RMO1B-5

A 19pJ/pulse UWB Transmitter with Dual Capacitively-Coupled Digital Power Amplifiers

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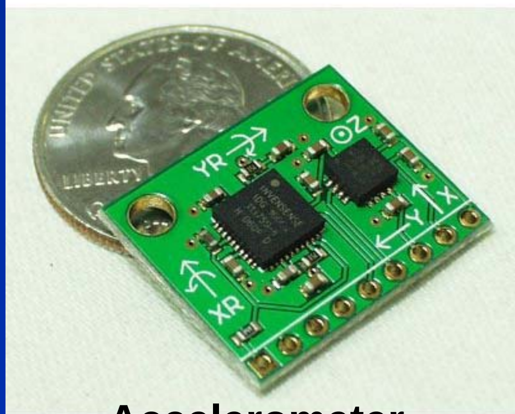
Outline

- Architectural Motivation
- Generating UWB Pulses Digitally
- Transmitter Design
- Measurement Results
- Conclusions

Research Vision

- Ubiquitous wireless nodes for Body Area Networks

- Key requirements:
  - Long battery life
  - Small form factor (< $1cm^3$)
- Key characteristics:
  - Low data rate (< 500kbps)
  - Short range (1-10m)



Accelerometer

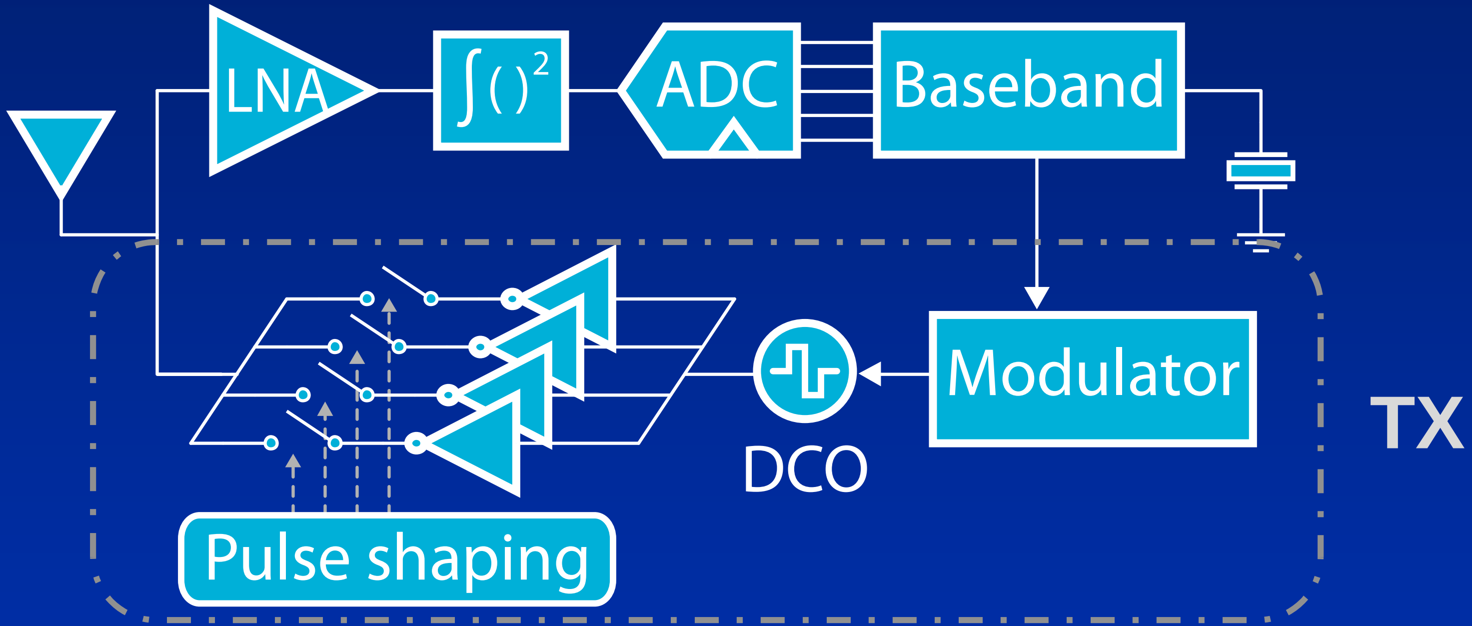
Energy-Efficient/Low Area Design

- Need a system-level view to meet low energy and area requirements

System observations and/or requirements	Questions
Low data rates	Can we reduce circuit complexity at the expense of sensitivity?
Duty cycling	Can we shut off circuits for extended periods of time?
No off-chip components	Can we filter on-chip without consuming too much area?
Digital, digital, digital	Can we design with scalable single-ended digital circuits?
Clocking	Can we use poor quality oscillators and no PLLs?

UWB System Architecture

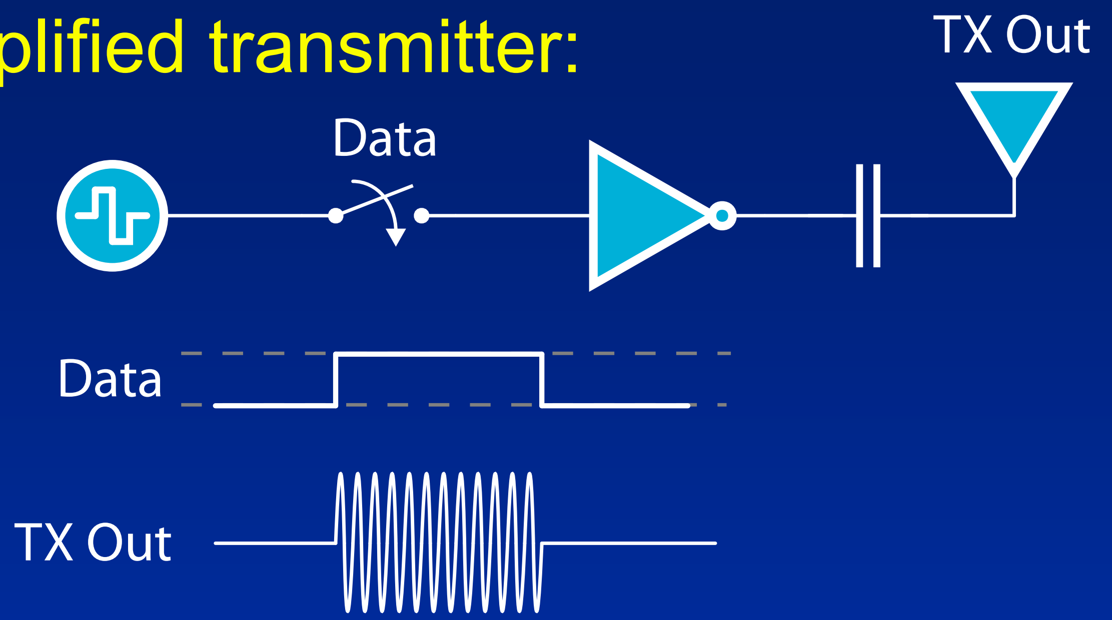
- Non-coherent pulsed-UWB can answer many of these questions



