Impulse based UWB Transmitter in 0.18 μm CMOS for Wireless Interconnect in Future ULSI

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1. Introduction
To meet the challenge of 3D-intergation in future ULSI, global wireless interconnection (interconnect distance above 300 μm) which utilizes electromagnetic wave transmission by using integrated antenna and ultra wideband (UWB) transceiver system has been proposed [1, 2] as shown in Fig. 1. Among the different techniques for UWB system, impulse radio based UWB uses very short Gaussian monocycle pulses (GMP) as transmitted signal. Since the GMP transmission does not require any carrier, the transceiver circuit will be simple and occupies small area as it does not require complex frequency recovery system. In this paper an impulse based UWB transmitter for wireless interconnect in future ULSI is presented. The transmitter output is on-off keying (OOK) modulated differential Gaussian monocycle pulse. The developed transmitter is implemented in 0.18μm CMOS. It occupies small area and consumes low power.

2. Gaussian Monocycle Pulse Generation
A differentiator generates two impulses at the rising and falling edges of the input if the input of the differentiator is a rectangular pulse as shown in Fig 2. The interval between the two impulses depends on the rectangular pulse duration (t_r). If the duration is reduced, the negative impulse shifts to the left until it coincides with the end of the positive impulse and this forms Gaussian monocycle pulse as shown in Fig. 2(d). The GMP’s duration (t_m) depends on the rising (t_i) and falling (t_f) time of the zero interval rectangular pulse (i.e. Triangular pulse (TP) which has Gaussian properties) and is given as t_m=t_i+t_f. The GMP center frequency (f_c) will be reciprocal of t_m. The above mentioned technique has been applied to generate the differential GMP wavelet for impulse based UWB transceiver [3].

3. Transmitter Circuit and Simulation
A schematic block diagram of the developed impulse based UWB transmitter is shown in Fig. 3. The circuit is implemented in 0.18 μm CMOS process. Each circuit block of the transmitter and the chip layout is shown in Fig. 4. Simulation is done from extracted netlist by HSPICE. Parasitic resistance, capacitance and coupling capacitance are taken into account during simulation.

The differential voltage controlled ring oscillator (VCO) first generates rectangular shaped clock pulse with a frequency of 1.408 GHz as shown in Fig. 5(a). This differential clock pulse is then digitally mixed with the non-return-zero (NRZ) data as shown in Fig. 5(b) by using ‘AND’ gate to generate on-off keying (OOK) modulated signal. The triangular pulse (TP) as shown in Fig. 5(c) is then generated from OOK modulated signal by using digital pulse shaping circuit. The FFT of TP as shown in Fig. 5(d) depicts the gaussian characteristic of the TP signal. The TP is differentiatied to generate GMP. The differentiator is designed using metal-insulator-metal (MIM) capacitor (C) and poly resistor (R) in such a way that it behaves as close as to ideal differentiator in the frequency range of interest. The amplitude of the GMP as shown in Fig. 6(a) depends on derivative time constant (RC), t_i and t_f. The amplitude of the negative impulse of GMP is found to be the half of that of positive impulse because t_i is twice of the t_f. The GMP duration is found to be 0.41 ns which is slightly higher than that of t_i+t_f. To reduce the common mode noise and transmit the GMP by integrated dipole antenna, single ended GMP is converted to differential GMP (DGMP) by using single input differential output (SIDO) amplifier. The DGMP is further amplified by differential output amplifier. The Output amplifier has a voltage gain of 7.28 dB at the center frequency of GMP (2.4 GHz) and wide bandwidth. The amplified DGMP is shown in Fig. 6(b). The FFT of GMP as shown in Fig. 6(c) depicts that the GMP has a center frequency (f_c) of 2.4 GHz and 3-dB bandwidth (BW) of 2.8 GHz. A source follower circuit (shown in Fig. 3) is used to avoid reflection due to impedance mismatch between the transmitter circuit and antenna.

To confirm the transmission of OOK data modulated signal in interchip communication by integrated antenna in silicon, simulation is done together with the transmitter layout extracted netlist and HSPICE netlist macromodel of integrated transmit and receive dipole antenna separated by 3 mm [4]. The simulation results as shown in Fig. 7 depicts that the received signal is the derivative of the transmitted signal and the transmission and reception is achieved at the rate of 1.4 GHz.

4. Conclusion
The architecture of impulse based UWB transmitter in wireless inter/intra-chip data communication is discussed. The developed circuit occupies a small area (0.06 mm²) and consumes a total power of 47 mW in transmit mode from 1.8 V supply. The simulation confirms data transmission by using integrated antenna and developed transmitter in Si. A maximum data transmission rate of 1.4 Gbps could be achieved using the developed transmitter.

