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Developing UWB Pulse Generator with Output Split Inverters for Breast Imaging System

Sara Fouad[a], Reda Ghoname[b], Abdelmonem Elmahdy[c], Abdelhalim Zekry[d]

[a,c]*Electronics and Communications Eng. Dept., Higher Institute of Engineering, Modern Academy, Cairo, Egypt.*
[b]*electrical and computer Engineering Department, Facultiy of Engineering , king Abd el Aziz University, Saudi Arabia*
[d]*Electronics and Communications Eng. Dept., Faculty of Engineering, Ain Shams University, Cairo, Egypt*
[a]*Email: sarafouad2012.s.m.a@gmail.com*
[b]*Email: rd_ghoname@ hotmail.com*

Abstract

A digital glitch monocycle pulse generator in a standard 0.13-μm CMOS technology is designed for breast cancer imaging system. A successful low power pulse generator is proposed whose central frequency is digitally controlled to cover 5.2 GHz. The generator is based on delay gate of Output Split Inverter (OSI).The OSI consists of an inverter with current limiting transistor which controls the biasing voltage digitally. The biasing circuit contains current mirror, PMOS transistor which enables 96.5ps delay values. A glitch circuit is designed for a monocycle pulse width of 193 ps thought for breast cancer detection application. The proposed generator consumes 369 µw at 200 MHz pulse repetition frequency (PRF), and 1.2 V power supply voltage. Its design layout area amounts 67.2× 43.7 μm^2.

Keywords: Pulse generator; Gaussian monocycle; Ultra Wideband; digital OSI; glitch generator; breast cancer.

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* Corresponding author.

1. Introduction

Breast cancer is one of the main causes of women death [1, 2]. An early detection of tumor existence increases the chance of successful treatment and quick recovery.

The X-ray mammogram is the primary technique used in breast cancer detection. However, this technique poses several problems, such as the use of ionizing radiation, breast compression, complications in its use especially for younger women [1], and difficulty in detecting early tumors.

Microwave breast tumor detection is a non-invasive technique which uses a non-ionizing radiation and it is also considered a potential alternative to X-rays [3, 4]. The tumor detection principle is based on analyzing the contrast in the dielectric properties between the healthy and malignant tissues [3].

Ultra-wideband (UWB) communications is one of the newest technologies employed in imaging systems that are utilized for human’s body imaging. The motivation is mainly based on using ultra-narrow pulses in the time domain to detect and contrast between normal and malignant tissues. The frequency range between 1 and 10 GHz is the optimum band for this application. This band showed high spatial resolution especially at higher frequencies and good penetration depth mainly at lower frequencies [5].

Transmitter circuit is an important part in UWB systems; it represents the reference to define the other parts of the system. In this way, the circuit of the UWB pulse generator is the main obstacle in the transmitter, which must provide an adequate signal level for the requirements of the proposed application. It must have a minimum of energy consumption and cost [6].

UWB pulse generators can primarily be classified in accordance with the shape of the pulse to:

- Gaussian pulse,
- Monocycle pulse, and
- Multicycle pulse.

A Gaussian pulse has the Gaussian shape whose frequency spectrum does not meet the FCC regulations, because the bandwidth is too large, and contain a dc value [6]. Monocycle pulses [7] are preferred to simple pulses because they have no dc components, which could represent a limit for the spectral mask compliance and radiation antenna efficiency. As well as the case for UWB frequency range from 3.1 GHz to 10.6GHz.

In particular, for the UWB monocycle pulse generator, the main design challenges consist of reaching a very short duration time for mask compliance, the adequate amplitude to drive directly the antenna without requiring any additional amplification, and the full integration on silicon.

There are many ways to generate monocycle pulses: one of these techniques is based on digital circuits and Gaussian filters. Gaussian filters are implemented by cascading small complex analog signal filters, which provide pseudo Gaussian monocycle pulses through the filtering of small signals (typically, triangular pulses)

The aspects of the published pulse generators can be recognized at first glance by summarizing the performance of the most relevant works of the literature, which are reported here in after.

