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-intergration 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_d). 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_r) and falling (t_f) time of the zero interval rectangular pulse (i.e. Triangular pulse (TP) which has Gaussian properties) and is given as $t_m=t_r+t_f$. 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 differentiated 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_r and t_f. The amplitude of the negative impulse of GMP is found to be the half of that of positive impulse because t_f is twice of the t_r. The GMP duration is found to be 0.41 ns which is slightly higher than that of t_r+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 mm^2) 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

[1] A. B. M. H. Rashid. et al. IEEE EDL, vol. 23, No. 12, Dec 2002, p. 731
[2] P.K. Saha et al. Proc. ISSSTA 2004, Australia, p. 962.
[3] P.K. Saha et al. SSDM 2005, Kobe Japan, paper accepted.
[4] S. Watanabe et al. Proc. IEEE AP-S symposium, USA, 2004, p. 2277.

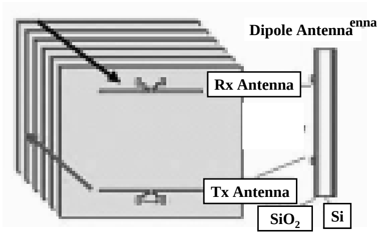

Fig.1 Intra/interchip wireless interconnect system for future ULSI.

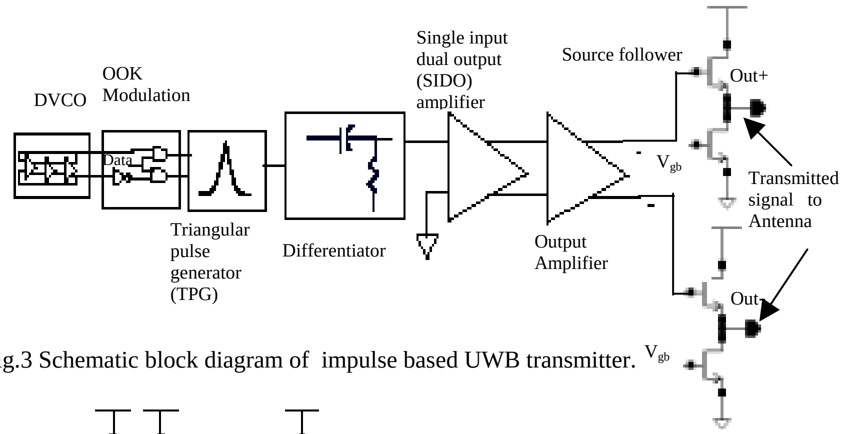

Fig.3 Schematic block diagram of impulse based UWB transmitter.

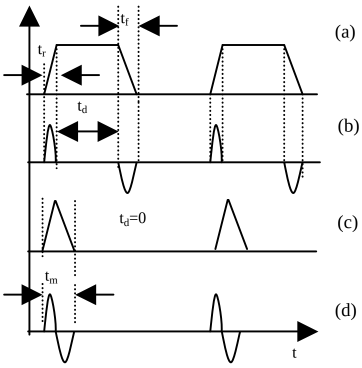

Fig. 2 Generation of Gaussian monocycle pulse. (a) Rectangular pulse. (b) Gaussian Impulse. (c)Triangular pulse. (d) Gaussian monocycle pulse .