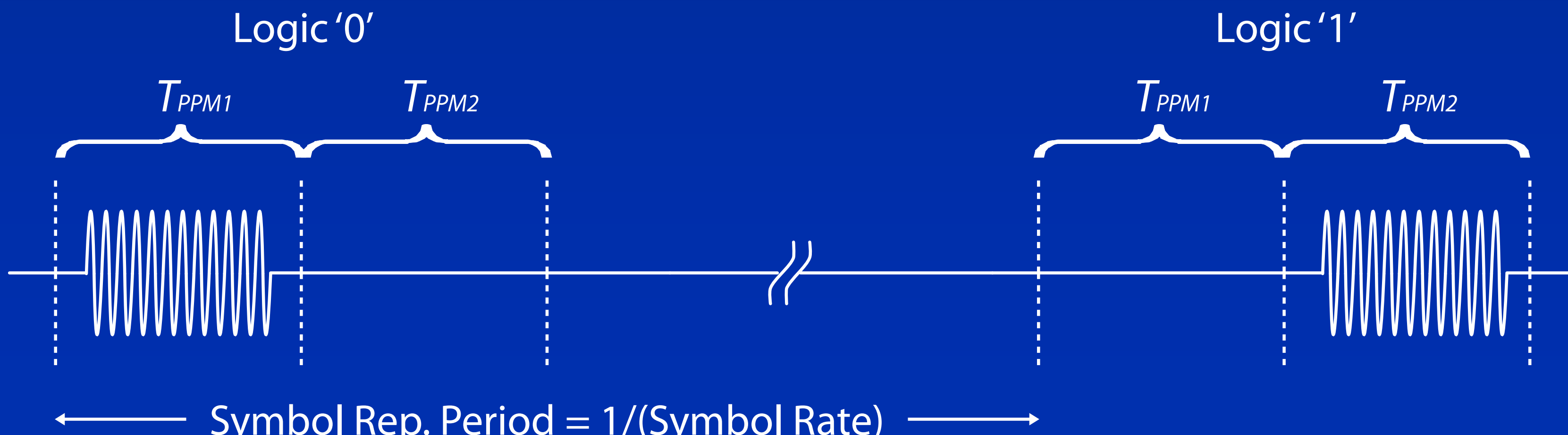
Advantages	Disadvantages
Simple, low-power	Inherently less performance
Oscillator accuracy relaxed	Localization accuracy reduced
Fast turn-on times	Long preambles often required

Generating UWB Pulses Digitally

- Simplified transmitter:

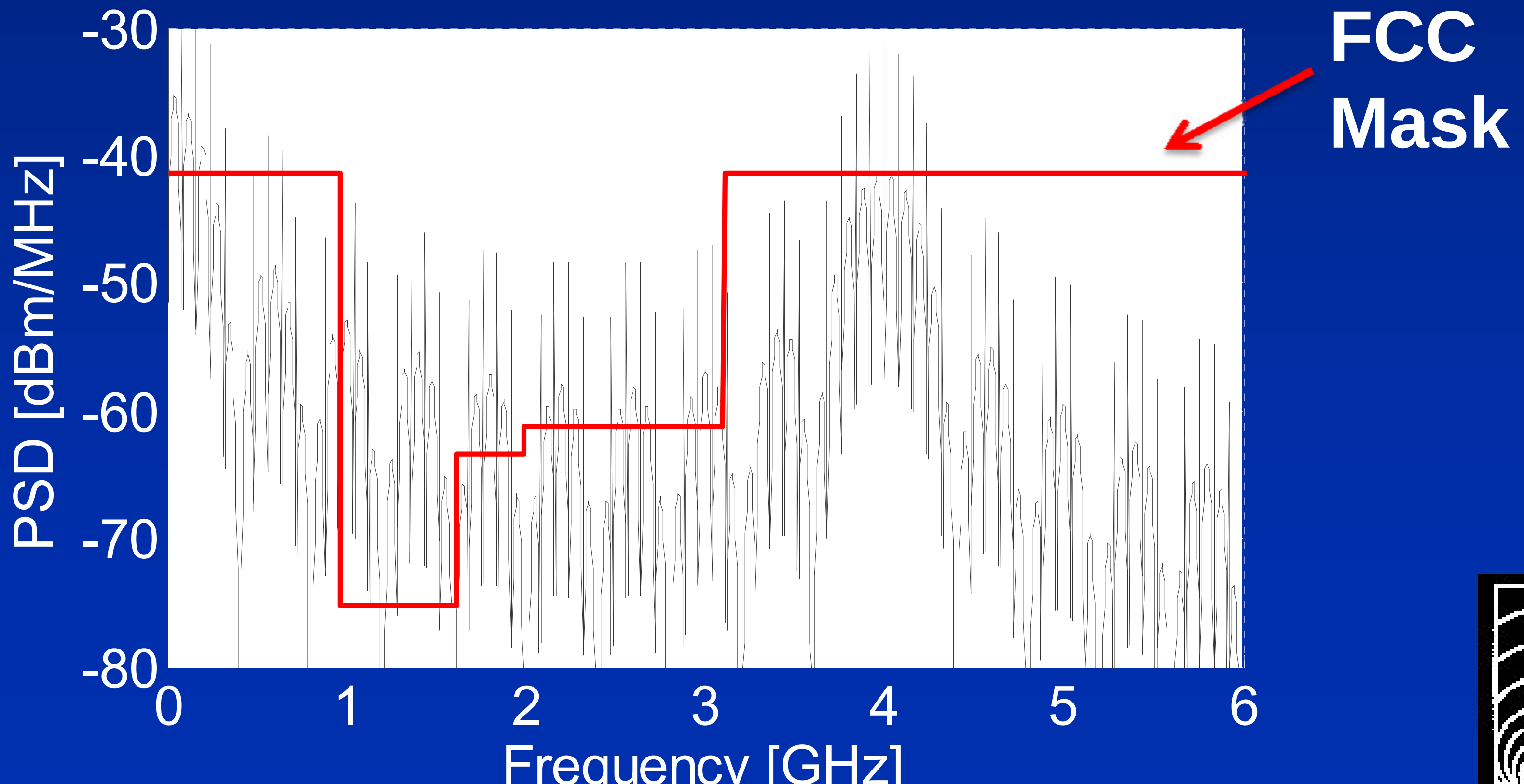


- Data can be modulated using OOK or PPM:



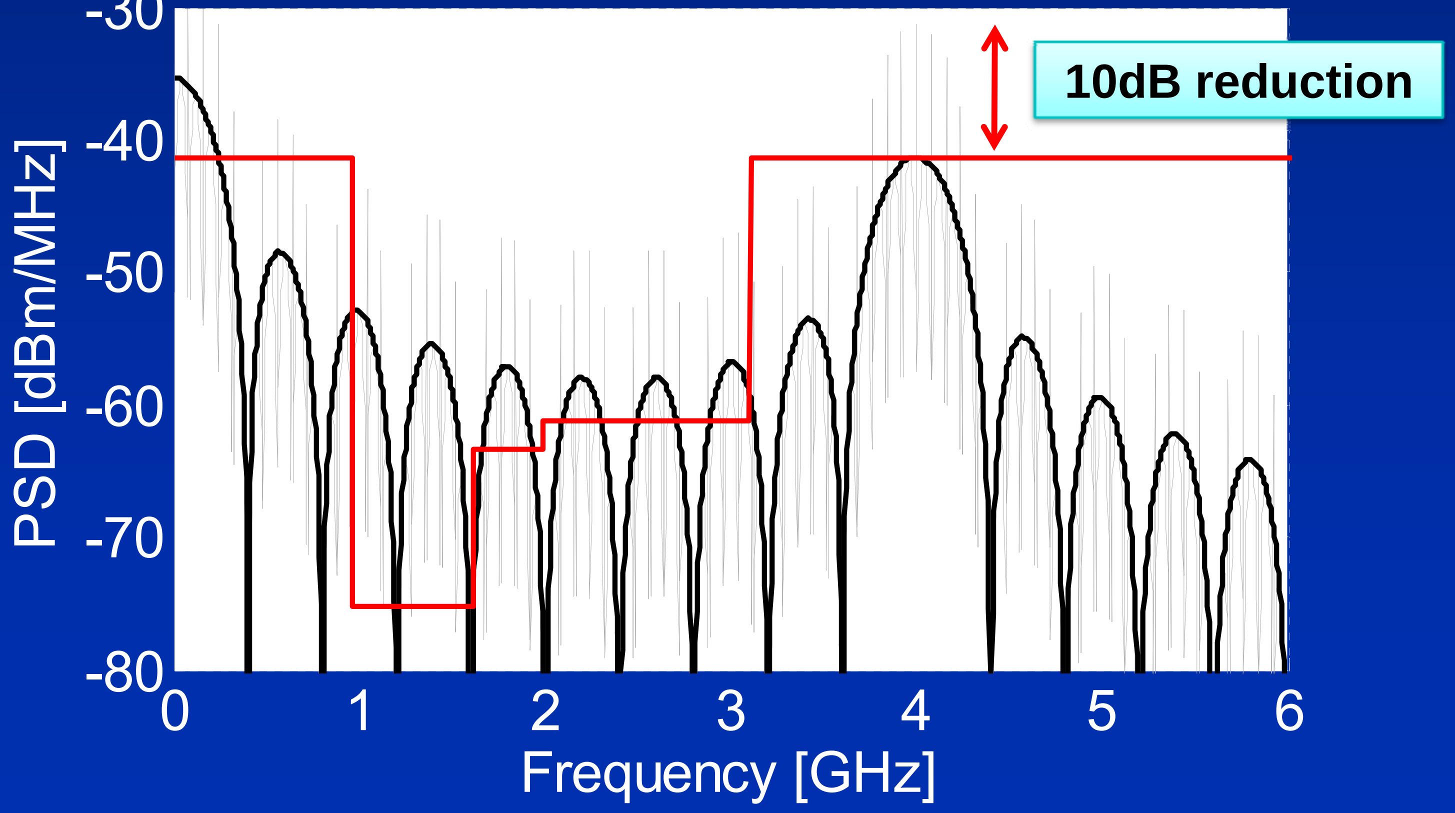
Spectral Problems

- Spectral lines
- Large sidelobes
- Large low frequency components



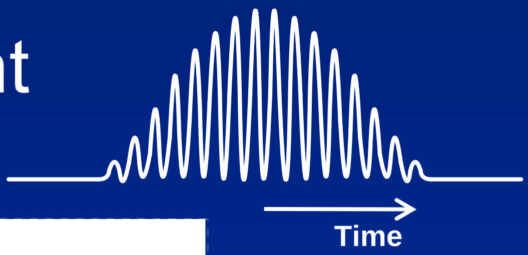
Spectral Scrambling

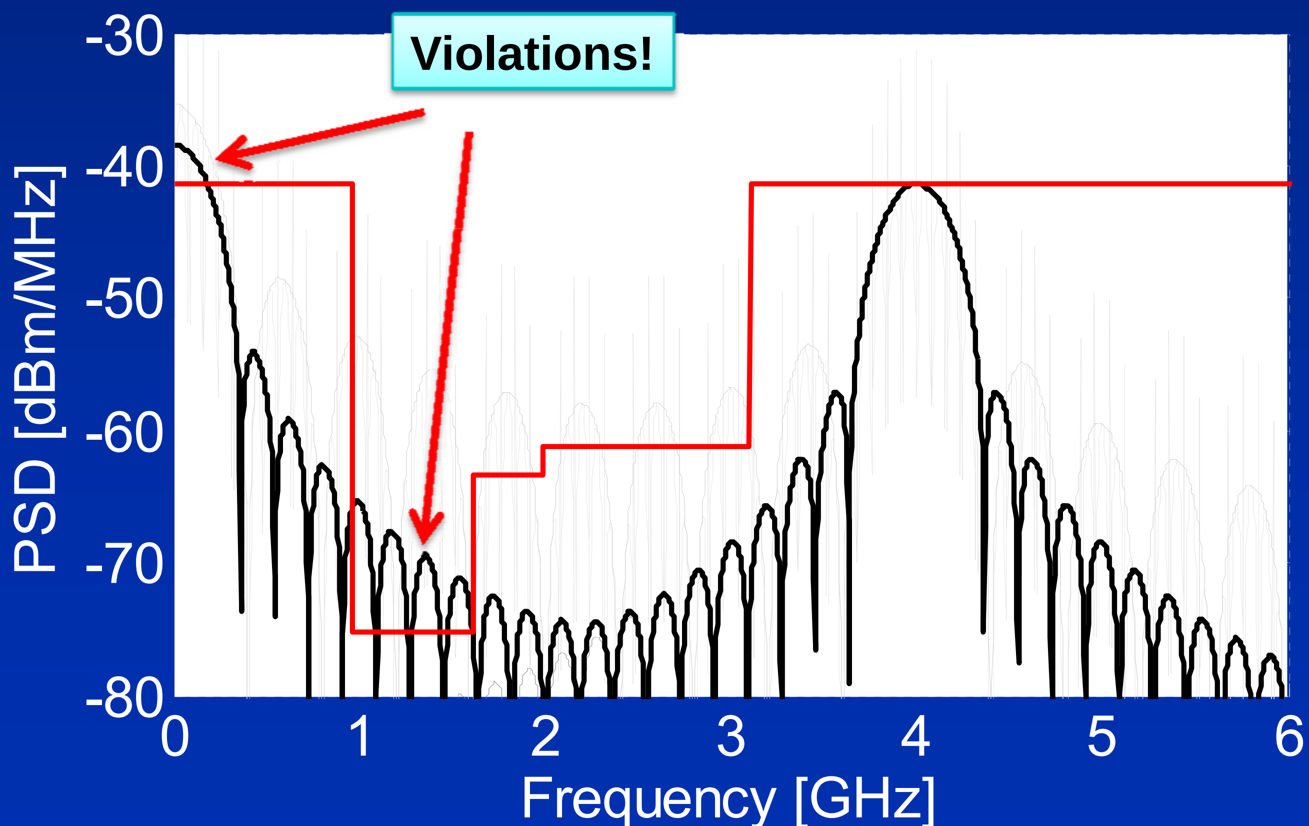
- BPSK scrambling to eliminate spectral lines
- Still have RF sidelobes + low frequency content



Pulse Shaping

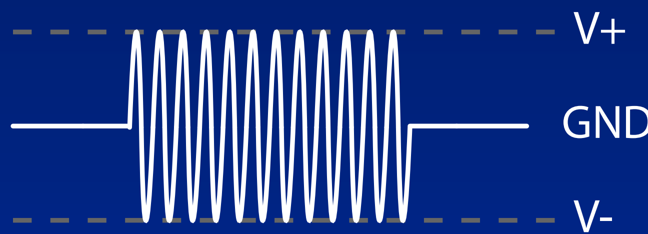
- Reduces sidelobes at RF
  - E.g.: raised-cosine shaping
  - Still have low-frequency content



