Compact CMOS IR-UWB transmitter using variable-order Gaussian pulse generator

M.M. Reja, Z. Hameed, K. Moez and S. Shamsadini

An area-efficient CMOS impulse radio ultra-wideband (IR-UWB) transmitter capable of generating variable orders of Gaussian pulses is presented. The core of the pulse generator is constructed using the cascade connection of *RC* differentiator networks separated by tunable amplifiers. Tuning the bias current of the amplifier using a voltage-controlled current-source allows for generation of varying orders of Gaussian pulses, which in turn allows for controlling the power and spectral mask of transmitted signals. Fabricated in a TSMC 90 nm digital CMOS process, the measurement shows that the fully integrated transmitter can generate fifth- to sixth-order Gaussian pulses. The core transmitter consumes 10.0–12.0 mW at 200 MHz pulse repeating frequency and occupies a chip area of 0.008 mm^2 only.

Introduction: The FCC regulates transmitted impulse radio ultra-wideband (IR-UWB) pulses such that they occupy a minimum bandwidth of 500 MHz with maximum allowable radiated power of − 41 dBm/MHz within the 3.1–10.6 GHz band [1]. Several types of impulse-like signals such as Hermite, Gaussian, Gaussian monocycle and Manchester monocycle have been proposed for IR-UWB communications [2]. Among these, a Gaussian pulse and its higher-order derivatives exhibit excellent time resolution and large bandwidth suitable for UWB applications. Notably, the fifth to seventh-order derivatives of Gaussian pulses fulfil the FCC spectral power density limit for UWB systems while maximising the bandwidth [3]. Among different techniques of generating Gaussian pulses and their higher-order derivatives, LC-filter Gaussian-pulse generators are area inefficient as on-chip inductors occupy a large chip area. Digital switching techniques for generating pulses require a synchronisation of multiple phases of signals over a very short time period (< ns), which is quite challenging [4]. In this Letter, a passive inductorless compact IR-UWB transmitter (Gaussian pulse generator) constructed by cascading *RC* differentiators separated by tunable amplifiers to produce variable-order of Gaussian pulses is presented.

UWB transmitter design: The proposed IR-UWB transmitter consists of an impulse generator which generates triangular pulses from the data input. A DC control voltage ($V_{N,\,P}$) controls the width of the impulse. The triangular pulses are then fed to a pulse-shaping circuit, namely the Gaussian pulse generator, where a number of differentiations of the pulses results in a higher-order derivative of Gaussian pulses. The control voltage (V_{CON}) is applied to vary the order of the Gaussian pulses. The final stage of the transmitter is a shunt-feedback two-stage drive amplifier (DA) to drive the broadband (50 Ω) antenna.

Configuration of impulse generator: The proposed impulse generator circuit is shown in Fig. 1, where a transmission gate (TG) is added in the delay line of the inverter chain. From the input data of the pulse repeating frequency (PRF), and its delayed version, a narrow triangular impulse is generated. The TG is used to adjust the width of the impulse by applying complementary control voltages V_N and V_P to the gates of the NMOS and PMOS transistors of the TG. Since a TG can be modelled as a variable resistor, its varying resistance with changing control voltages provides impulses of varying widths from 50 ps (V_N = 1.2 V, V_P = 0 V) to 135 ps (V_P = 0 V, V_N = 1.2 V).

