(RMO4A-2)

An Energy Efficient OOK Transceiver for Wireless Sensor Networks

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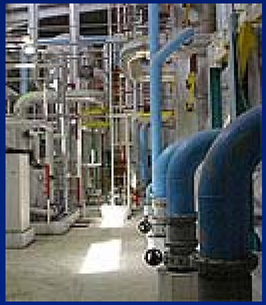
Outline

- System overview
- Receiver front end optimization
- Circuit implementation
- Measurement results

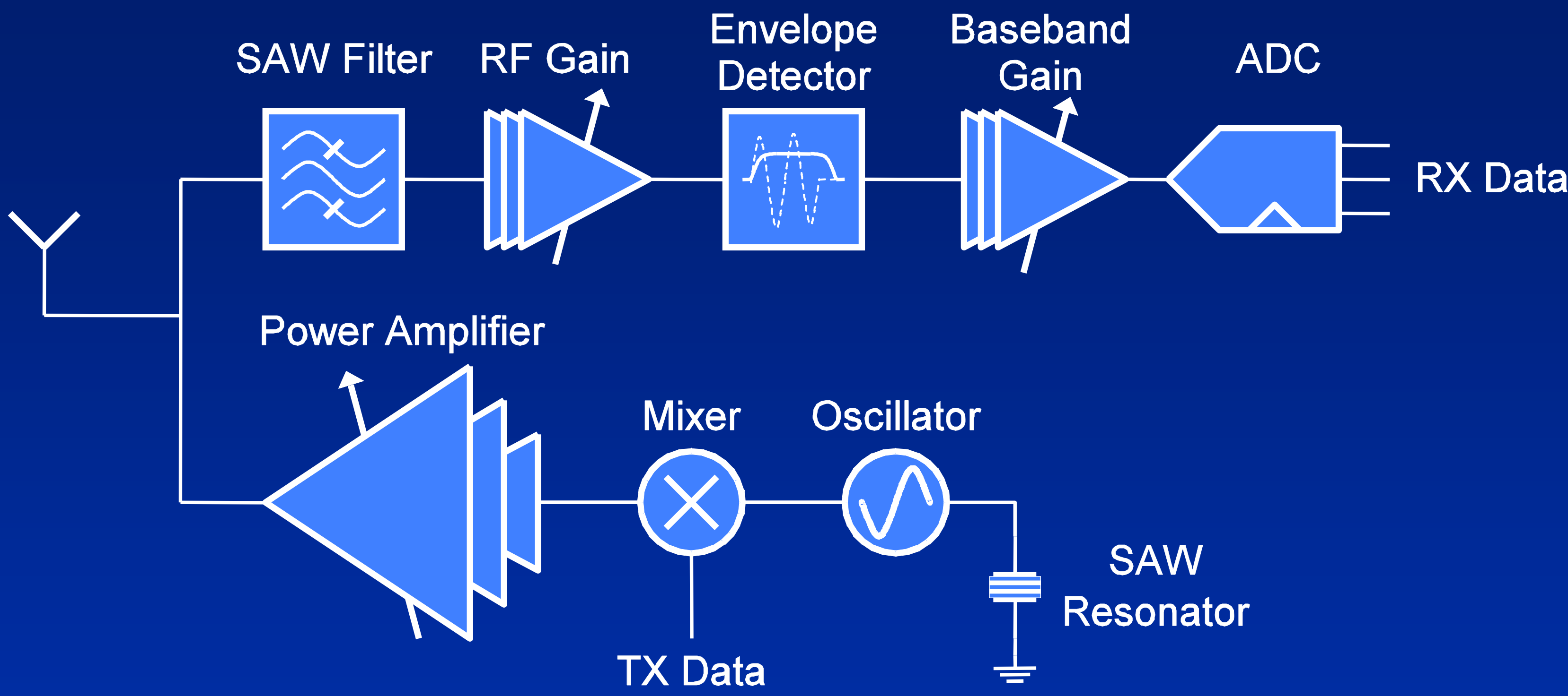
Transceivers for Sensor Networks



- Sensor network specifications:
  - Closely spaced nodes: ~10 meters apart
  - Average power: 10 μW to a few mW
  - Data rate: <10 kbps
- Both power *and* energy efficiency critical
- Transceiver must be duty cycled

Goal: *To design a custom, energy-efficient wireless transceiver for wireless sensor networks*