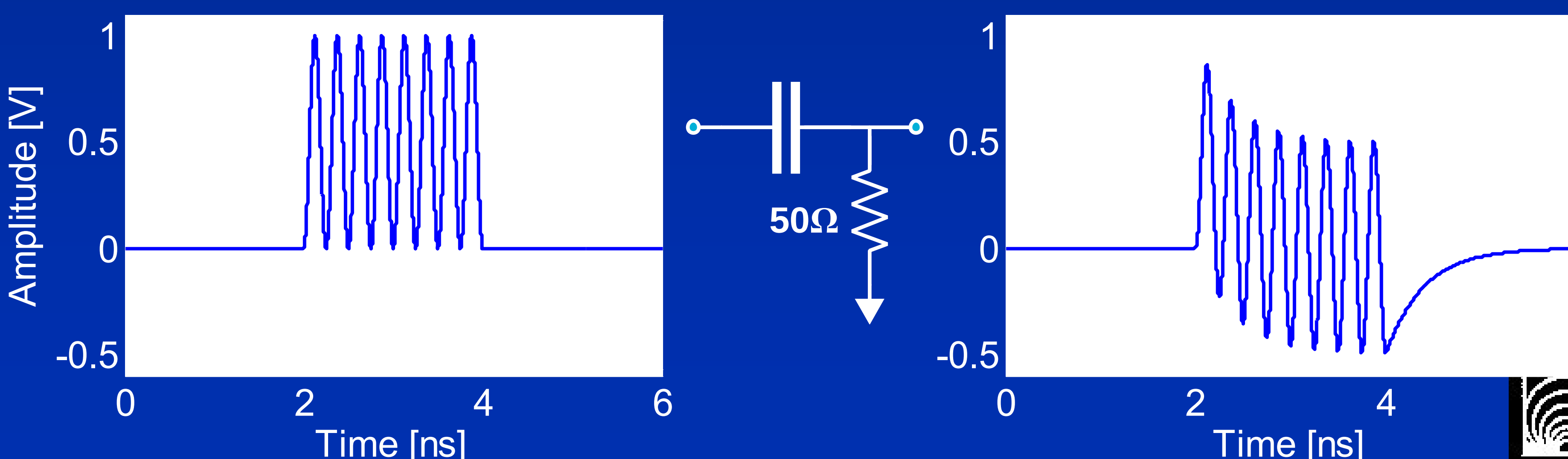


Dealing with Low Freq. Content

- Ideally, we want RF pulses with zero DC components

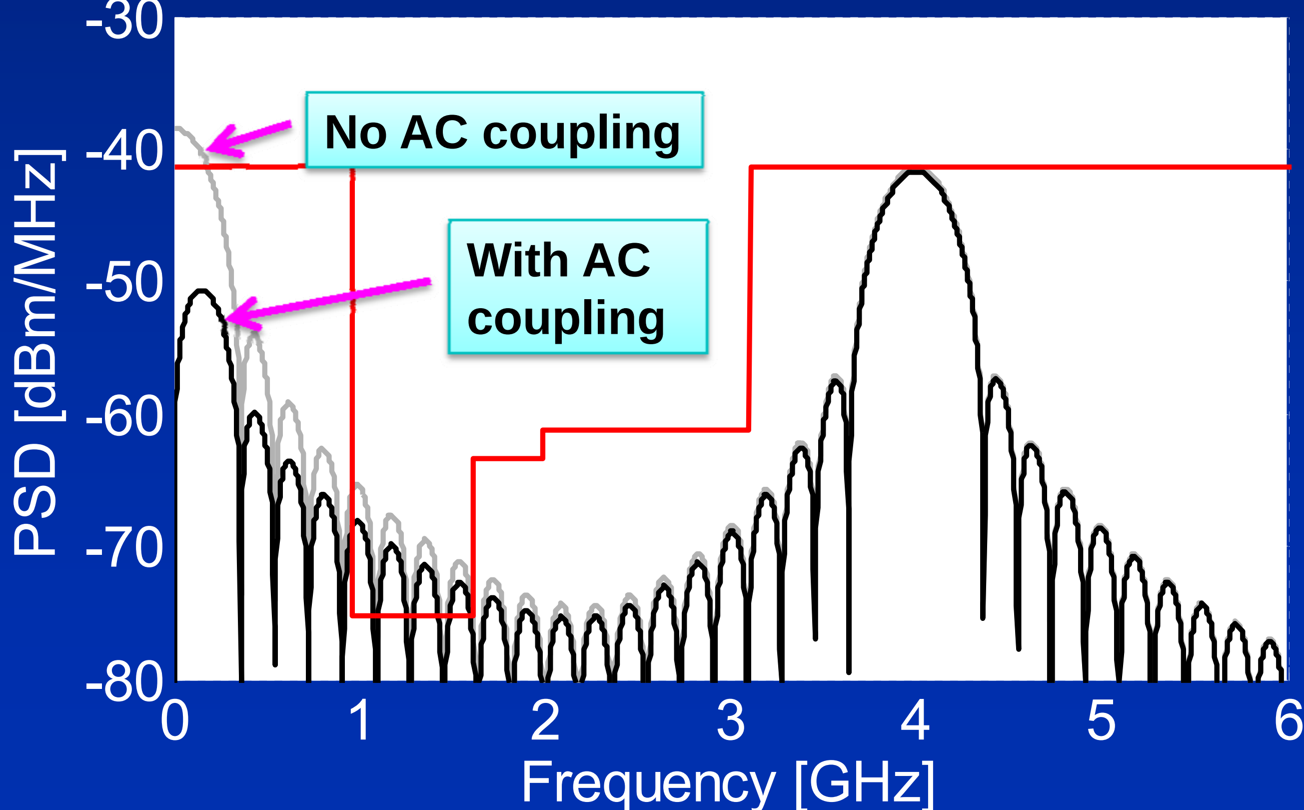


- We only have two levels to work with in single-ended digital CMOS (GND and VDD)



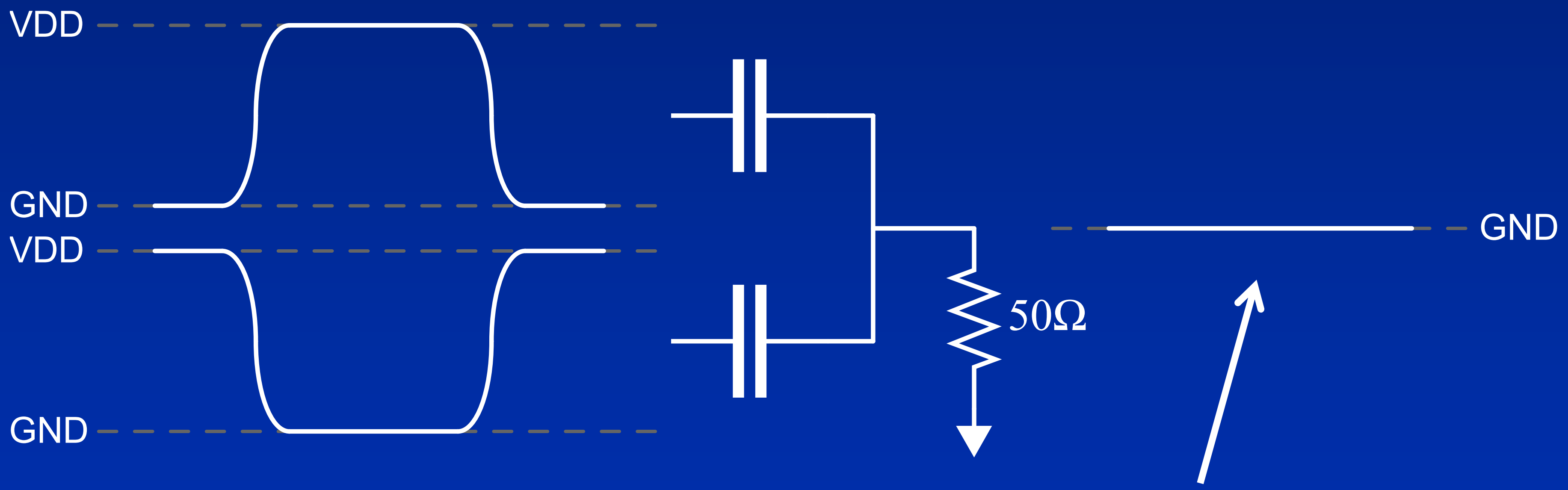
AC-Coupling: Freq. Domain

- First order filtering does not provide the required attenuation
  - Filter must have steep roll-off filter to meet FCC
  - Large off-chip component likely necessary



