A Tunable Energy Efficient UWB Transmitter Design for Medical Applications

Ishmam Mahbub,[1,*] Nouroz Rahman Amon ,[1]and Pran Kanai Saha[1]

[1] Department of Electrical and Electronics , Bangladesh University of Engineering and Technology (BUET)
Dhaka-1205, Bangladesh

[*]Ishmam.Mahbub@yahoo.com

Abstract— **This paper describes two configurable ultra-wideband (UWB) pulse generators for imaging and communication specially targeted for medical applications. Transmitted pulse is controllable in amplitude and duration, enabling flexible shaping of the Power Spectral Density (PSD) of the signal. Both circuits use IR-UWB based on edge combining methods. Pulses of 220ps-380ps (center frequency 5GHz-8GHz) duration and 140mV-320mV peak to peak amplitude is achievable. Both the circuits draw energy of around 4.4pJ/pulse. A maximum data rate of 3.3Gbps is achievable for communication.**

Keywords—ultra-wideband(UWB), medical imaging, high data rate communication.

I. INTRODUCTION

After the revision of part 15 in the FCC regulations for UWB systems in 2002, usage of UWB systems for data communication, ground-penetrating radar (GPR) and imaging became a growing research interest [1]. Specially, in recent times, UWB imaging techniques have shown potential for non-invasive early breast cancer detection [2], cardiology imaging [3], obstetrics imaging [4]. Because of the difference in the electrical properties of different tissues in the UWB range, microwave imaging with UWB techniques are considered a future alternative for traditional imaging methods like X-ray or MRI [5].

In this paper, we have developed an all digital impulse radio (IR) based 5^{th} derivative Gaussian pulse (5^{th} DGP) UWB transmitter. Now, two of the main challenges in transmitter designing are: firstly, whether or not these pulses comply with FCC regulations [1] and secondly, whether or not the whole system is low-power, low-cost. In this regard, the popularly used 1^{st} and 2^{nd} derivative of Gaussian pulse does not satisfy FCC regulations [6]-[7]. It is reported that the 5^{th} derivative of the Gaussian pulse has the most effective spectrum under FCC limitation floor and can be used without filtering [8].

Now, for a battery powered device, the issue of power is very crucial. On this issue, impulse radio (IR) signaling has been chosen for its low complexity, low power implementation [9]-[11]. While simple and small in size, it can reach high data rates. Also, this avoids any need for an up conversion mixer, whose CMOS implementation is known to be extremely power hungry [12]-[13]. Finally, a digital implementation is adopted, because an analog transmitter circuit consumes large amount of static power and also is more complex to implement as compared to a digital circuit.

Existing works on 5^{th} DGP UWB transmitters can be found in [14]-[16]. But these circuits do not provide any pulse shaping facilities. Contrasting these works, the proposed circuit has the ability to control both pulse duration and amplitude. Firstly, these calibration features in the proposed circuit can overcome the problem of variations in the circuit performance due to parasitic capacitances and process variations. Now, a tunable pulse generator can be used for optimizing the absorbed and radiated power of an isolated target. Power optimization is needed for enhancing discrimination and evaluation of electrical properties associated with a target [17]. Tunable generators can be used to achieve various radiation intensities, varying penetrating depth and different range resolutions by changing the shape and center frequency of the pulse spectrum, due to different frequency dependent electrical characteristic of targets.

II. UWB TRANSMITTER CIRCUIT DESIGN

We have presented two topologies for low-power implantable transmitter. Both circuits are impulse radio based and use edge combining approach. The first circuit can be used for imaging purposes and the second circuit for communication. Both circuits are clock independent as used in [18] and for modulation, a combination of Bi-Phase modulation and On-Off Keying is used [18].

Figure 1(a) shows the transmitter circuit for medical imaging. The circuit consists of two identical Gaussian mono-pulse (GMP) generators and control voltage (ctrl_5) is used to control the delay for the overlapping of the two GMP pulses to create 5^{th} derivative pulse. All the delays in the circuit are tuned by current starved inverters as shown in Figure 1(c) and Figure 1(d).