Architecture



- On-off keying (OOK) modulation
- 1 Mbps at 916.5 MHz carrier

Architecture

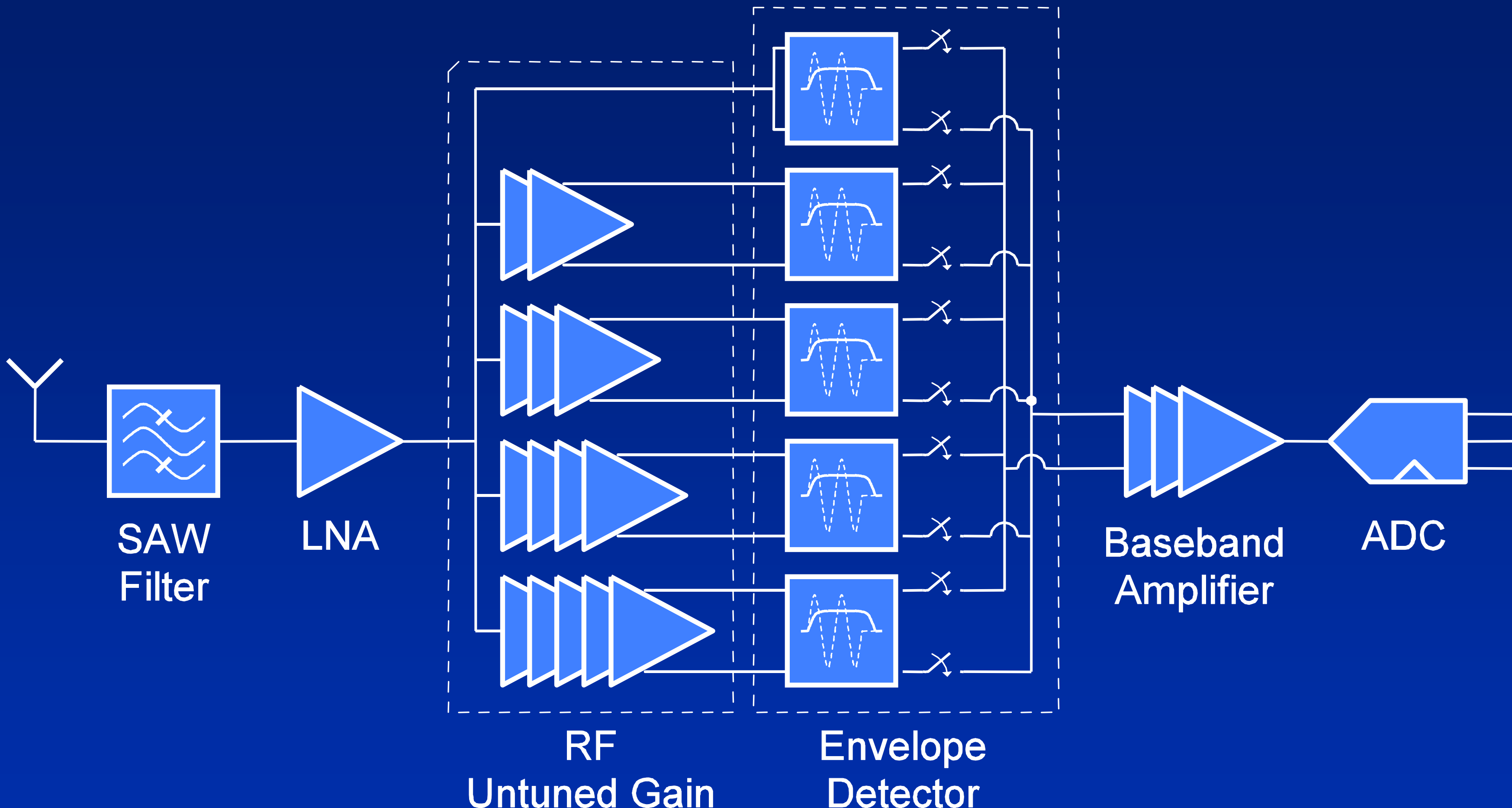
Advantages

- Fast RX startup time
- No oscillator required for receiver
- Receiver circuit power scales with gain
- No PLL required for transmitter

Disadvantages

- Higher SNR required
- Single channel is susceptible to interferers
- Requires offchip SAW components
- Significant RF gain is required in receiver

Scalable Receiver

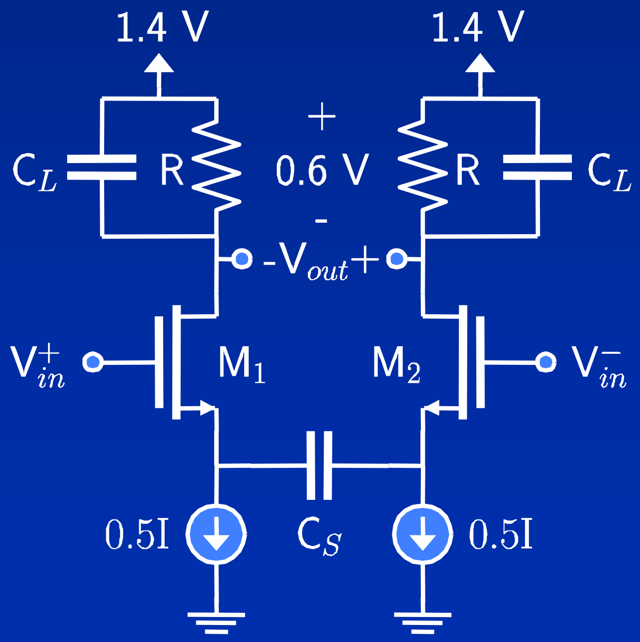


RF and baseband gain scalable to achieve optimum energy efficiency

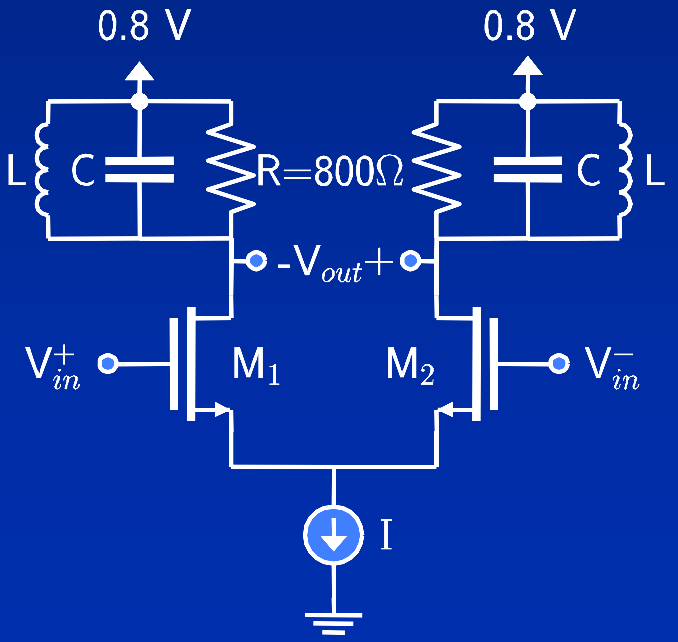
RF Gain – Untuned vs. Tuned

- What is the most energy efficient way to generate 45dB of RF gain?

