical LCD display consisting of two lines with 20 characters each. As a result, the instrument can be comfortably used as a standalone device. The second task of the microcontroller is communication with a PC computer via RS-232 interface, which

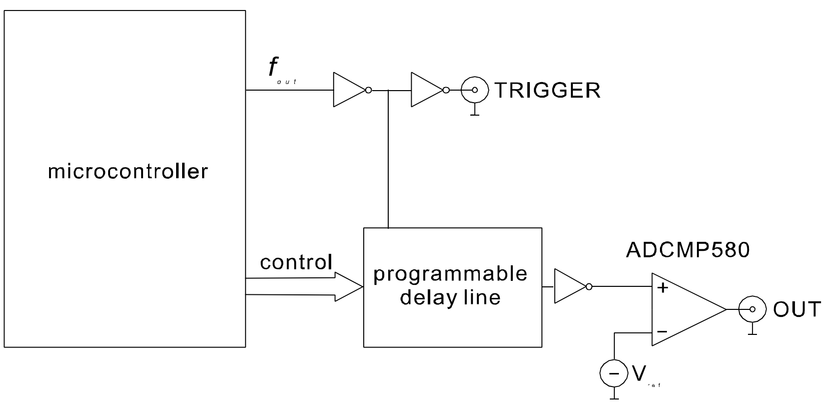

Fig. 1. Block diagram of the pulse generator.

can be used for implementation of automatic measurements. RS-232 was chosen due to its simplicity and common use. Relatively slow data transfer was not a problem in the discussed application. The third main function of the microcontroller is to produce a square wave of reasonable stability. This is done by division of the system clock frequency in an internal timer/counter. As a result it is possible to set the output signal frequency to a value from below kilohertz to over megahertz. Taking into consideration that the system clock is derived from a crystal oscillator and that the timer works in a hardware mode, the output frequency is very stable.

As the output current capabilities of the microcontroller I/Os are relatively weak, the square wave is fed into inverter (74AC04), which works as a current buffer, and which also increases speed of the square wave edges. A second inverter is used as a driver of the generator's trigger output. As in some applications trigger signal must be ahead of the main pulse, the main signal path contains an additional delay line (Maxim/Dallas DS1021S-25). The delay line is digitally programmable with a step of 250 ps up to maximum delay of approx. 75 ns. Signal from the delay line output is passed through one more inverter, which was used in order to speed-up edges of the signal and to compensate thermal changes of the propagation time introduced by the inverter used at the trigger output. Finally the signal is used to drive non-inverting input of an ADCMP580 comparator, which is in fact the key component of the design. The comparator is manufactured in Si-Ge technology and, according to its specifications, has typical output rise/fall time of 32 ps (20% to 80%). Its strong advantage is CML output stage with internal 50 ohm resistors, which means that output of the comparator can be connected directly to the SMA output connector, as no additional passive or active circuits (fitting output impedance to 50 ohms) are needed. Produced pulses have amplitude of approx. 0.4 V at 50 ohm load.

4. RESULTS

When evaluating quality of pulse generators, it should be noted that in many applications not only electrical or time characteristics are crucial, but also shape of the produced signal is important. This means, that not only rise/fall times should be as short as possible, but also the edge should be smooth, with constant gradient and possibly without oscillations. Fig. 2, at which an example of a pulse is shown, proves that producing fast pulses of a nice shape is not an easy task. The presented pulse has some disturbances in the middle and at the end of the edge, and significant oscillation (approx. 20%) at the end. Pulse produced in the generator discussed in the paper is presented at fig. 3. Although its shape is not perfect, the edge is very regular, and end oscillations are of moderate amplitude. The most important is the rise time of approx. 50 ps. Relatively small edge dispersion proves reasonable stability and acceptable level of phase noise of the circuit.

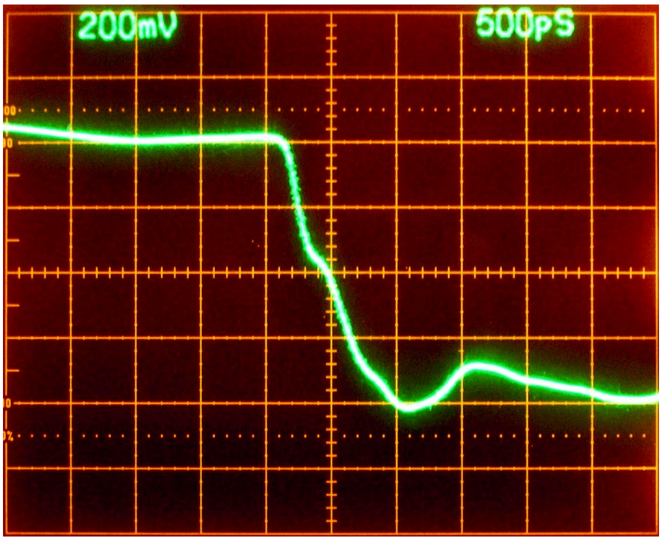

Fig. 2. Example of a pulse obtained in a circuit based on a step recovery diode.