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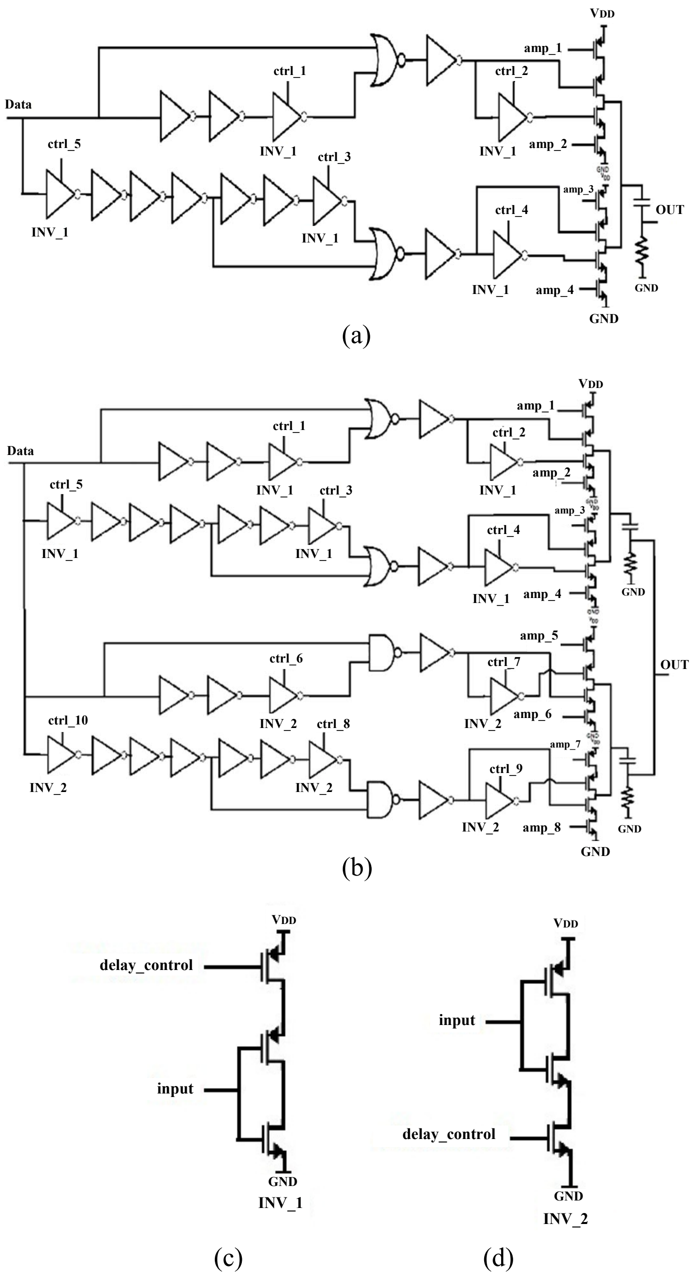

Figure 1: (a) Transmitter for medical imaging (b) Transmitter for data communication. Circuit of (c) INV_1 and (d) INV_2

Now, the circuit does not use any external clock and uses the edges of the input data to create the pulses. The input is delayed, inverted and fed to NOR gate with the input itself to produce a triangular pulse. This delay is governed by control voltage ctrl_1 and ctrl_3. The width of the triangular pulse depends on the delay provided, which thereafter determines the period of the final pulse. So, ctrl_1 and ctrl_3 determines the period of the pulses. The generated triangular pulse and its delayed inverted version (controlled by ctrl_2 and ctrl_4) are fed to NMOS and PMOS transistors to generate two separate GMP. Also as we vary the time period of the final pulse, we need to vary the delay between the triangular pulse and the inverted triangular pulse.

Finally, four current sources, controlled by amp_1, amp_2, amp_3 and amp_4, are provided to control current through the transistors fed by triangular pulses. Thus, the amplitude of each of the four segments of the 5^{th} derivative Gaussian pulse can be dictated. By changing amp_3 to VDD and amp_4 to 0V, this circuit can also work as a GMP generator.

Figure 1(b) shows the transmitter for data communications. For communication, bi-phase signals are required. This circuit is principally same as the one described before, except to create a pulse of the opposite phase, NAND gates are used as opposed to NOR gates. The circuit, to indicate data status, creates two opposite phased pulses for two opposite transitions (0 to 1/ 1 to 0).