In [9], a pulse duration time of 280ps, a peak-to-peak amplitude of 123 mV, and a power consumption of 12.6 mw from a 1.8-V supply is obtained for a fully integrated solution in a 0.18-μm CMOS process by exploiting the digital circuit approach.

A monocycle pulse with a duration time of 500 ps and peak-to-peak amplitude close to 100 mV from a 1.8-V supply voltage is produced in [10] using fully integrated solution in 0.18-μm digital CMOS technology by exploiting distributed devices and analog and digital circuits.

In [11], a monocycle pulse with duration time of 380ps, peak-to-peak amplitude of 660 mV, and a power consumption of 19.8 mw from a 1.2-V supply voltage are obtained with a fully integrated solution in a 90 nm CMOS process by exploiting the triangular pulse generator approach.

In this work, a new an Output Split Inverter (OSI) [12],is designed and implemented as a delay element controlled digitally to obtain UWB monocycle pulse generated at 5.2 GHz center frequency to be compatible with breast cancer imaging system.

The paper is organized as follows: the UWB breast cancer imaging system description is introduced in section 1.1, the Output Split Inverter (OSI) as a delay element controlled digitally to obtain a 96.5 ps delay is explained in section 1.2, in section 1.3, a Glitch pulse generator using OSI and AND gate is presented to obtain Gaussian pulse. The combining between a Gaussian and its inverted pulse results in 193 ps monocycle pulse by using pulse shaping transistor and capacitor. The Simulation results and calculations using cadence virtuoso tools are presented in section1.4, while section 1.5 concludes the paper.

1.1. System description

Ultra-wideband (UWB) communication is one of the latest techniques used in imaging systems for human body. It is mainly based on the use of ultra-narrow pulses in the time domain to detect and get a useful contrast between normal and malignant tissue. The building blocks of the UWB transceiver are shown in Figure.1.

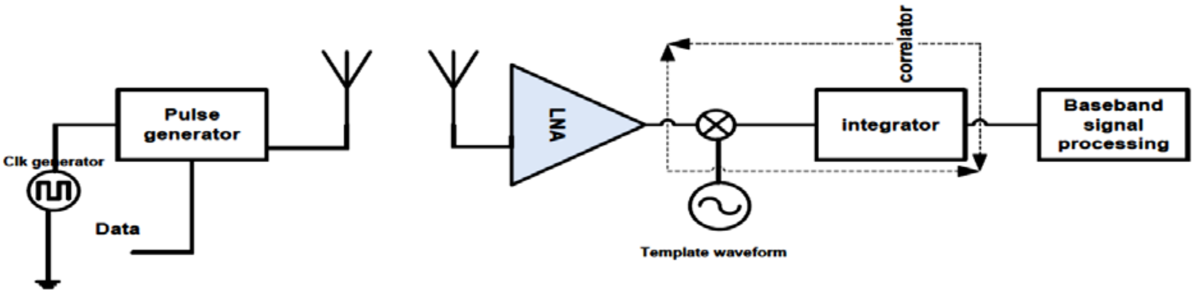

Figure 1: Transceiver of ultra wideband system.

Medical imaging systems of UWB have significant differences compared with the narrow band systems. The base one is that, there is no carrier in this type of communication. There is no need to modify, the most complex blocks used in the transfer of conventional continuous wave systems. The absence of these complex components makes UWB transmitter architecture inexpensive and simpler in design and easier in implementation with respect to conventional radio systems. From this point of view, UWB system block diagram is much simpler than the narrow band.

The pulse generator circuit is the main block of the transmitter. It is a critical part in UWB systems and it is a reference to define the other parts of the system. The receiver architecture consists of three major blocks: a low-noise amplifier (LNA), a correlation circuitry and a block for providing template waveform for correlation circuit.