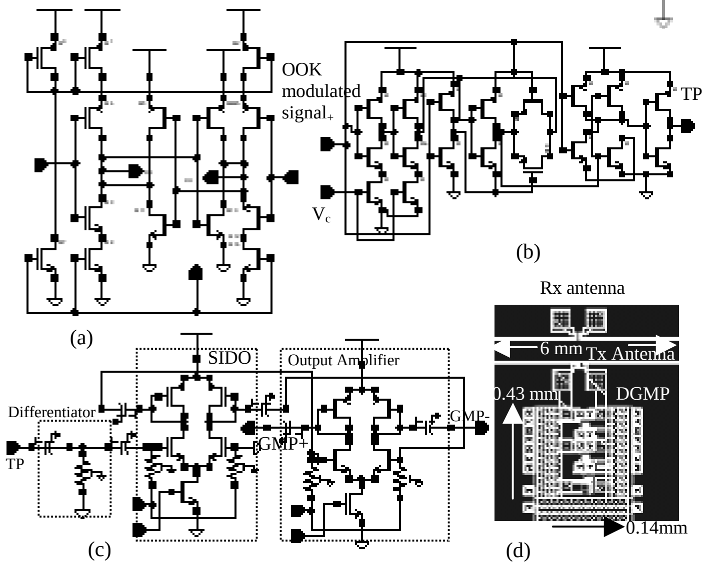

Fig. 4 Circuit block of Transmitter. (a) Differential delay cell for VCO. (b) TP generation circuit. (c) DGMP generation circuit. (d) Circuit layout. Antenna size is not in scale.

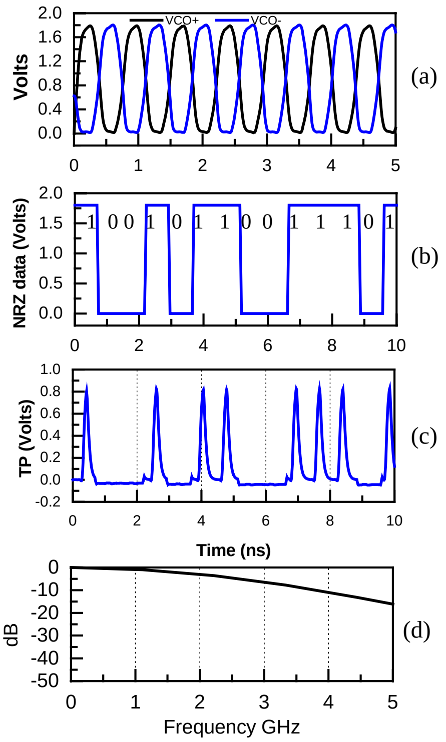

Fig. 5 OOK modulated triangular pulse generation. (a) clock from VCO. (b) Non-return-zero pseudo random data bit (PRBS). (c) Triangular pulse (TP). (d) FFT of TP.

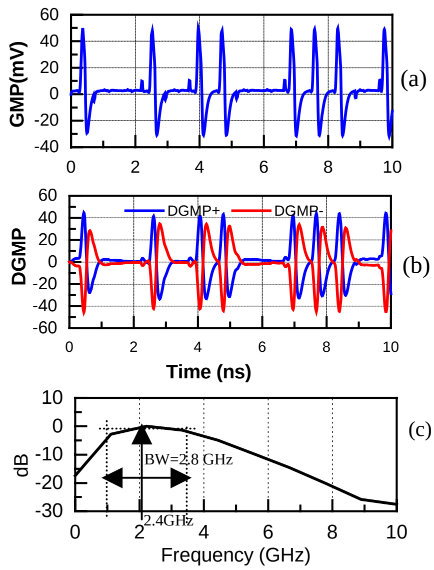

Fig. 6 Generation of differential Gaussian monocycle pulse (DGMP) from OOK modulated TP signal . (a) Gaussian monocycle pulse (GMP). (b) DGMP . (c) FFT of GMP.

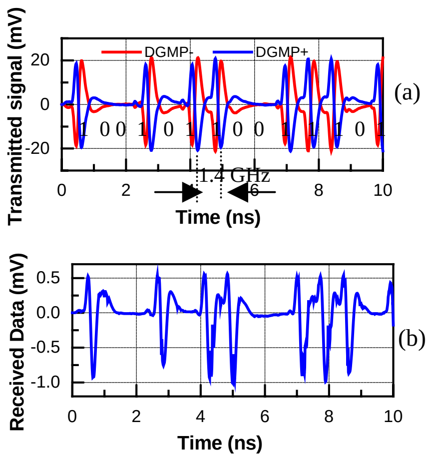

Fig. 7 Interchip transmission of OOK modulated data using integrated dipole antenna in Si. (a) Transmitted signal (b) Received signal at 3 mm distance.