Untuned RF gain



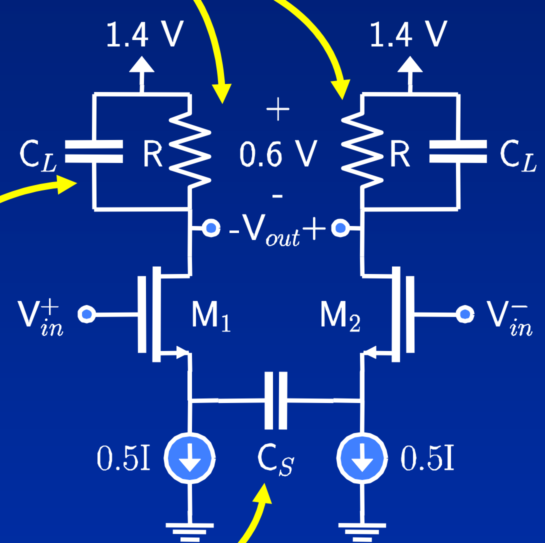
Tuned RF gain



Untuned RF Amplifier

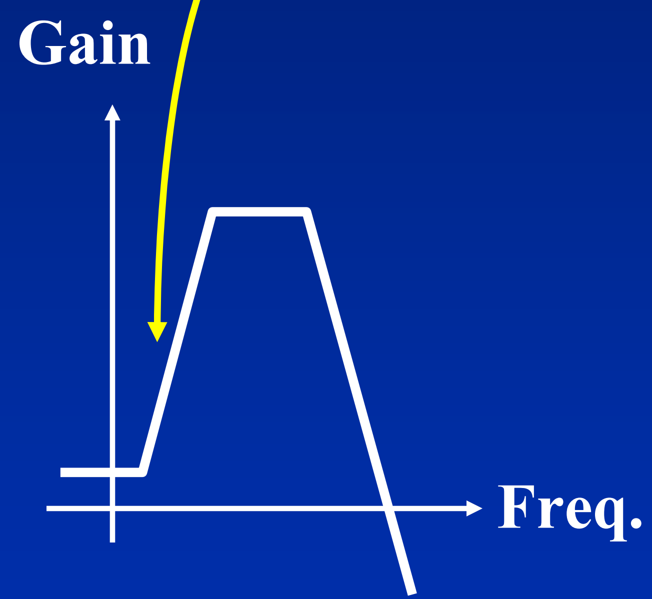
Resistors sized for noise constraints

No significant load inductors or capacitors



Input ac coupling capacitor at source allows for minimal gain reduction due to parasitics

Input low frequency noise filtered



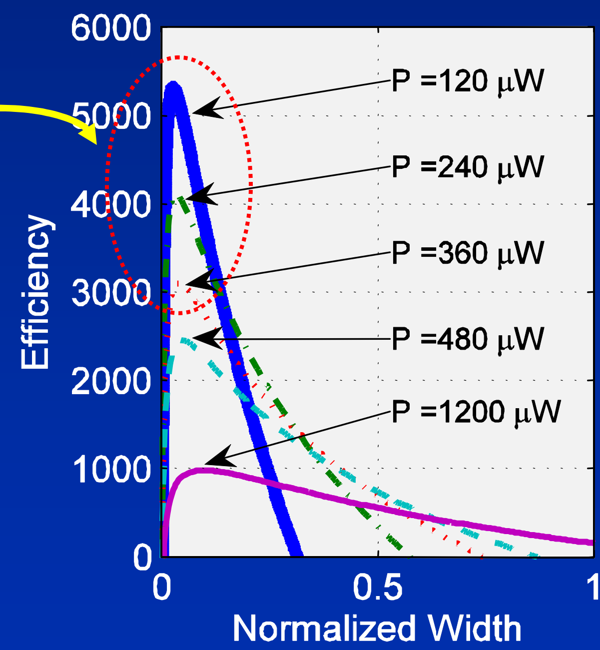
RF Gain - Optimization

Efficiency Metric:

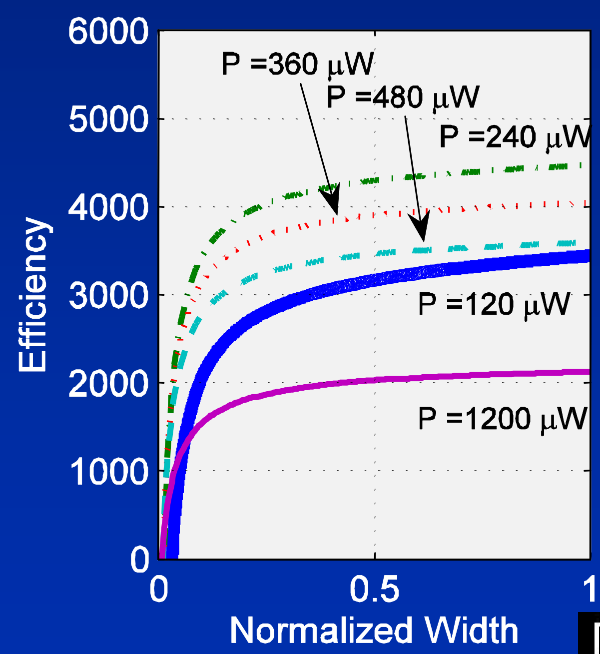
$$\frac{\log(Gain)}{Power}$$

Comparable efficiency to tuned gain

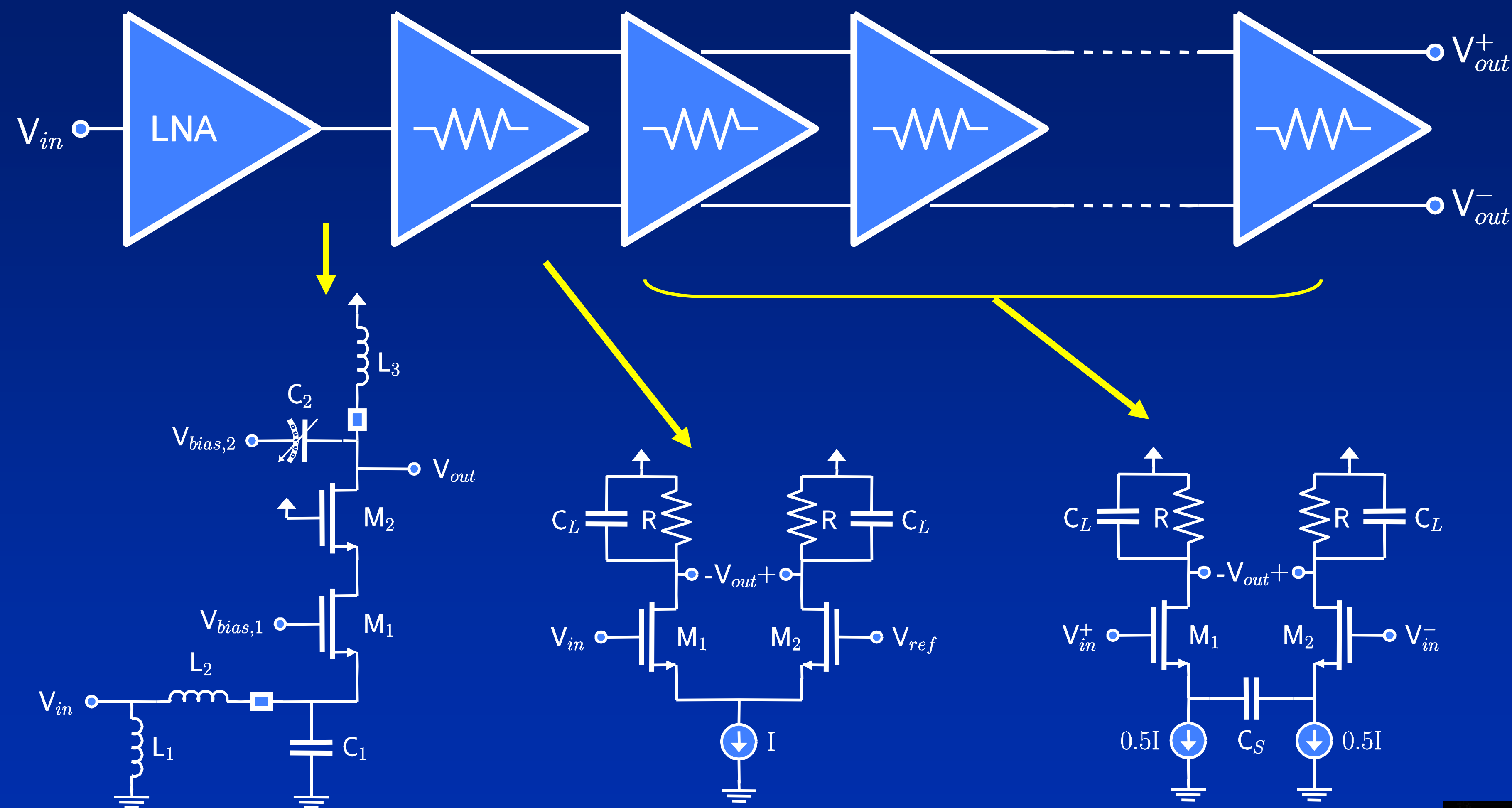
Efficiency of untuned gain



Efficiency of tuned gain



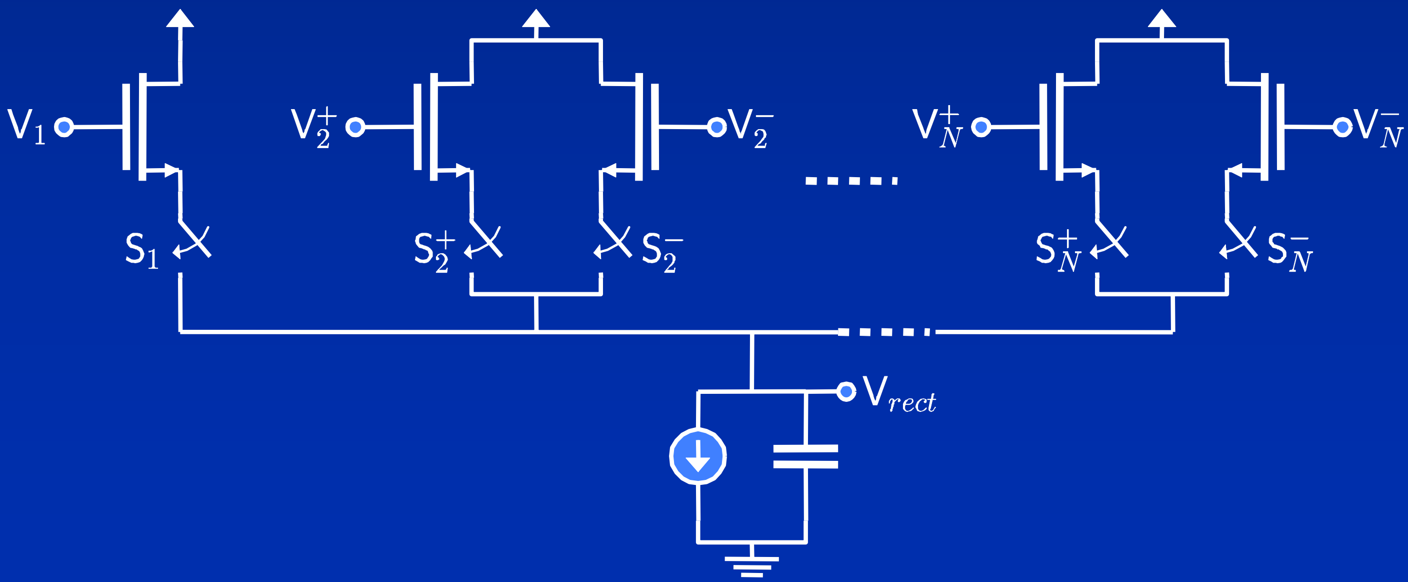
RF Front End Architecture