III. SIMULATION RESULTS

For simulation and circuit design Cadence was used. The transmitter circuits were designed using IBM 90nm Standard CMOS process. For the imaging circuit, the area of the layout was 56μm×28μm. After the simulation, 140mV-320mV peak to peak amplitude was achieved at any center frequency. The time period was adjustable from 220ps-380ps (center frequency 5GHz-8GHz). Figure 2 shows three pulses of 240ps, 315ps and 360ps. The 240ps pulse (Figure 2(a)) takes 884μW total power and energy of 4.42pJ/pulse, the 315ps pulse (Figure 2(b)) takes total power of 911μW and 4.55pJ/pulse energy and 360ps pulse (Figure 2(c)) takes 840μW of power and 4.31pJ/pulse of energy. All power and energy measurements are at a pulse repetition frequency (PRF) of 200MHz. Total power depends on pulse amplitude and data rates. The pulses have -10dB bandwidth covering the entire UWB range.

A 100μm×47μm layout was done for the circuit proposed for communication. Figure 3 shows simulated results of pulse trains at PRF of 1GHz which consumes 4.51pJ/pulse energy and 9mW power. As can be seen from this figure, a positive and a negative edge produces two opposite phased pulses. Two or more consecutive 0s' or 1s' will not produce any pulse. So, the modulation is a combination of Bi-phase modulation and on-off keying. A maximum PRF of 3.3GHz is achievable by the circuit as shown in Figure 4. At PRF of 3.3GHz, total power of 13.25mW is consumed while an energy of 4.41pJ/pulse is needed.

Finally, Table 1 compares this work with other existing works. Comparing these works, it can be remarked that while GMP generators are faster and more energy efficient than the proposed circuit, they have the disadvantage of not complying with the FCC regulations. The proposed circuit has a lower per bit energy consumption and faster data rates than any existing 5^{th} DGP transmitter and provides additional pulse shaping.

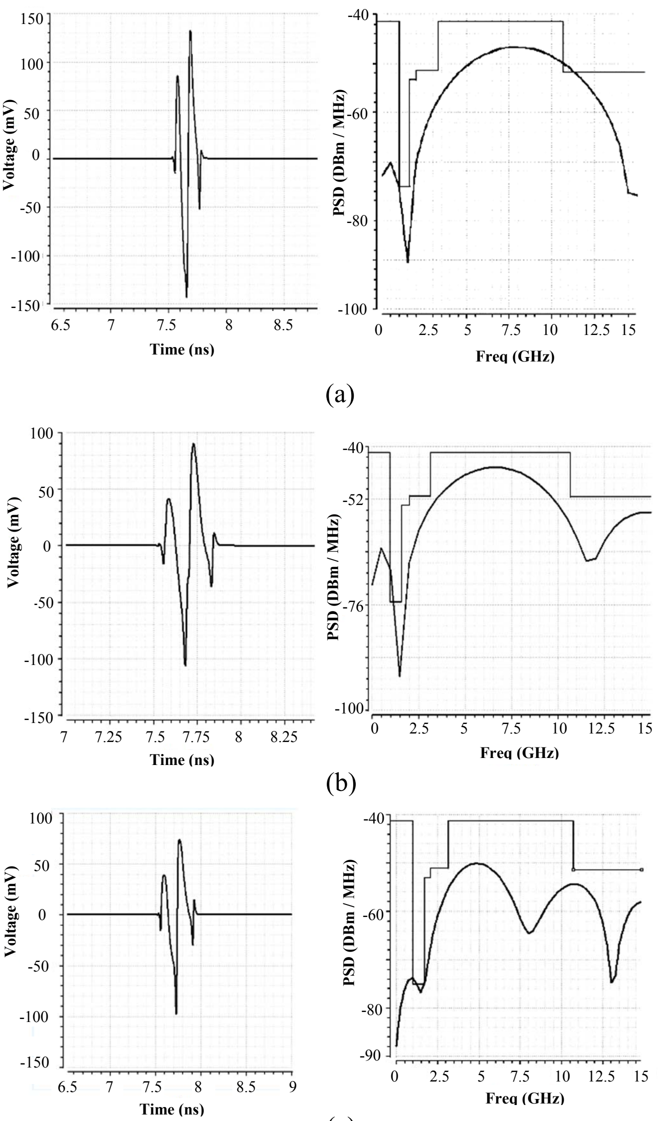

Figure 2: (a) 240ps (b) 315ps (c) 360ps UWB pulse and its Power Spectral Density (PSD)