Eliminating Low-Freq. Content

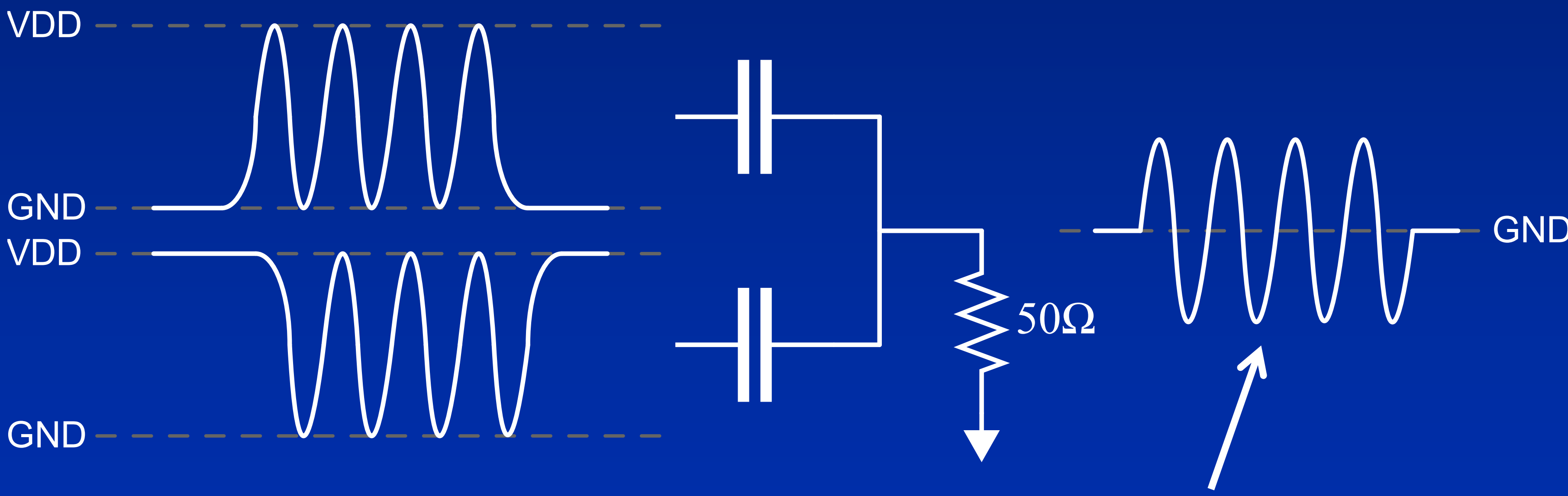
- Dual paths capacitively combined:
  - Paths start off with *opposite* DC commons-modes
  - Generate differential low-frequency pulses



Capacitors charge and discharge at the same rate – net zero voltage change on output

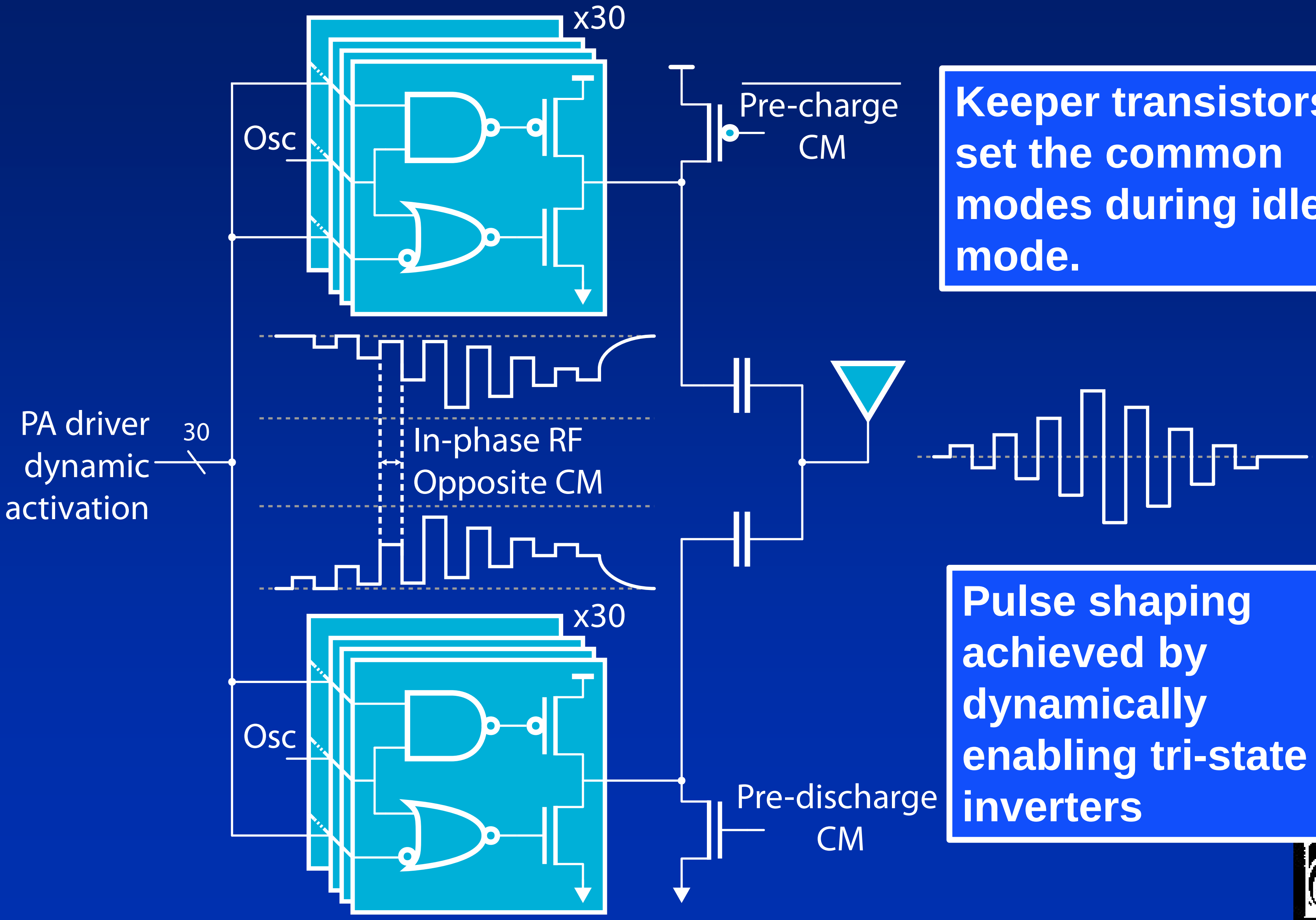
Eliminating Low-Freq. Content

- Now, add in-phase RF tones to each path
  - In-phase RF signals propagate to output