Early stages supplied additional current to meet noise constraints

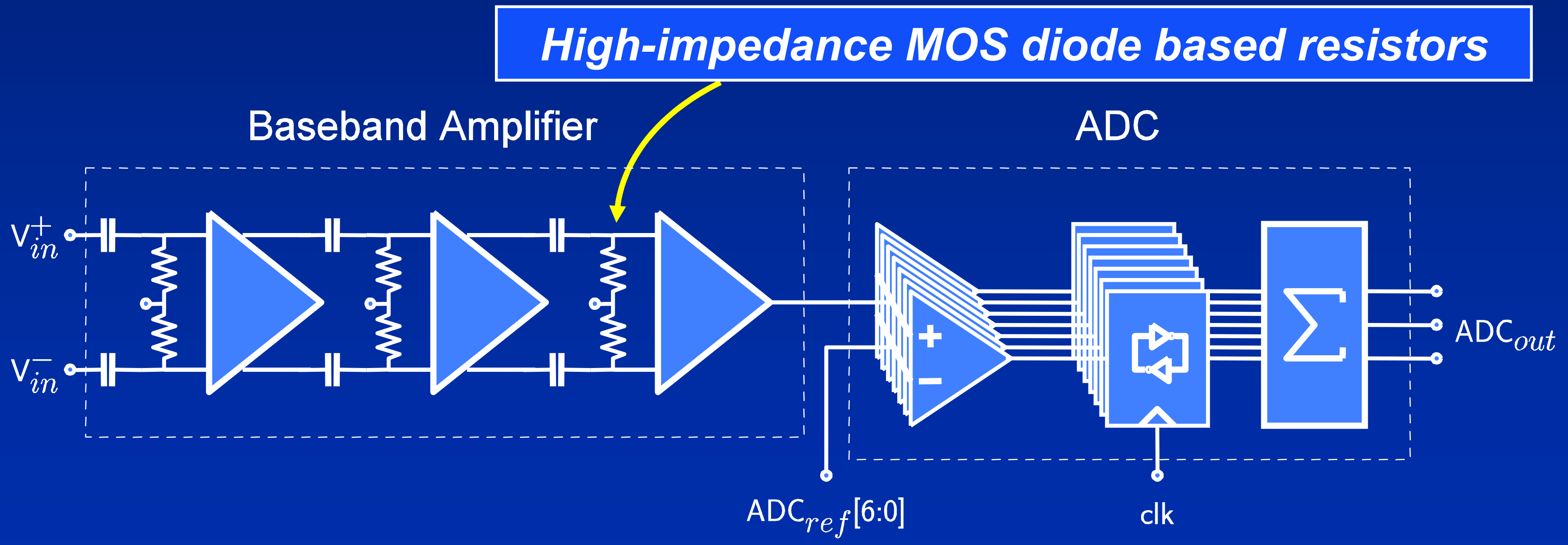
Envelope Detector

- Envelope detector is a differential pair, with the output at the source terminal
- There are multiple inputs, each corresponding to a different RF gain setting