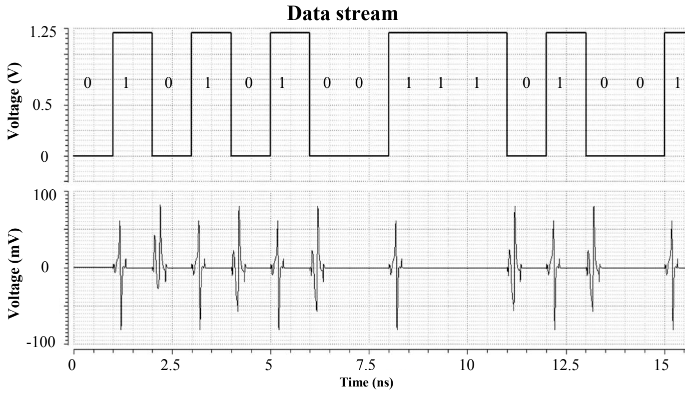

Figure 3: Pulse train at PRF of 1GHz

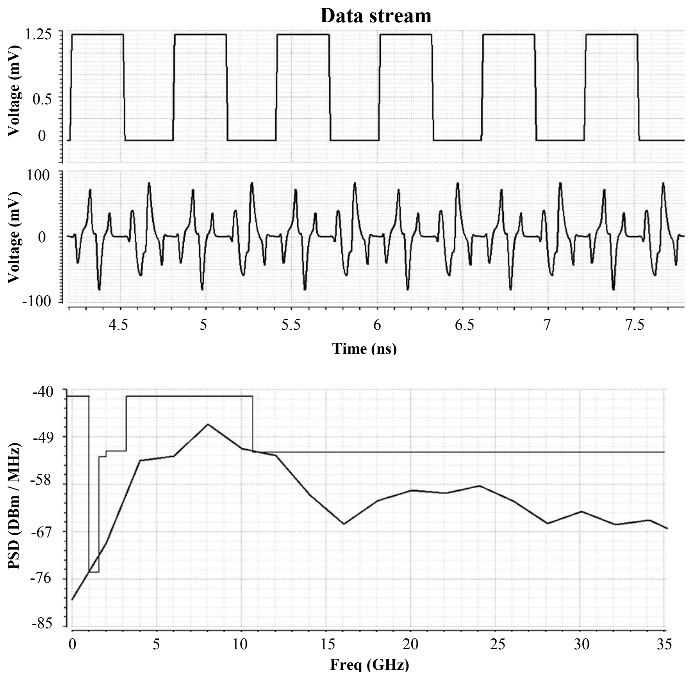

Figure 4: Pulse train at PRF of 3.3GHz and PSD of the pulses.

TABLE I: PERFORMANCE COMPARISON

Ref	Technology (CMOS)	Pulse shape	Modulation	Energy Consumption pJ/pulse	P-P pulse Amplitude (mV)	Pulse Width (ps)	Max data rate (Gbps)	-10dB Bandwidth (GHz)	Power Supply (V)
[19]	90nm CMOS	GMP	BPSK	1.13	500	142	7	3-12	1.2
[18]	130nm CMOS	GMP	BPSK + OOK	2.23	390	183	5	5-10	1.2
[20]	0.18μm CMOS	5th DGP	OOK	8.9	211	500	0.2	3-10	1.8
[21]	0.18μm CMOS	5th DGP	BPSK,OOK	7	140	800	0.500	3.1-7	1.2
[22]	0.5μm CMOS	5th DGP	BPSK	(1.3mW)	289-337	3360-4560	0.01	0-0.96	5
This work	90nm CMOS	5th DGP	BPSK+OOK	4.41	140-320	220-380	3.3	3-12	1.2

IV. CONCLUSION

The proposed circuits were designed using IBM 90nm standard CMOS process and simulations were done. Pulses of 140-320mv peak to peak and 220-380ps duration are successfully achievable by the circuit. For communication, a maximum of 3.3Gbps data rate is possible with a combination of OOK and BPSK modulation. Energy consumption for both circuits is around 4.4 pJ/pulse.

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