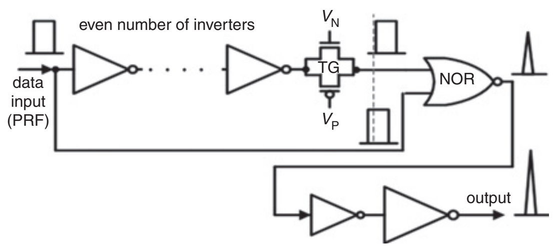

Fig. 1 *Proposed impulse generator*

Configuration of Gaussian pulse generator: The architecture of the proposed Gaussian pulse-shaping circuit is shown in Fig. 2. It is a cascaded connection of five passive *RC* coupling networks or differentiators, and four amplifiers. Here, the *RC* networks differentiate their input signals if their time constants ($\tau = RC$) are much smaller than the period of the input impulse. The values of R_1 and C_1 are chosen such that the voltage drop across R_1 remains much smaller than the voltage drop across C_1 [5] as $V_1 = R_1C_1$ (dV_i/dt). For R_1 and R_2 of 250–400 Ω, and C_1 and C_2 of 40–50 fF, time constants $\tau_1 = R_1C_1$ and $\tau_2 = R_2C_2$ are in the range of 10–16 ps, which is much smaller than the width of the pulse (50–135 ps). The amplifiers (denoted as amp) are designed using a common-source configuration with a current-source (I_D) load. As seen from Fig. 2, the two consecutive differentiators are separated by an amplifier. The operation of an intermediate differentiator depends on the operation region of the transistor. In the linear mode (triode) of operation, the output impedance (r_{o1}) of the transistor is much smaller than the combined impedance of R_2 and C_2, and hence the intermediate differentiator works as expected. However, when the transistor operates in the saturation region, its output impedance ($r_{o1} = 1/\lambda I_D$) is comparable with the combined impedance of R_2 and C_2, causing weak second differentiation. With fixed biasing voltage (gate–source voltage) for the transistor, the operation region of the amplifier can be controlled on the voltage-controlled current-source load I_D, which itself is controlled by an external control voltage, V_{CON} (0–550 mV). With five cascaded RC networks, up to the sixth derivative Gaussian pulse can be generated. As shown in Fig. 3*a*, two voltage dividers are constructed with resistors R_{1A}, R_{1B}, R_{2A} and R_{2B} to bias the transistor's gate and drain terminals.

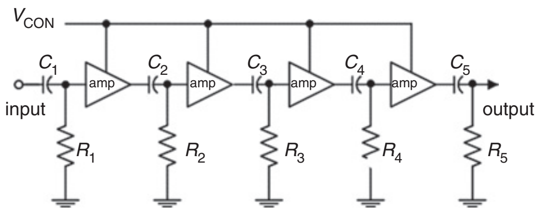

Fig. 2 *Proposed Gaussian pulse-shaping circuit*

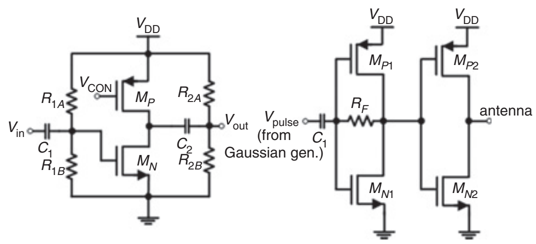

Fig. 3 *Biasing and driving circuit for proposed transmitter*
a Resistor divider
b Antenna driver

Configuration of DA: The signal produced by the Gaussian pulse generator cannot drive an antenna with 50 Ω input impedance. A two-stage DA is used as shown in Fig. 3*b*. The first-stage is a self-biased shunt-feedback DA. The signal is coupled with this amplifier through a coupling capacitor C_C. The second-stage is an inverter amplifier. This stage is kept biased around mid-supply voltage to ensure it works as an amplifier preventing it from going to the switching mode.

Results: The proposed fully active (passive inductorless) UWB transmitter is designed and implemented in TSMC 90 nm digital CMOS process. The capacitors with values of 40–50 fF are realised using a metal–insulator–metal capacitor. The proposed UWB transmitter occupies an active chip area of 0.008 mm^2 (160 × 50 μm) as shown in Fig. 4. The impulse-width control voltages are set as V_N = 1.2 V and V_P = 0 V (Fig. 1). Operated with a 1.2 V supply, the proposed UWB transmitter draws a current of 16.0 mA (V_{CON} = 520 mV) to 17.5 mA (V_{CON} = 400 mV), whereas the core circuit (excluding the output buffer) draws a current of 9.0 to 10.5 mA. The transmitter is tested using an on-wafer probe with a 50 Ω broadband load as the antenna. The data input (PRF in Fig. 1) of 200 MHz is generated using an Agilent 81134A pulse pattern generator. The output pulses are measured with an Agilent-Infinium digital oscilloscope. Fig. 5 shows the measured fifth (top) and sixth (bottom) derivative Gaussian pulses for control voltages of 400 and 520 mV, respectively. Representing the pulses of Fig. 5 in the frequency domain, the power spectral density (PSD) in dBm/MHz is plotted in Fig. 6. The sixth-order Gaussian-derivative pulses have lower levels of signal power density compared with the fifth order while falling within the FCC-radiated power limit.