Analog filtering method is one of UWB generator methods. A common way of directly generating an UWB pulse without using a carrier is to first form a baseband impulse with very short time duration and a high frequency bandwidth. Then filter the impulse using a band-pass or a pulse shaping filter. Digital logic circuits can be employed to create baseband impulses. They consist of inverters to find a small delay got by a NOR gate to generate an impulse on every falling edge of a trigger signal as shown in Figure 2 and the relative timing of the signals at the input of the NOR gate is shown in the same figure also.

The NOR gate is used to combine the falling edge of the trigger signal and its delayed inverted replica to form a positive impulse. NAND gates have also been used in place of the NOR gate to realize impulses with the opposite polarity on every rising edge of the trigger. In [14], high-speed current mode logic (CML) is used for the delay cell to create a baseband impulse with very short time duration of 75ps and at frequency spectrum out to 10 GHz. The generated impulse is then applied to the third-order LC ladder Bessel filter to form the UWB pulse.

In the following sections a complete design of the pulse generator will be introduced. Our design is based on an output split inverter as a delay element instead of conventional inverter, as well as AND gates to obtain a Gaussian pulse. Then the Gaussian pulses will be combined to form monocycle pulses [16].

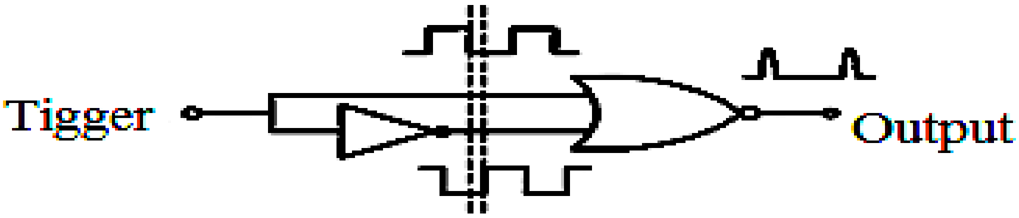

Figure 2: Digital logic for impulse generator.

1.2. Digital Delayed Output Split Inverter

It is shown in [12] that the output split inverter (OSI) could be used as delay element instead of conventional inverters. Its delay can be controlled by biasing of an extra pull down transistor connected in series with the initial pull down transistor. It employs the idea of reducing the output slope by discharging the output capacitance with the drain current of a current limiting transistor.

The designed digital delayed output split inverter is depicted in Figure 3 [15]. It consists of a biasing circuit at the left and two cascaded split inverters followed by a conventional output inverter. The transistors $\mathrm{M}_{4,}$and M_6 as is in the ordinary logic inverter while M_5 and M_8 act as current sources controlled by the gate voltage coming from the reference circuit. In this way the pull down current can be controlled by these transistors and there by controlling the delay time between the input and output.

The proposed OSI model from M_4 to M_{11} are the main elements for achieving a comparable delay (96.5 ps), which is used in pulse generator breast cancer imaging system. The controlling current of the split transistors is adjusted by the biasing current mirrors of the transistor $\mathrm{M}_{2,}$. The discharging current is controlled by transistor M_5 acting as a current source. The passing current through this transistor is determined by the gate voltage obtained from M_2 which act as a diode. The gate voltage of M_5, is determined by the current passing through the drain of $\mathrm{M}_1$with applied voltage corresponding to logic 0 to control the circuit digitally. OSI is used in our delay element as a two stage to ensure stability and the output is taken from a conventional inverter. The circuit diagram is shown in Figure 3.