Baseband Amplifier and ADC

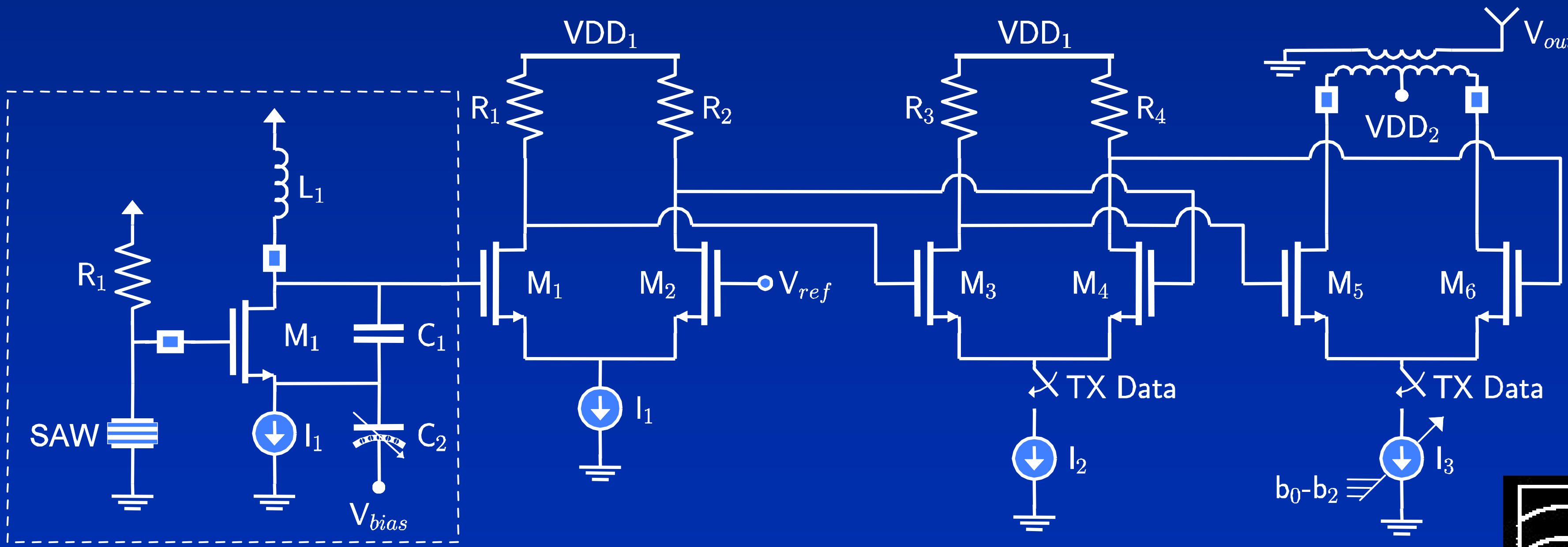
- 3-stage baseband amplifier
- ADC is 8 MSPS, 3-bit flash converter



Open-loop amplifiers with passive offset compensation for low power operation

Transmitter

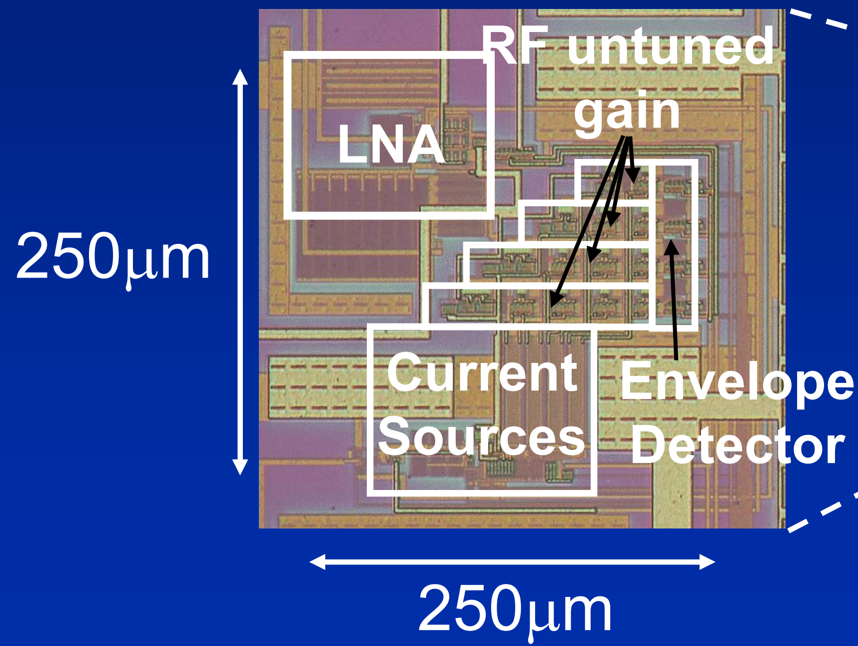
- Mixer integrated with power amplifier
- Scalable P_{out} from -11.4 dBm to -2.2 dBm
- Maximum power efficiency of 6.9%