Opposite common-modes cancel, close to zero low frequency content on the output

Dual Digital Power Amplifiers

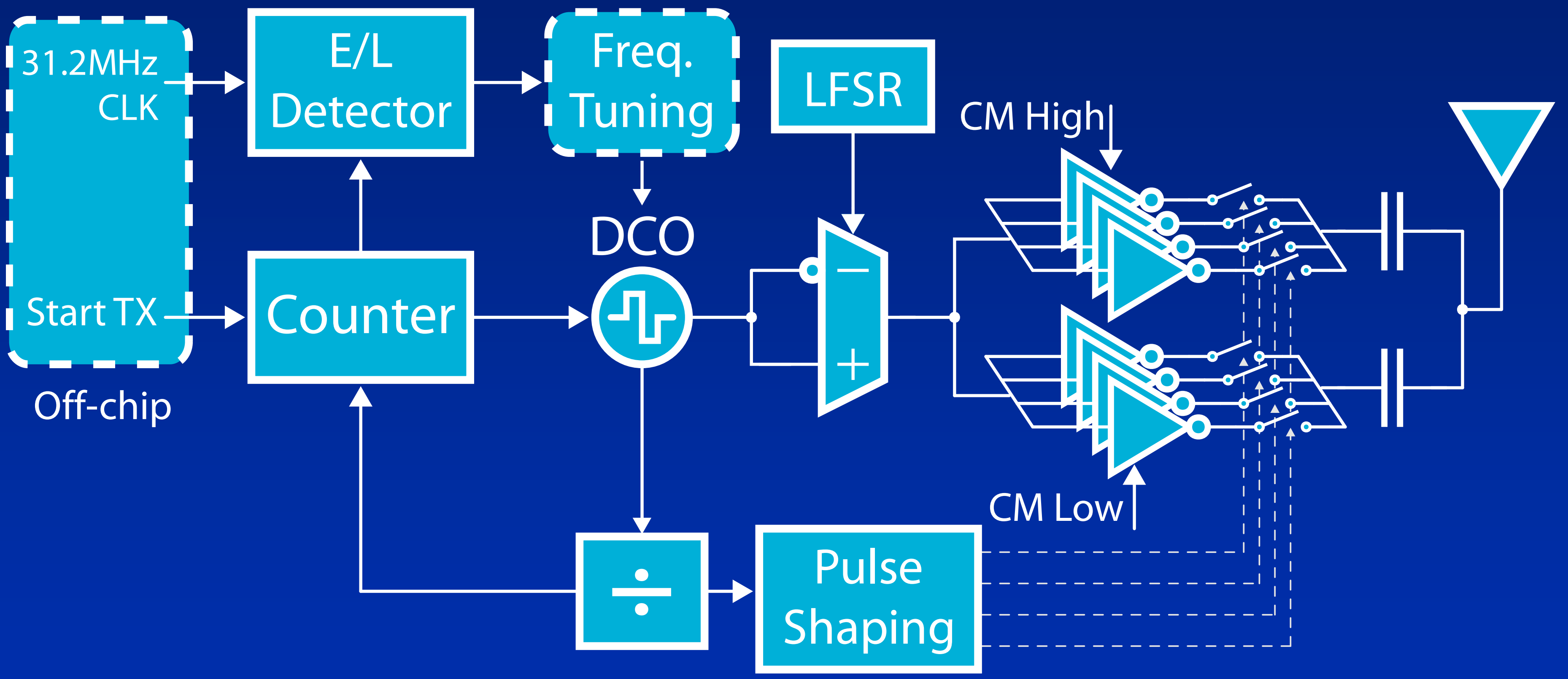


Keeper transistors set the common modes during idle mode.

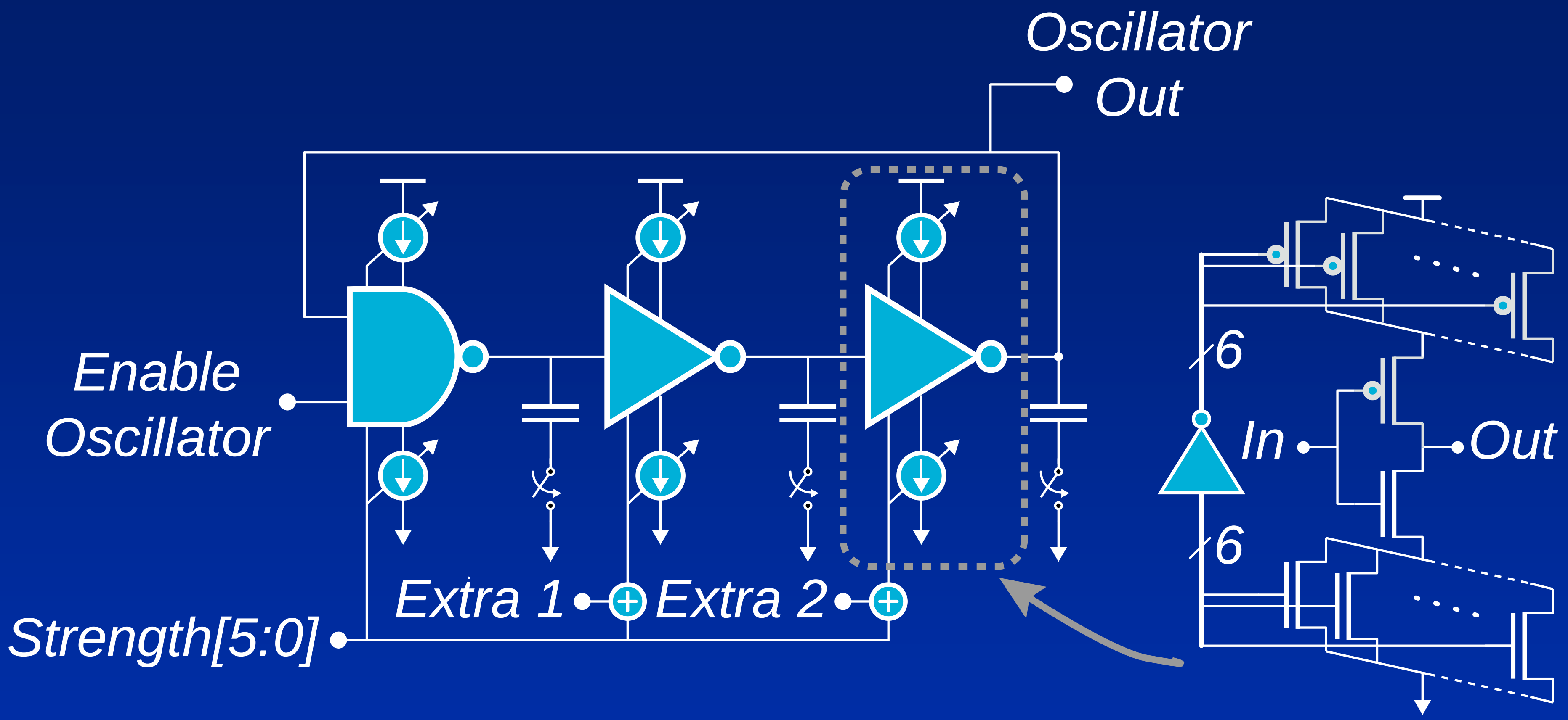
Pulse shaping achieved by dynamically enabling tri-state inverters

Transmitter Architecture

All digital!



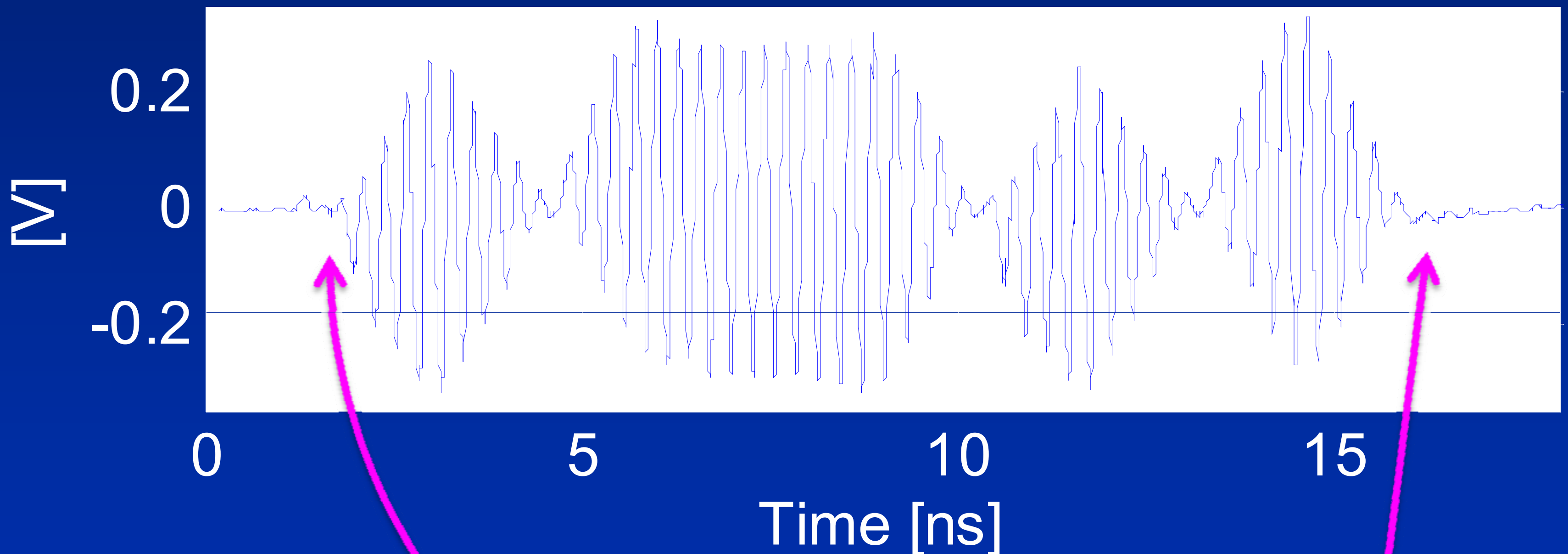
Digitally Controlled Oscillator



- ❑ Single-ended structure
- ❑ Tunable from 3-to-5GHz
- ❑ Accurate to within 2800ppm (good enough for non-coherent)