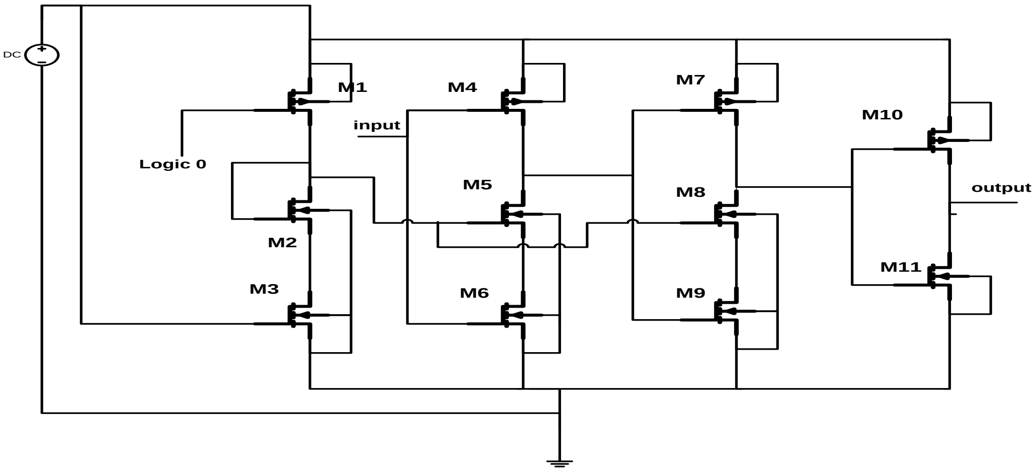

Figure 3: Digital controlled Output split Inverter.

1.3. Transmitter Design

Now, the developed delay circuits are used to generate a monocycle pulse for the UWB transmitter. The schematic of the UWB transmitter is shown in Figures 4. It is designed to generate the monocycle pulse depicted in Fig 5. The UWB pulse generator is designed to produce glitches at the rising edges of the clock signal. In our circuit, the glitches are produced by passing the clock pulses either directly to one of the inputs of the AND gate and through an OSI delay network to the other input as depicted in Fig 5.The two identical glitch generators (GGs)are labeled as GGA, and GGB.

The GGA output is inverted and applied to PMOSFET M_{12} of the output pulse shaper; as a result, the pulse-generator output voltage become V_{DD} . The output signal of GGB (which is identical to GGA) is delayed using an eight-stage inverter chain and applied to NMOSFET M_{13}that drives the output voltage to 0 V, and generate the negative pulse.

The sizes of output pulse shaper stage transistors M_{12} and M_{13} have to be selected carefully for correct pulse shape. During the design procedure, the supply voltage is kept constant at its nominal value of 1.2 V. The gate sizes for the building blocks are determined to have an UWB pulse of 193 ps. The transmitter output at the drains of pulse shaper transistors is applied to the package and off-chip printed circuit board (PCB) through a wire bond that can be simplified as an equivalent 2.5-nH inductance L_{wb}as shown in Figure 4 [16]. A 5.2 GHz-band BPF is realized using a 0.2 pF series capacitance C_{ps} withL_{wb}.The proposed Monocycle pulses with 193 *ps* pulse duration approximate 5.2 GHz center frequency operation is shown in Fig. 5.A Gaussian monocycle of 193-ps width is obtained after PEX test. The peak-to-peak voltage is 460 mV.