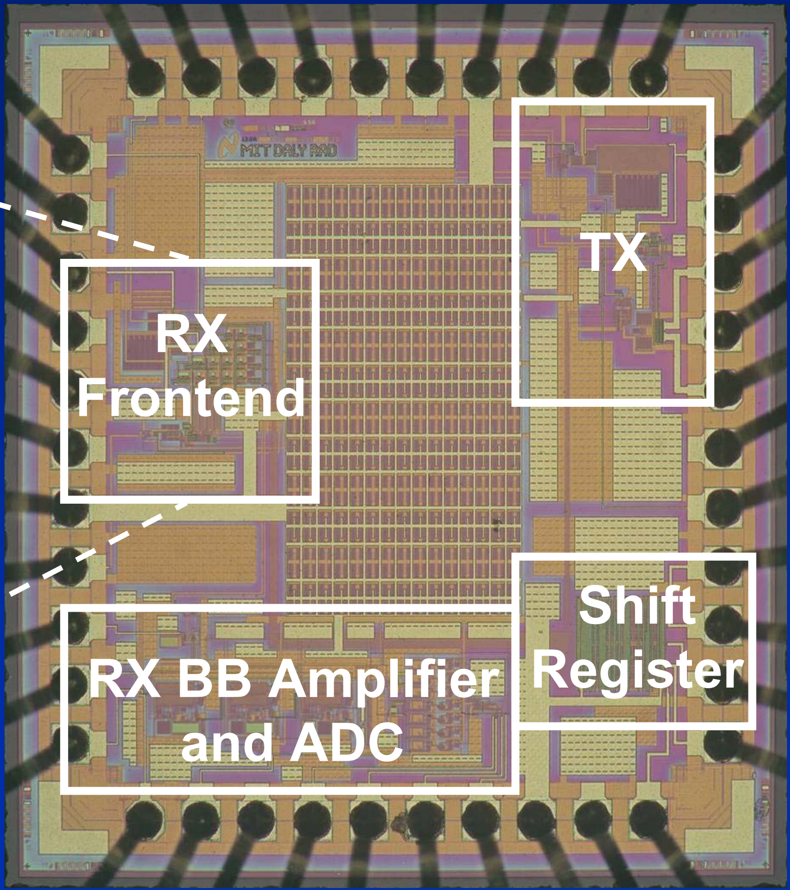


SAW Stabilized Oscillator

Die Photo

1.3mm by 1.4mm
Active Area: $0.27mm^2$



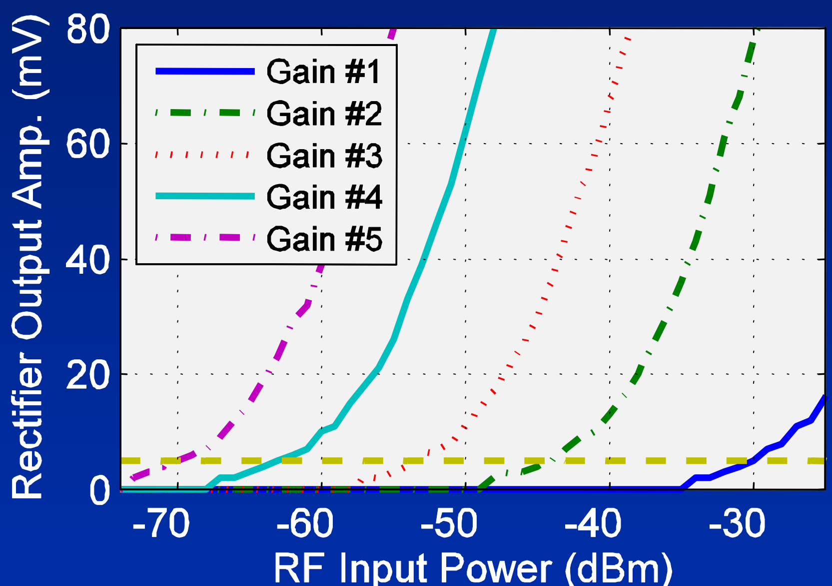


Measured Results

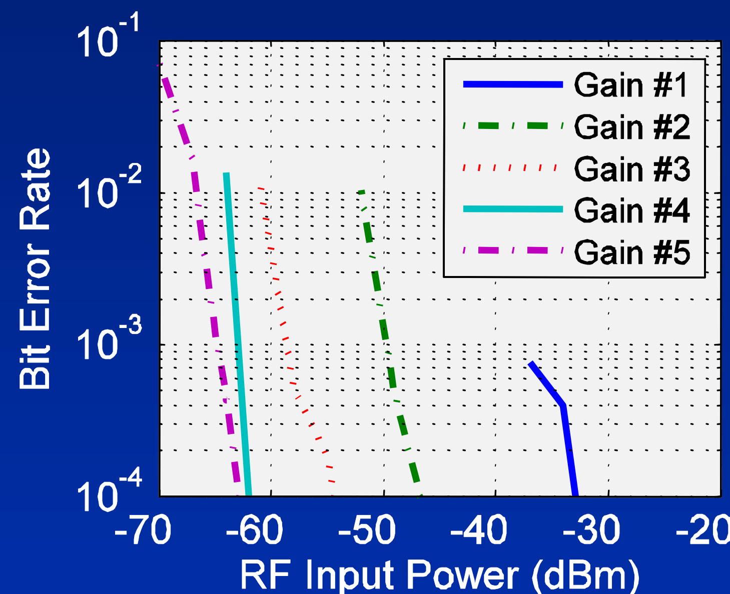
Specifications							
Data Rate	1 Mbps						
Center Frequency	916.5 MHz						
Technology	0.18μm CMOS						
Die Area	1.3mm by 1.4mm						
Receiver (5 gain settings)							
Power consumption (mW)	2.6	2.4	1.7	1.2	0.5		
Sensitivity at 10^{-3} BER (dBm)	-65	-62	-58	-49	-37		
Startup time	2.5μs						
Transmitter (7 power settings)							
Power consumption (mW)	3.8	4.8	5.8	6.7	7.6	8.3	9.1
Output Power (dBm)	-11.4	-7.2	-4.9	-3.6	-2.9	-2.4	-2.2
Startup time	<60μs						