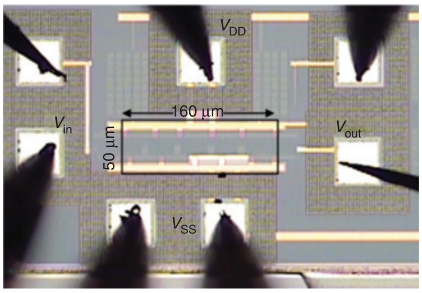

Fig. 4 *Die photo of fabricated IR-UWB transmitter*

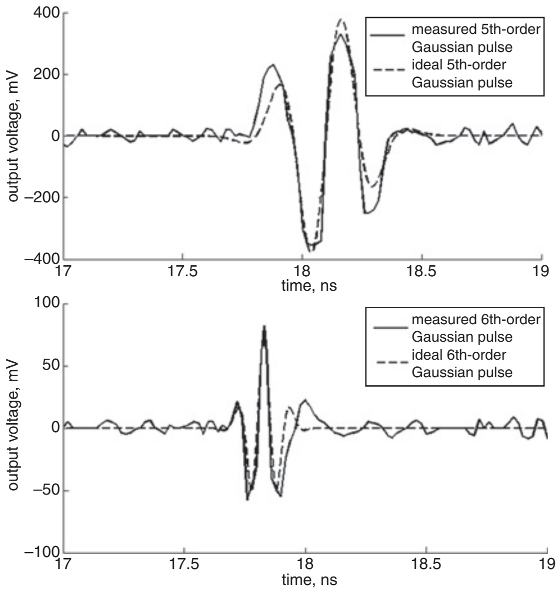

Fig. 5 *Measured output pulses of proposed transmitter*

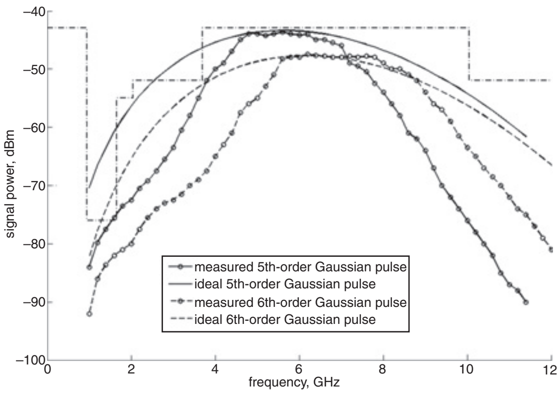

Fig. 6 *Measured PSD of output pulses of Fig. 5*

Conclusion: A novel architecture of a tunable UWB transmitter capable of generating variable orders of Gaussian UWB pulses is presented. Cascaded RC networks are used to generate derivatives of Gaussian pulses. The proposed circuit can generate variable orders of Gaussian pulses, which allows for controlling the PSD of transmitted signals. Moreover, the passive inductorless design results in a compact transmitter occupying a core die area of only 0.008 mm^2 and which compatible with low-cost standard digital CMOS processes.

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One or more of the Figures in this Letter are available in colour online.

M.M. Reja, Z. Hameed, K. Moez and S. Shamsadini (*Department of Electrical and Computer Engineering, University of Alberta, Edmonton, AB, Canada T6G 2V4*)

E-mail: kambiz@ualberta.ca

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