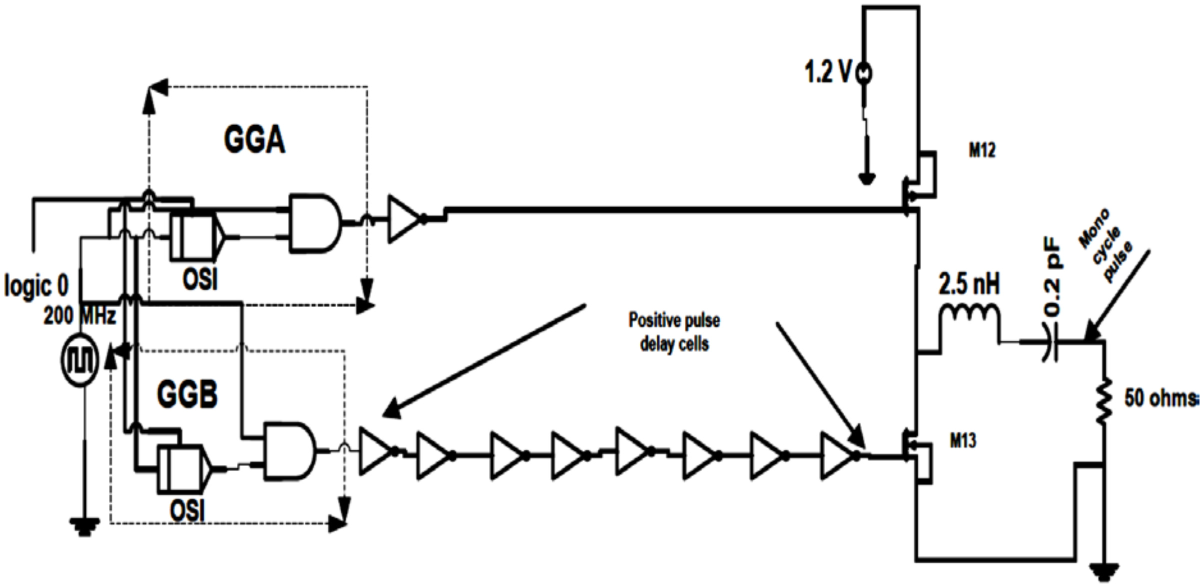

Figure 4: block diagram of the proposed transmitter.

1.4 Simulation results

The proposed transmitter is simulated using cadence virtuoso assuming UMC MMRF 130-nm CMOS process. The layout is shown in Fig. 6 after DRC and LVS check. The whole transmitter including the Glitch generator and inverters occupies only an area of $67.2\ \mu m \times 43.7\mu m$.

Slow-slow, Fast-Fast, and Typical-Typical tests at T=27^0 C is applied on monocycle pulse. The variation of the amplitude and the pulse duration after Parasitic (PEX) extraction is shown in Table 1, and depicted in figure 7. The slow model parameters resulted in pulse duration of 207ps corresponding to center frequency of 4.8 GHz. While the fast model parameters resulted in pulse duration of 190 *ps*corresponding to a center frequency of 5.3

GHz. These values are compatible to breast cancer applications as presented in table 1 also.

The pulse duration of S-S expanded to 225 ps at T=-20^0 C approximating frequency of 4.4 GHz, while F-F give a value approximating 5.6 GHz, as shown in Figure 8 and Table 2.