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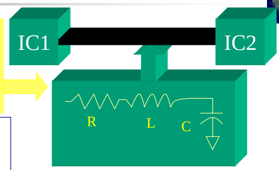
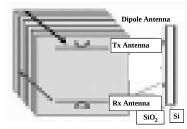
MOTIVATION

Problem: Transmission delay due to R, C and L 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: upto 300 μm)**
- **Electromagnetic wave transmission using integrated antenna and UWB transceiver circuit.**



Intra/Inter Chip Wireless Interconnection in 3D integration for Future ULSI

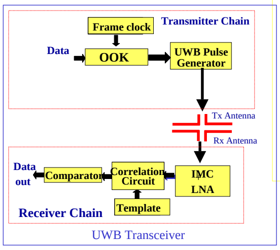
High data rate and wide bandwidth is desirable for wireless interconnection in future ULSI

Shannon's channel Capacity theorem

$$C = B\log_2\left(1+\frac{S}{N}\right)$$

- Ultra Wideband (UWB) technology can be applied in wireless interconnection for short distance and high data ra

UWB TRANSCEIVER

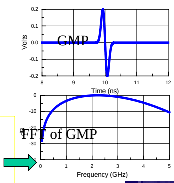


UWB Transceiver

Benefits of Impulse based UWB Transmitter

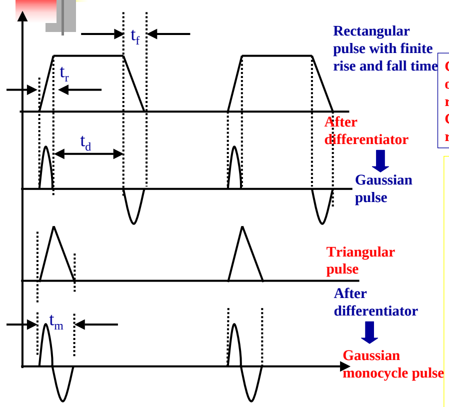
- **Carrierless transmission, so no frequency recovery system requires at receiver side.**
- **Simple transceiver circuit**
- **Wide-bandwidth and Low power transmission**
- **Occupies small area and so low cost**

- Gaussian monocycle pulses (GMP) is used as transmitted and template signal in Impulse based UWB Transceiver



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

GMP GENERATION PRINCIPLE



Generally twice differentiation of rectangular pulse having finite rise and fall time generate Gaussian monocycle pulse at the rising and falling edge.

t_m = Monocycle pulse duration

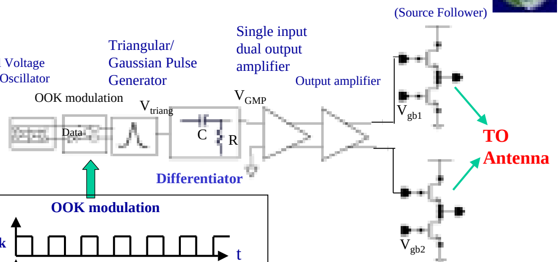
t_r= Rise time (time to reach 0 to 100 % of peak) of Triangular shaped pulse

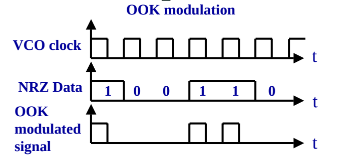
t_f= Fall time (time to reach from 100 % of peak to 0) of Triangular shaped pulse

$t_m = t_r + t_f$

$f_c = 1/t_m$

TRANSMITTER CIRCUIT



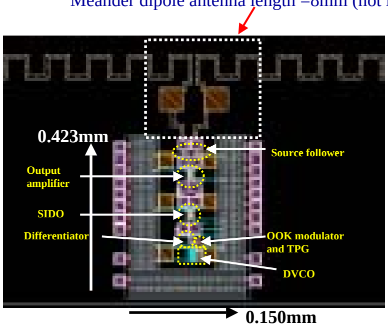


Triangular shaped pulse is generated from OOK modulated signal using digital pulse shaping circuit

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

TRANSMITTER CHIP LAYOUT

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



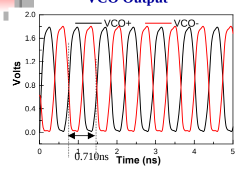
Hspice netlist is created from layout using Calibre ™ parameter extraction program