5. CONCLUSIONS

A result of the described work is a miniature pulse generator, capable of producing pulses with the rise/fall time of 50 ps and very regular shape. The instrument can be used as a standalone device or controlled by a PC via RS-232 interface and used in automatic measurements. The generator has additional feature of digitally programmable delay between output trigger and the main output pulse. Use of technologically advanced components resulted in substantial reduce of the cost (total below 50$), small size, and relatively simple design. Output pulse amplitude of 0.4 V at 50 ohms can be disadvantageous, but still acceptable in many applications. Very high speed of the designed circuit requires high quality PCB layout. For the same reason, careful selection of all components (including capacitors, connectors, etc.) is critical. Testing of the circuit requires high bandwidth (at least 10 GHz) equipment. Due to in-circuit programming of the microcontroller, firmware upgrades of the device are possible and very easy.

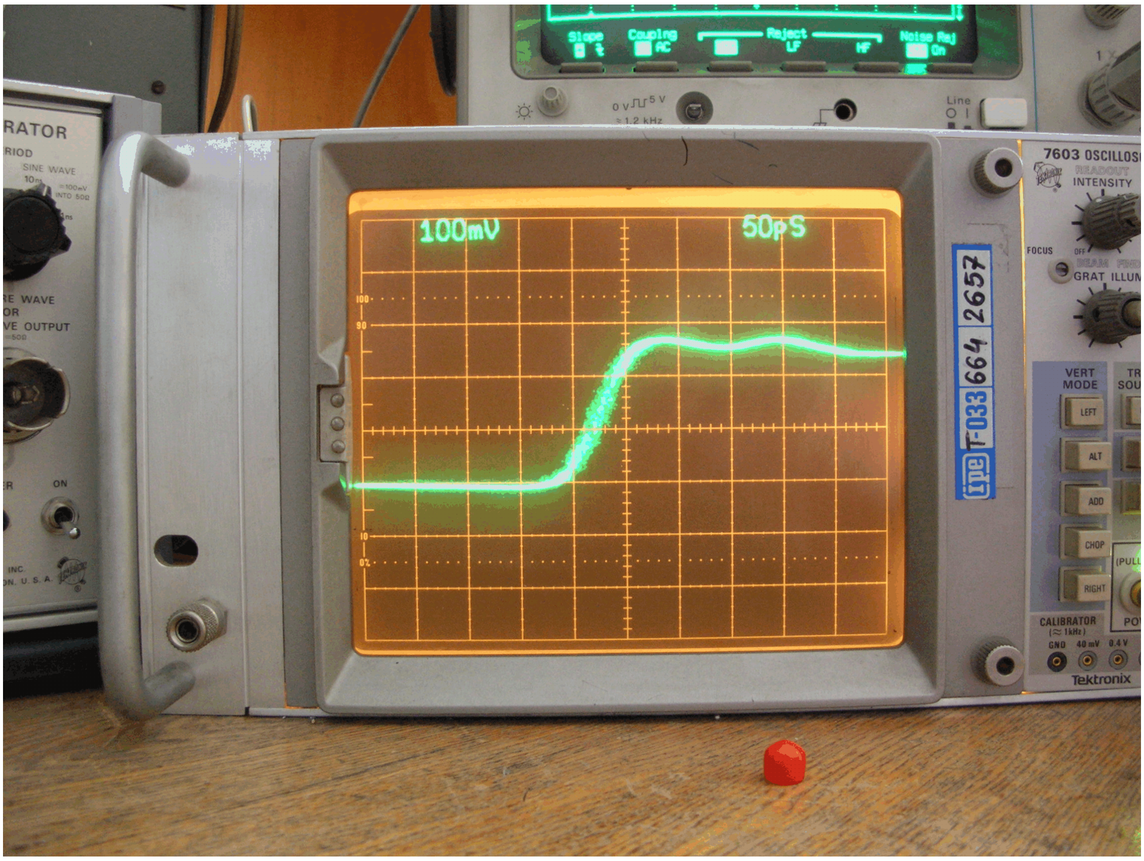

Fig. 3. Pulse observed at the output of the designed generator.

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