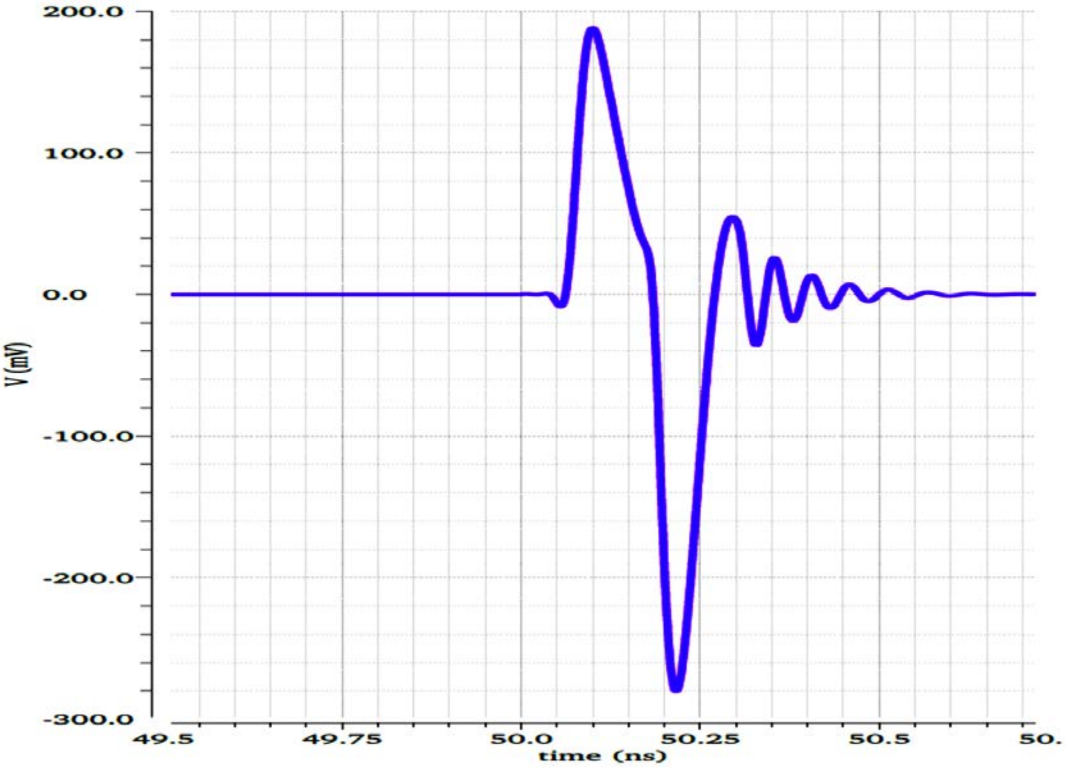

Figure 5: 193ps monocycle UWB pulse.

Figure 9 and Table 3 shows that the pulse duration of S-S and F-F expanded to 250 ps and 210 ps at $\mathrm{T} = 70^0$ and center frequency approximating to 4GHZ, and 4.8GHz which is acceptable for UWB imaging breast cancer.

The comparison between the developed UWB PGs and previous monocycle generators [10, 11, 16, and 17] is presented in Table 4. From this table, it is seen that our UWB pulse generator has low power dissipation except [16], because the smaller band, and the smaller amplitude compared to ours. The distributed and triangular pulse generator as analog and digital pulse generator in [10, 11] have higher power consumption than ours one has to define some figure of merit for sake of fare comparison.

1.5 conclusions

A proposed OSI element is designed as delay element to control the delay digitally. This OSI element is designed for providing 96.5 Ps delays to a pulse signal . A fully integrated monocycle pulse generator of a center frequency of about5.2 GHz UWB CMOS transmitter has been achieved. The designed OSI as a delay element is used for breast cancer imaging system in SoaC pulse radar to obtain a monocycle pulse. This circuit provides a 460 -mV sinusoidal-like monocycle with a duration time of about 193 ps when it is activated by a positive edge of a low-frequency command signal. The overall power consumption amounts to 369 μw and the layout area is 67.2 μm × 43.7μm . for strict comparison with the published one may introduce a suitable figure of merit.