Measured Transient Waveform

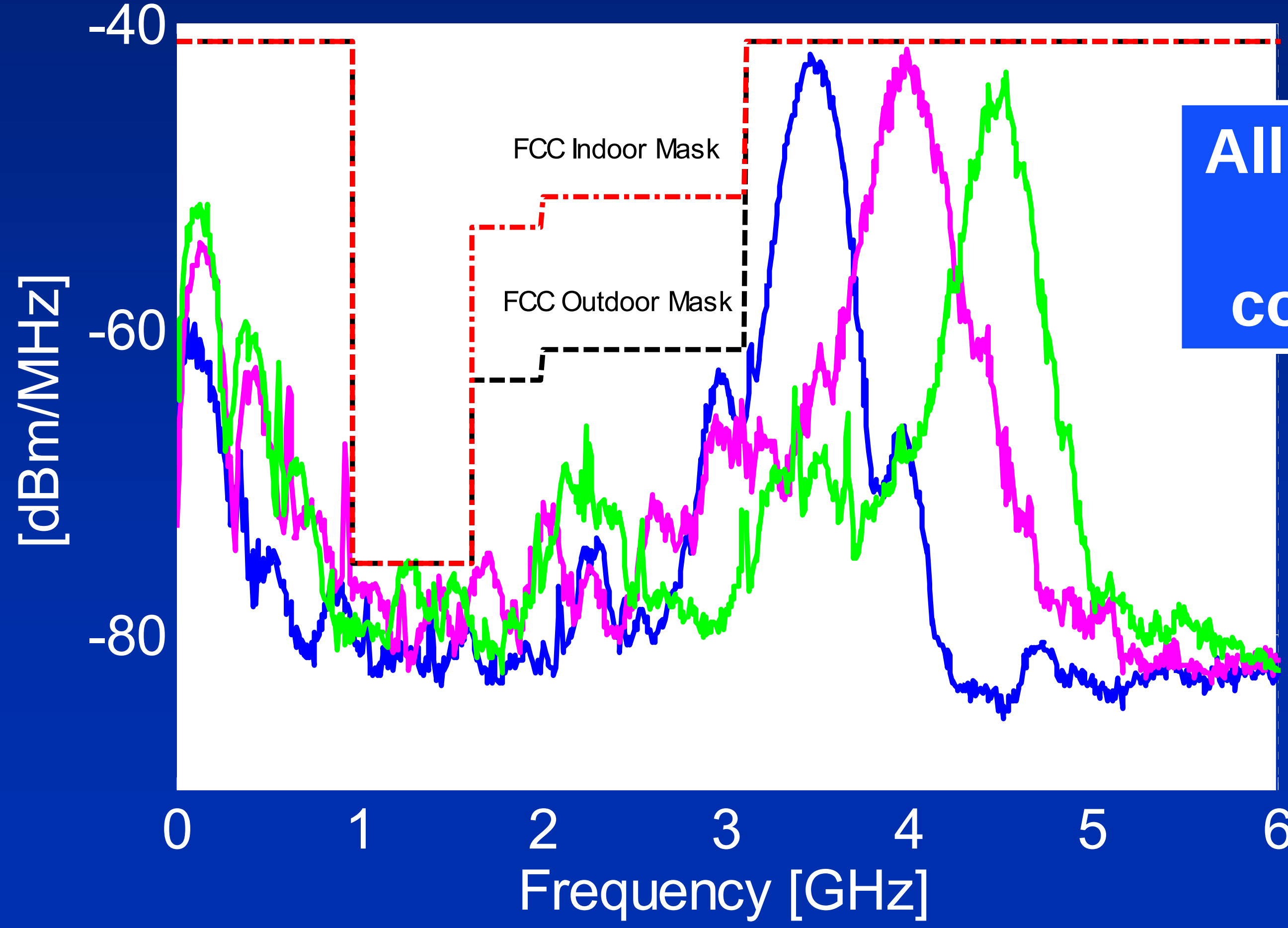
- Burst of five UWB pulses, individually BPSK-modulated



No large visible turn-on/off low-frequency transients

Measured Spectra

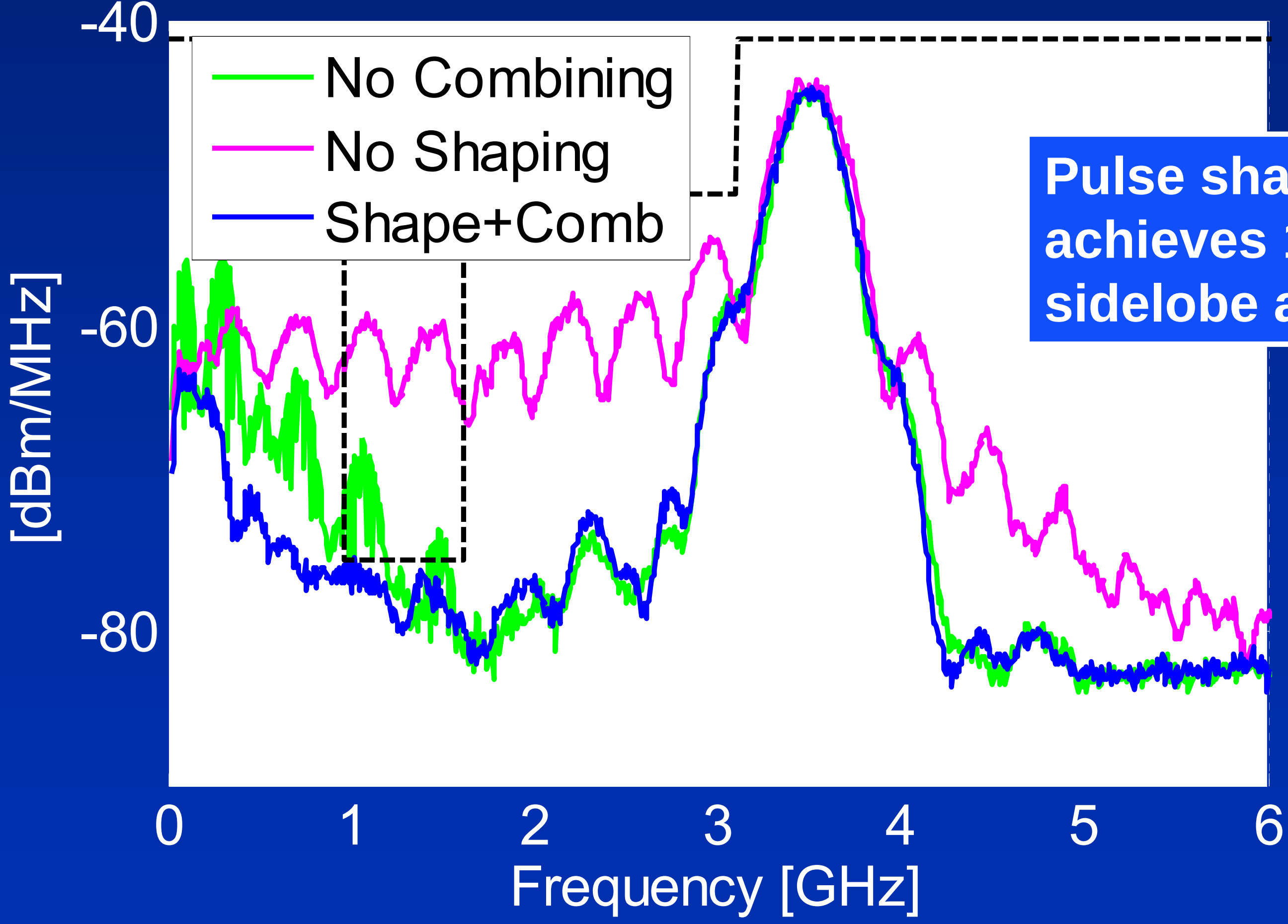
- Overlaid spectra in the 3.5, 4.0, and 4.5GHz channels