Receiver Results

Rectifier output versus RF input power



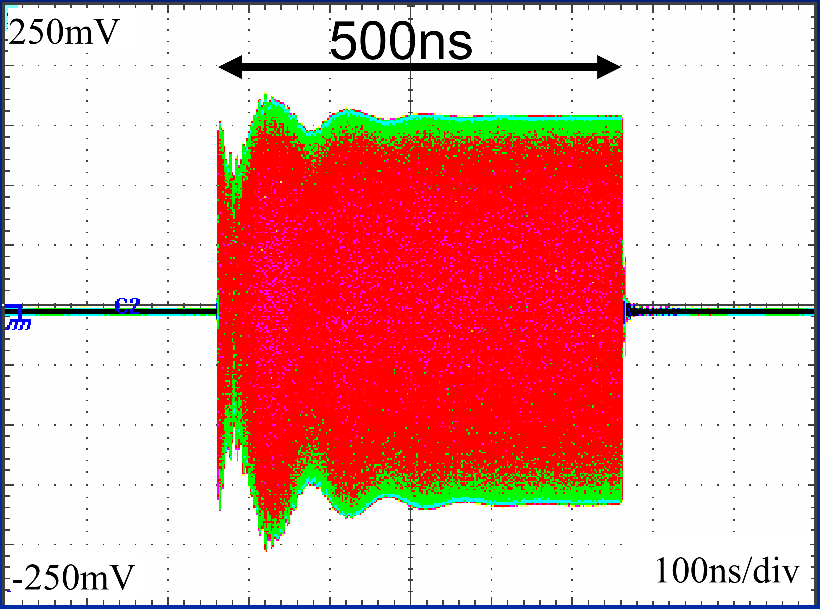
BER versus RF input power



- BER limited by RF noise, not gain at small input power levels

Transmitter Results

Transient Response

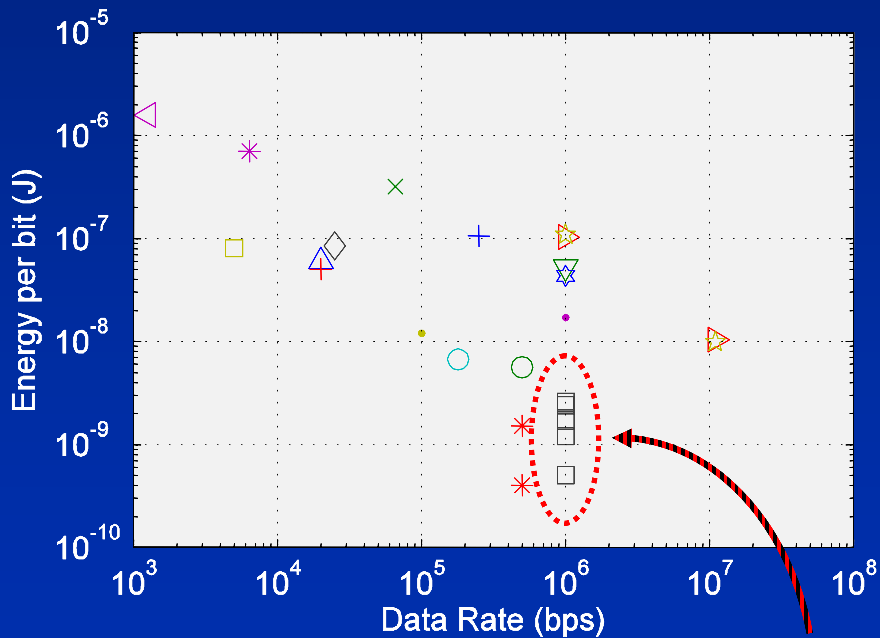


- Data is Manchester encoded to remove dc content

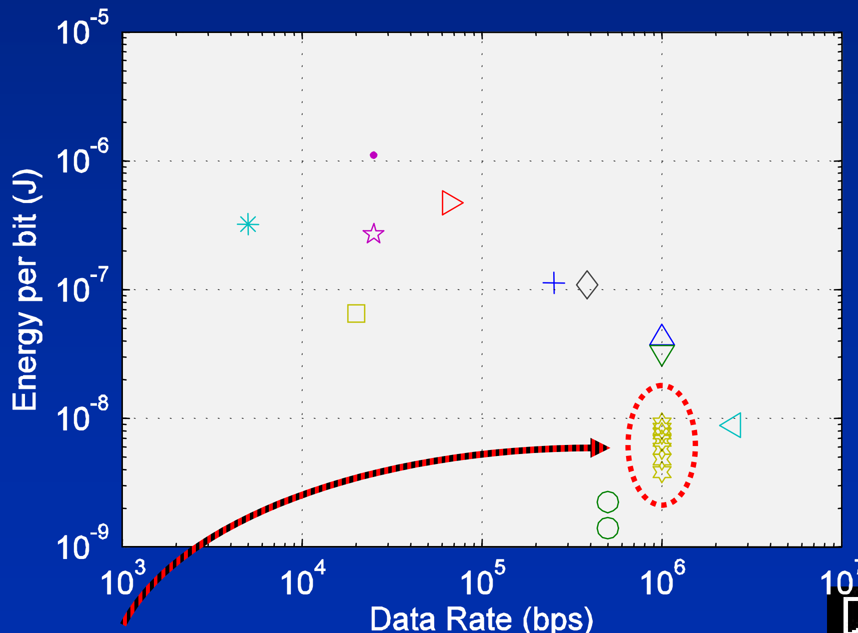
Energy Per Bit Ratio

- For 50 bit packet, startup energy overhead:
  - RX overhead of 5%, TX overhead of 25%

Receiver



Transmitter



This work

Summary

- An energy-efficient, highly scalable transceiver has been designed for sensor networks
- It achieves a minimum energy per bit ratio of: 0.5 nJ/bit for the RX and 3.8 nJ/bit for the TX
- The architecture lends itself well to process scaling

Acknowledgements

- DARPA PAC/C
- National Semiconductor for chip fabrication
- NSERC Postgraduate Scholarship