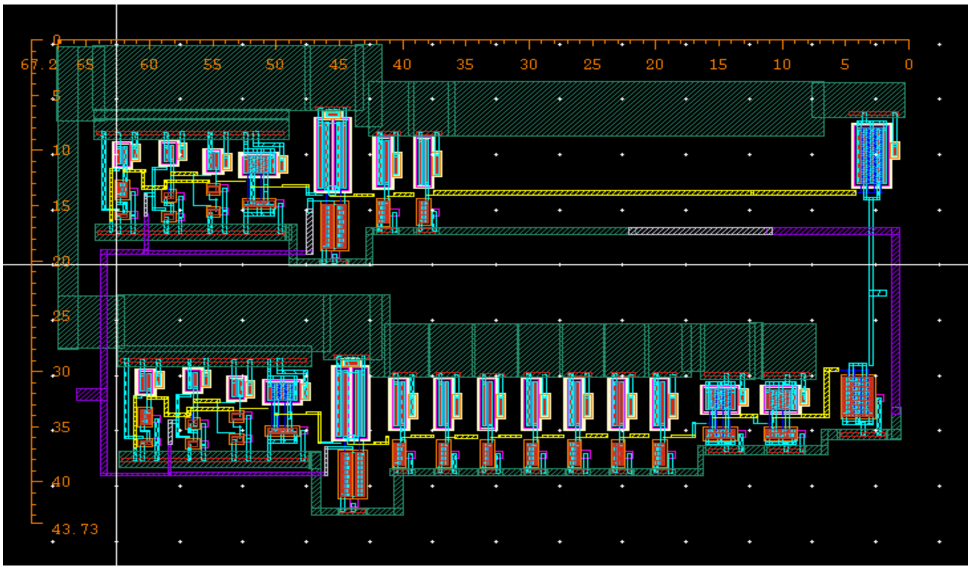

Figure 6: layout of UWB monocycle pulse generator

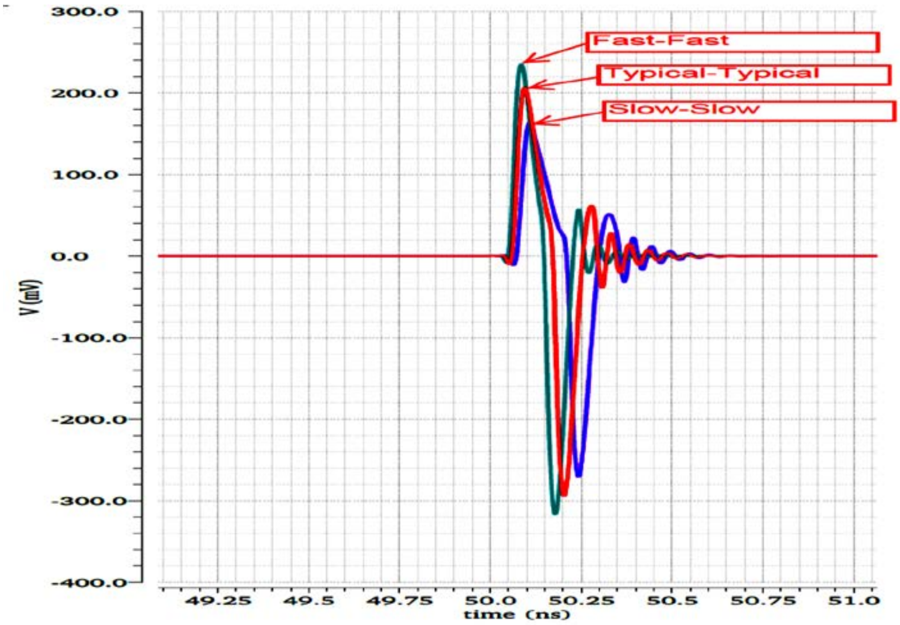

Figure 7: Fast-Fast, Typical-Typical, and Slow-Slow monocycle pulse at $T = 27^0\ C$.

Figure 8: Fast-Fast, Typical-Typical, and slow-slow monocycle pulse at $\mathrm{T} = -20^0$.