All channels FCC compliant!

Measured Spectra

- Overlaid spectra with and without shaping and/or capacitive combining



Pulse shaping achieves 15-20dB of sidelobe attenuation

Measurement Results

Technology	90nm CMOS
V_{DD}	1.0V
Core area	$0.07mm^2$
Max Data Rate	15.6Mbps
Power Consumption (100kbps–15.6Mbps)	180µW – 4.8mW
Nominal Leakage Power	124 µW
Energy per pulse (16 pulses per burst)	19pJ/pulse
RF Voltage Swing	165 mV_{pp} – 710 mV_{pp}
Turn-on time	7.2 ns

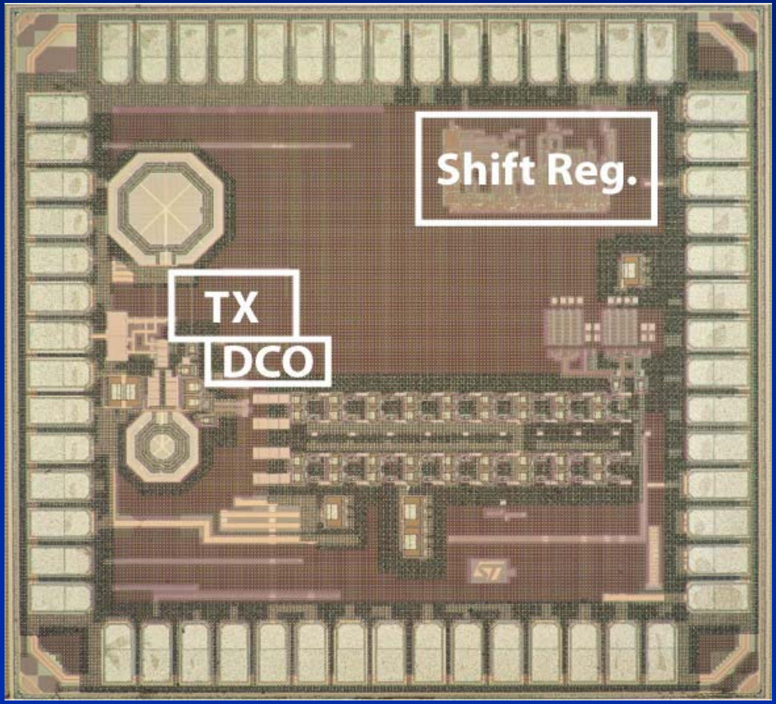
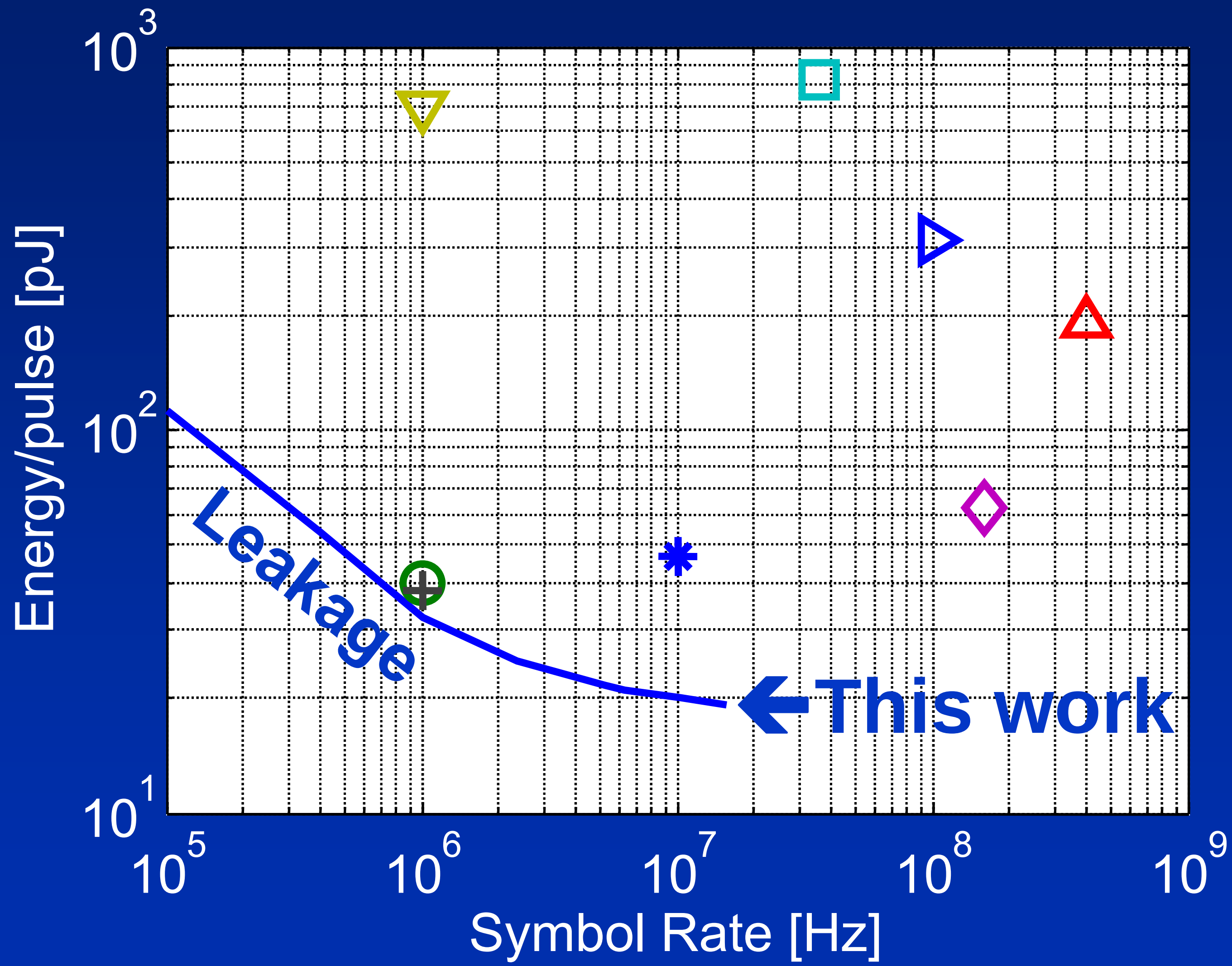


Figure of Merit



Conclusions

- All-digital Ultra-Wideband transmitter
  - Made possible by relaxed frequency tolerances
  - No static bias currents
- Energy efficient → 19pJ/pulse
- Small area → $0.07mm^2$
- No external filters required for FCC compliance
- Highly scalable in advanced CMOS processes
  - Future work: synthesizable transmitters

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