A 3.1-10.6 GHz Ultra-Wideband Pulse-Shaping Mixer

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Outline

- MIT UWB transceiver architecture
- Pulse shaping and generation
- Transmitter architecture
- Results
UWB Overview

- UWB is an overlay technology
- FCC restrictions
  - Min BW: 500MHz
  - Max avg. power: -41.3dBm/MHz
- 802.15.3a
  - 1st generation: 3.1~5GHz
  - Pulses in one 1.3GHz channel
  - OFDM in three 528MHz channels, hopping
MIT Architecture

- Message transmitted in BPSK Gaussian pulses
- Direct-conversion to/from the UWB band
- 4-bit ADC sufficient for AWGN and interferers
- All synchronization and demodulation in the digital domain

![Diagram of MIT Architecture]

14 Channel Frequency Plan

<table>
<thead>
<tr>
<th>Frequency [GHz]</th>
<th>Power density [dBm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1</td>
<td>-51.3</td>
</tr>
<tr>
<td>10.6</td>
<td>-61.3</td>
</tr>
</tbody>
</table>

Digital back-end

SiGe RF front-end

5-bit, 500MS/s dual ADC
Design Challenges

• Generate Gaussian pulse shape
• Tunability from 3.1-10.6 GHz
• Matched BPSK pulses
• Meet FCC requirements, spectral mask, LO feedthrough
Gaussian Approximation

- Exploit exponential behavior of a BJT
- *Tanh* response used to approximate a Gaussian

\[ I_B = i_{c1} + i_{c2} \quad i_{cn} = I_S e^{v_{ben}/V_{th}} \]

\[ i_{c2}/I_B = \frac{1 - \tanh(v_{in}/2V_{th})}{2} \]

![Diagram of circuit with BJT and current equations]

Normalized Tanh

![Graph showing normalized tanh function with input range from -2 to 2 on the x-axis and output range from 0.2 to 1 on the y-axis.]

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Pulse Shaping

- Apply a triangle signal to differential pair
- For appropriate input signal, output current approximates Gaussian pulse

![Diagram of differential pair with current and voltage signals](image.png)
Pulse Shape Optimization

- Goal: determine $A$, $PW$, $V_{off}$ that minimize the MSE between $\sim\tanh$ pulse and Gaussian reference pulse

$$V_{Gauss} = V_p e^{-t^2/2\sigma^2}$$

- Found empirically by sweeping parameter values and calculating MSE

- Optima found for a range of values of $\sigma$
Empirical Results

\[ V_{off} \geq 1 \]

\[ A = 2.4 + 2.0 \cdot V_{off} \]

\[ PW = \sigma(4.37 + 3.61 \cdot V_{off}) \]

- Only \( PW \) a function of \( \sigma \) for fixed \( V_{off} \)

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Resulting Pulse

- Max in-band error in spectrum: 1.7%
- Small percent of power out of band
BPSK Pulse Generator

• Up-conversion, pulse shaping in one circuit
• LO feedthrough reduced by increasing $(V_{high} - V_{cm})$ until limited by parasitics, biasing
• LO cancellation from double balanced mixer
• Expandable to QPSK
RF Amplifier

- Mixer output filtered by 2\textsuperscript{nd} order highpass reducing emissions below 3.1 GHz
- Output buffered by class A amplifier
- UWB antenna provides $S_{11} < -10\text{dB}$ for UWB frequency range, open-circuit at DC
Local Oscillator Buffering

- Differential LO routing
- R-loaded ECL buffers
- V-to-I conversion from resistors driving diode-connected BJT

1-2 Conversion

LO Switch

LO V-I Conversion

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Transmitter Architecture

- External LO
- Signal Gen
- High/Low Bank
- PLL
- RF Ref
- Data
- 100Mhz clock
- Bias adjust
- PA adjust
- PA V_{dd}
- 0.18\,\mu m SiGe Transmitter

PLL

Data

100Mhz clock

V_{high}

V_{cm}
### Die Photo

<table>
<thead>
<tr>
<th>Power [mW]</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mixer + LO</td>
<td>25.2</td>
</tr>
<tr>
<td>PA</td>
<td>6.1</td>
</tr>
<tr>
<td>Total</td>
<td>31.3</td>
</tr>
</tbody>
</table>

Dimensions:
- 1.7mm width
- 1.4mm height

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Steady-State Matching

- Measured matching with on-chip VCO
- Comparison to ideal \( \text{tanh} \) response
- Finite LO feedthrough
• No spectral lines for random data
  – Amplitude reduced, spectral envelope preserved
• Pulse shaping, BPSK matching limited by packaging
Conclusions

• The Gaussian pulse shape has desirable time- and frequency-domain responses
  – Can be approximated using the $\tanh$ transfer function of a differential pair

• The proposed pulse shaping technique has several benefits:
  – No “reset” phase in pulse generator
  – BPSK from inverted LO
  – Mixing and pulse shaping in one circuit
  – Generate triangle with known techniques
Acknowledgements

• HP-MIT Alliance
• National Science Foundation
Modeled Temperature Variation

- Between 0-85°C
  - 3% increase, 8% decrease in BW
  - -0.05dB to 0.13dB change in amplitude