HPSICE Simulation is done from layout extracted netlist considering parasitic RC

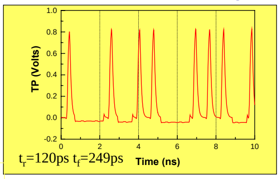
Technology: TSMC 0.18 μm CMOS mixed signal process

SIMULATION RESULTS

VCO Output

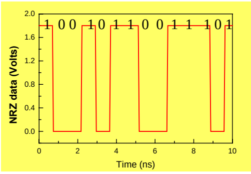


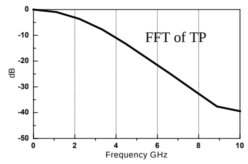
TP from OOK data modulated signal



f=1.408 GHz Rise time =185 ps Fall time =210 ps

PRBS NRZ Data

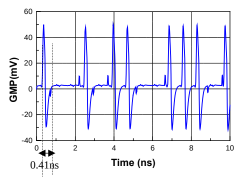




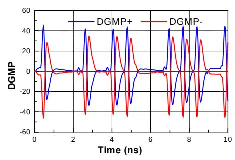
FFT of TP shows the same characteristic as that of Gaussian pulse

DIFFERENTIAL GAUSSIAN MONOCYCLE PULSE (DGMP)

GMP Contain Data

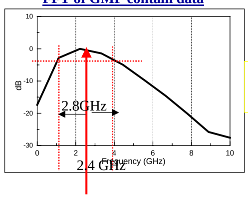


Differential Gaussian Monocycle contain Data after output amplifier



- Since, $t_f \cong 2t_r$, amplitude of the negative portion of GMP is about half of that of the positive portion of GMP.

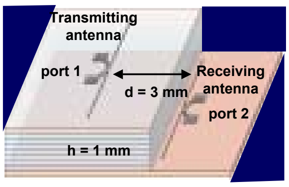
FFT of GMP contain data



Output Amplifier gain at 2.4GHz is 7.28 dB

3-dB bandwidth=2.8 GHz
Center frequency=2.4 GHz

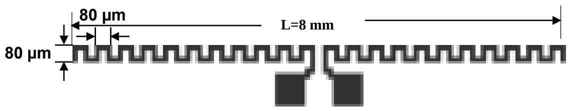
INTERCHIP DATA TRANSMISSION USING MEANDER DIPOLE ANTENNA



Meander dipole antenna: L = 8 mm

Si substrate resistivity (ρ) = 10 Ω·cm

Total meander length=1.612 cm



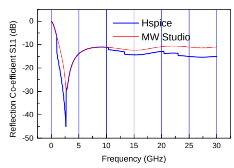
Meander dipole antenna

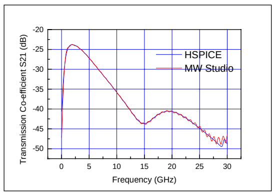
Characteristics (S-parameter) of antenna pair is obtained from MW Studio Simulation

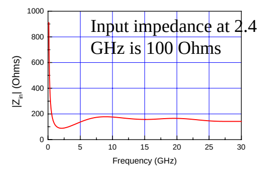
Hspice macro model is generated from S-parameter obtained from MW studio simulation by using EMtoSpice™ Converter

MEANDER DIPOLE ANTENNA PERFORMANCE FROM HSPICE MACROMODEL AND MW STUDIO

Hspice macromodel is generated from S-parameter obtained from MW studio simulation by using EMtoSpice™ Converter





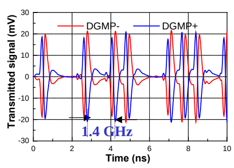


Resonance frequency of 2.5 GHz from Hspice macromodel simulation of antenna pair is same as that from MW studio simulation.

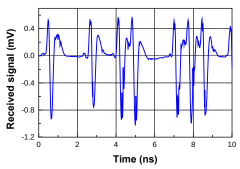
Antenna Input impedance at 2.4 GHz is 100 Ohms from Hspice simulation

TRANSMITTED AND RECEIVED SIGNAL

Transmitted Signal after Source Follower



Received Signal



Received antenna is terminated by 100 Ohm

Received signal is found the first derivative of the transmitted signal (Gaussian monocycle pulse)

Low received signal level is due to the use of low antenna gain.

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 of 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 .