Pulse-Based Ultra-Wideband Transmitters for Digital Communication

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Ultra-Wideband (UWB) Signaling



FCC defines UWB as bandwidth >500MHz

UWB signals are narrow in time Energy spread over wide bandwidth

UWB Regulations



- FCC issues notice of inquiry in 1998
- First report and order in 2002 opening 3.1-10.6GHz band for wireless communication

Advantages and Challenges

 High data rate
 Precise locationing
 Low interference and probability of interception



- × Interference
- × Multipath
- Wide bandwidth circuits

Outline

- High data rate transmitter
 Gaussian pulse shaping
- Variable low data rate transmitter
 All-digital architecture
- Conclusions and future directions

High Data Rate System

- 100Mb/s at 10m in dense multipath
- Minimize acquisition time, energy/bit
- Sub-banded frequency plan

Application	Data Rate
HD Video	19.2Mb/s
Dolby 5.1	13.8Mb/s
PC Monitor	63-1000Mb/s
MPEG2	75-150Mb/s



Transceiver Architecture



Gaussian Pulse Generator

- Generate Gaussian pulse shape
- Tunable from 3.1-10.6GHz (14 channels)
- Matched BPSK pulses



Tanh Approximation

- Exploit exponential BJT
- Apply empirically optimized triangle signal
- Output current approximates Gaussian pulse





Differential Input Signal





Optimization Results



Optimized Pulse



1.7% maximum in-band error between Tanh and Gaussian pulse

Pulse-Shaping Mixers



RF Amplifier



Class A amplifier directly drives UWB antenna

Measured Spectrum

Channel 1



Channel 14



BPSK Matching



- Measured matching using on-chip VCO
- Comparison to ideal Tanh response

Measured Pulse



Performance Summary

Process	0.18µm SiGe BiCMOS
Modulation	BPSK
Pulse shape	Gaussian
Pulse width	1.7-3.3ns
Supply voltage	1.8V
Total power	31.3mW





[VCO by B. Ginsburg]

- Pulse-shaping and up-conversion in one circuit
- BPSK inversion in RF for improved matching

High-Rate System Summary

- Custom chipset and antenna solution
- Pulse-based, 14 channel, CDMA architecture
- Total power at 100Mb/s
 - Receive mode: 227mW
 - Transmit mode: 51mW



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Motivation

Low data rate, energy-constrained apps.



Impulse-UWB signaling inherently duty-cycled



System Specifications

PPM signaling with non-coherent receiver



Three channel frequency plan



Energy-Detection Receiver

- **RF front-end performs channel-selection**
- **Energy detection by square-and-integrate**



No RF oscillator required

Pulse Generation Principle

 Use a tapped variable delay line and edge combiner to synthesize a pulse



Transmitter Block Diagram



Digital Delay Stage



Delay Line Calibration



Delay Range and Accuracy

Simulated RF Output



Delay Range and Accuracy

Measured RF Output



Ring output is an accurate measure of pulse center frequency

30-Edge Combiner



RF Pad Driver



Spectrum Scrambling



Spectrum Scrambling



DB-BPSK Implementation



Per-stage delay is 1/2 RF period

Mask values offset by 1 bit

FCC Mask

4.4

4.3

4 2

DB-BPSK Pulses PPM + DB-BPSK Spectrum 25 [ZHW/wap] dSd 2.5ns PPN 650mV **DB-BPSK** PPM -65

3.7

3.8

3.9

4 0

Frequency [GHz]

DB-BPSK Modulation

Coherent Receiver Simulations



DB-BPSK can replace BPSK in a coherent receiver with 0.2dB loss

Measured Spectrum



Transmitter Summary

Technology	90nm CMOS	
Active Area	0.11x0.22mSmoot ²	
Modulation	PPM	
Scrambling	DB-BPSK	
Supply	1V	
Leakage Power	96µW	
Active E/pulse	37pJ/pulse	
PRF Range	10kHz to 16.7MHz	◆ 0.5mSmoot
Total E/bit	9.6nJ/bit to 43pJ/bit	

- Energy consumed in sub-V_t leakage and CV²
- Digital architecture practical for non-coherent RX

Low-Rate System Demo



Demonstrated wireless link at 16.7Mb/s, 1kb packets

Acquisition and timing implemented on FPGA

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Summary of Contributions

- Gaussian pulse approximation
 - Spectrally efficient for dense networks
- All-digital pulse generation
 - Relax spectral efficiency requirement
 - Digitally programmable pulse spectrum
 - Ultra-low power
- Proposed DB-BPSK modulation
 - Suitable for scrambling PPM, BPSK replacement

Conclusions

- Exploit available bandwidth to reduce power in electronics
- UWB systems are receiver power dominated
- Energy/bit compares favorably to other work
 - Dominated by
 leakage currents
 at low data rates



Future Directions

- UWB suitable for high and low data rates
- Narrowband relies on fine-tuning
- UWB signaling enables relaxed frequency tolerance CMOS integration
- Highly digital radios
 - Use standard digital design flow
 - Benefit from process scaling
 - Ultra-low power and area

Synthesizable transmitter for UWB

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