Acknowledgement
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References
Fig. 1 Intra/interchip wireless interconnect system for future ULSI.

Fig. 2 Generation of Gaussian monocycle pulse. (a) Rectangular pulse. (b) Gaussian Impulse. (c) Triangular pulse. (d) Gaussian monocycle pulse.

Fig. 3 Schematic block diagram of impulse based UWB transmitter. V\text{ref}

Fig. 4 Circuit block of Transmitter. (a) Differential delay cell for VCO. (b) TP generation circuit. (c) DGMP generation circuit. (d) Circuit layout. Antenna size is not in scale.

Fig. 5 OOK modulated triangular pulse generation. (a) clock from VCO. (b) Non-return-zero pseudo random data bit (PRBS). (c) Triangular pulse (TP). (d) FFT of TP.

Fig. 6 Generation of differential Gaussian monocycle pulse (DGMP) from OOK modulated TP signal. (a) Gaussian monocycle pulse (GMP). (b) DGMP. (c) FFT of GMP.

Fig. 7 Interchip transmission of OOK modulated data using integrated dipole antenna in Si. (a) Transmitted signal (b) Received signal at 3 mm distance.
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**UWB Transceiver**

**Benefits of Impulse based UWB Transmitter**
- Carrierless transmission, no frequency recovery system required at receiver side.
- Simple transceiver circuit
- Wide-bandwidth and Low power transmission
- Occupies small area and so low cost

**FFT of GMP shows that GMP has wide bandwidth characteristics and no dc component**

**GMP Generation Principle**

Rectangular pulse with finite rise and fall time

Generally twice differentiation of rectangular pulse having finite rise and fall time generates Gaussian monocycle pulse at rising and falling edges.

- **t_m** = Monocycle pulse duration
- **t_r** = Rise time (time to reach 0 to 100% of peak) of Triangular shaped pulse
- **t_f** = Fall time (time to reach from 100% of peak to 0) of Triangular shaped pulse

**Transmitter Circuit**

- Differential Voltage Controlled Oscillator
- Triangular/Gaussian Pulse Generator
- Single input dual output amplifier
- Output amplifier

Triangular shaped pulse is generated from OOK modulated signal using digital pulse shaping circuit.

On-off keying (OOK) modulation is applied to encode data. Presence of signal represents bit '1', absence of signal represents bit '0'.

**GMP Generation Principle**

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**Transmitter Chip Layout**

Meander dipole antenna length =8mm (not in scale)

Hspice netlist is created from layout using Calibre™ parameter extraction program.

HPSICE Simulation is done from layout extracted netlist considering parasitic RC.

Technology: TSMC 0.18 µm CMOS mixed signal process

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**Motivation**

- Problem: Transmission delay due to R, L, C of interconnection is primary obstacle for high frequency clock and data transmission in future ULSI as well as in 3D integration.
- Solution:
  - Use of high conductivity and low K material
  - Inductive and capacitive coupling for local interconnection (interconnect distance: up to 300 µm)
  - Electromagnetic wave transmission using integrated antenna and UWB transceiver circuit.
- High data rate and wide bandwidth desirable for wireless interconnection in future ULSI.

**Ultra Wideband (UWB) technology can be applied in wireless interconnection for short distance and high data rate.**
**INTERCHIP DATA TRANSMISSION USING MEANDER DIPOLE ANTENNA**

- Meander dipole antenna: L = 8 mm
- Si substrate resistivity (ρ) = 10 Ω·cm
- Total meander length = 1.612 cm

**CHARACTERISTICS (S-parameter) OF ANTENNA PAIR**

- **Reflection Coefficient S11 (dB)**
  - Frequency (GHz) vs. Reflection Coefficient (dB)
  - Resonance frequency of 2.5 GHz from Hspice macromodel simulation of antenna pair is same as that from MW studio simulation.

**INPUT IMPEDANCE AT 2.4 GHz**

- Input impedance at 2.4 GHz is 100 Ohms from Hspice simulation.

**CONCLUSION**

- Architecture of Impulse based UWB transmitter in 0.18µm CMOS is developed for intra/interchip data communication in future ULSI.
- On-off keying modulation technique is used for simplicity.
- Circuit occupies small area (~0.06mm²) and total power dissipation is 47mW from 1.8 V supply.
- Differential Gaussian monocycle pulse is used to transmit NRZ data by using dipole antenna.
- Pulse repetition rate is 1.4GHz thus a maximum data transmission rate of 1.4Gbps could be achieved.