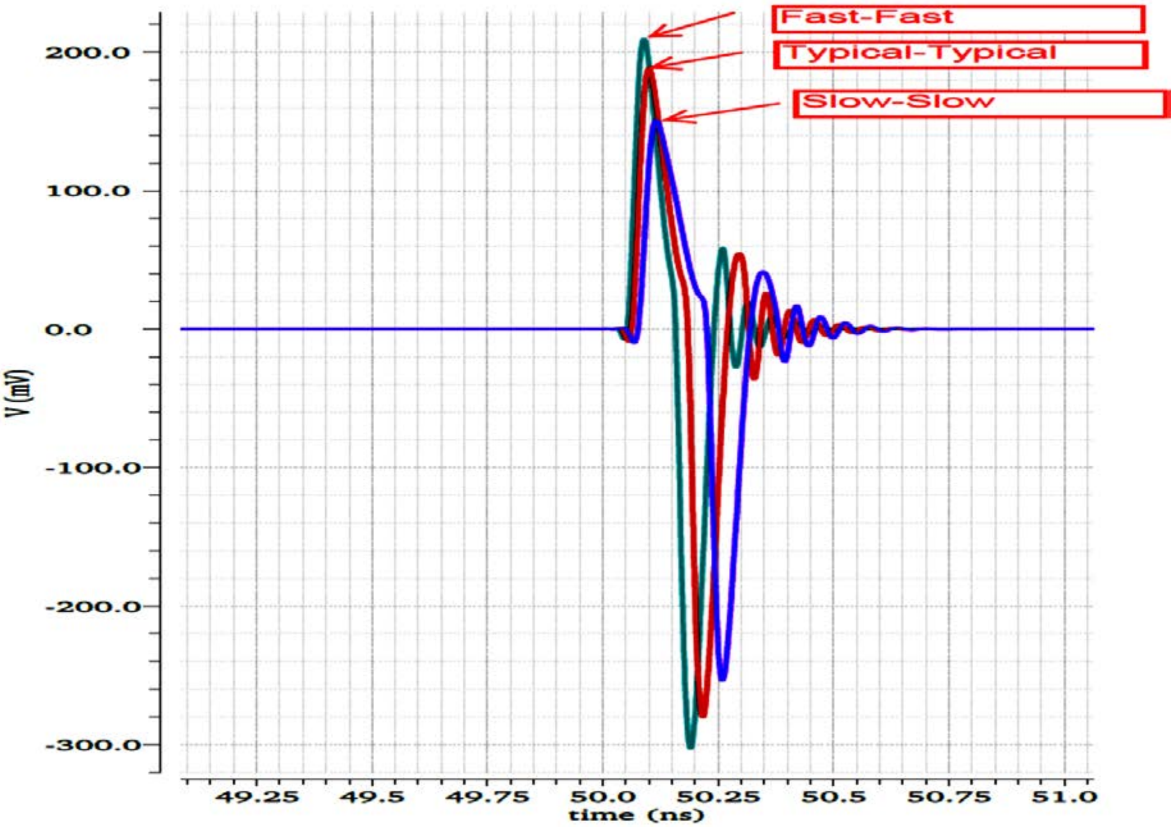

Figure 9: Fast-Fast, typical-Typical, and Slow-Slow monocycle pulse at$T = 70^0\ C$.

Table 1: Model parameter at T=27^0 C.

Model parameter	T-T	S-S	F-F
Amplitude V_{P-P}	460 mv	400 mv	510 mv
Duration pulseτ	198Ps	207 Ps	190Ps

Table 2: Model parameter at T=-20^0 C.

Model parameter	T-T	F-F	S-S
Amplitude V_{P-P}	500 mv	550 mv	420 mv
Duration pulseτ	193 Ps	180Ps	225 Ps

Table 3: Model parameter at T=70^0 C.

Model parameter	T-T	F-F	S-S
Amplitude V_{P-P}	440 mv	470 mv	380 mv
Duration pulseτ	205 Ps	210Ps	250Ps

Table 4: comparison performance

Refs	This work	[10]	[11]	[16]	[17]
Freq-band [GHz]	5.2	-	-	0-0.960	7.2
Tech $[\mu m]$	0.13	0.9	0.18	0.13	0.18
V_{pp} $[mv]$	460	660	500	340	115
τ $[ns]$	0.193	0.375	0.160	2	0.47
Pulse Type	monocycle	monocycle	monocycle	monocycle	fifth Derivate pulse
PRF [MHZ]	200	1	-	1	100
P_{DC} [mw]	0.369	19.8	-	0.056	-
E/pulse pJ/p	1.845	19800	-	56	-
Figure of merits [Mps]/[pJ/p]	108.4	5.056×10^{-5}	-	0.01785	-

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