An Energy Efficient 1 Gb/s, 6-to-10 GHz CMOS IR-UWB Transmitter and Receiver With Embedded On-Chip Antenna

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EECS 522 Analog Integrated Circuits

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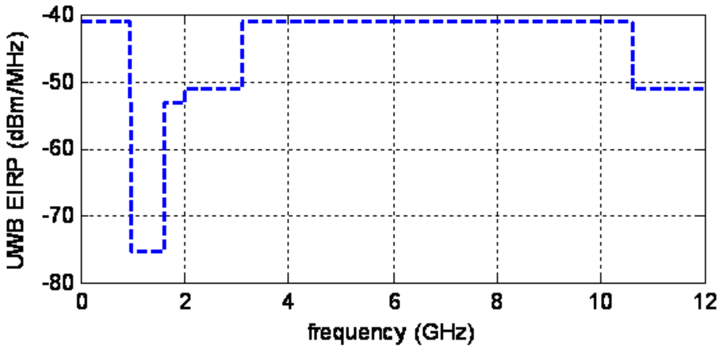
OUTLINES

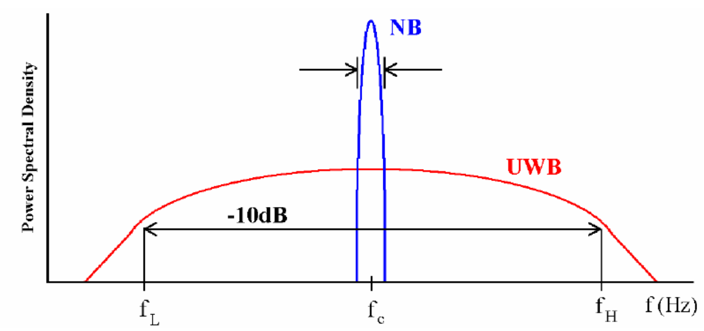
- **INTRODUCTION**
  - *What and Why UWB?*
  - *Comparison with other Schemes*
  - *How can UWB open new application opportunities?*
- **Overall System Architecture**
- **Ultra-wideband Transmitter**
  - *Data Modulation and Pulse Generation*
  - *Fully-Integrated On-Chip Antenna*
  - *Power Amplifier and FCC Mask Compliance*
- **Ultra-wideband Receiver**
  - *On-Chip Active Bandpass Filter*
  - *Low-Power, Low-Noise Amplifier*
- **Results and Comparison with Previous Work**
- **Conclusions and Future Directions**

Introduction

What is Impulse-Radio Ultra-Wideband (IR-UWB)?

- *Short-range, High-Bandwidth Communication*
- *Bandwidth (BW):* ***3.1 – 10.6 GHz***
- *Power Spectral Density Emission:* ***<-41.3 dBm/MHz***
- *Emitted Signal BW (-10dB):* ***> 500 MHz or 20% of*** f_C





Why UWB?

- Low-Power, Low-cost (min RF electronics)
- Small Interference to other Narrow-band Systems (e.g WLAN, Wi-Fi)

Introduction

Comparison with Others

- *Example: for Bio-Implantable Devices*

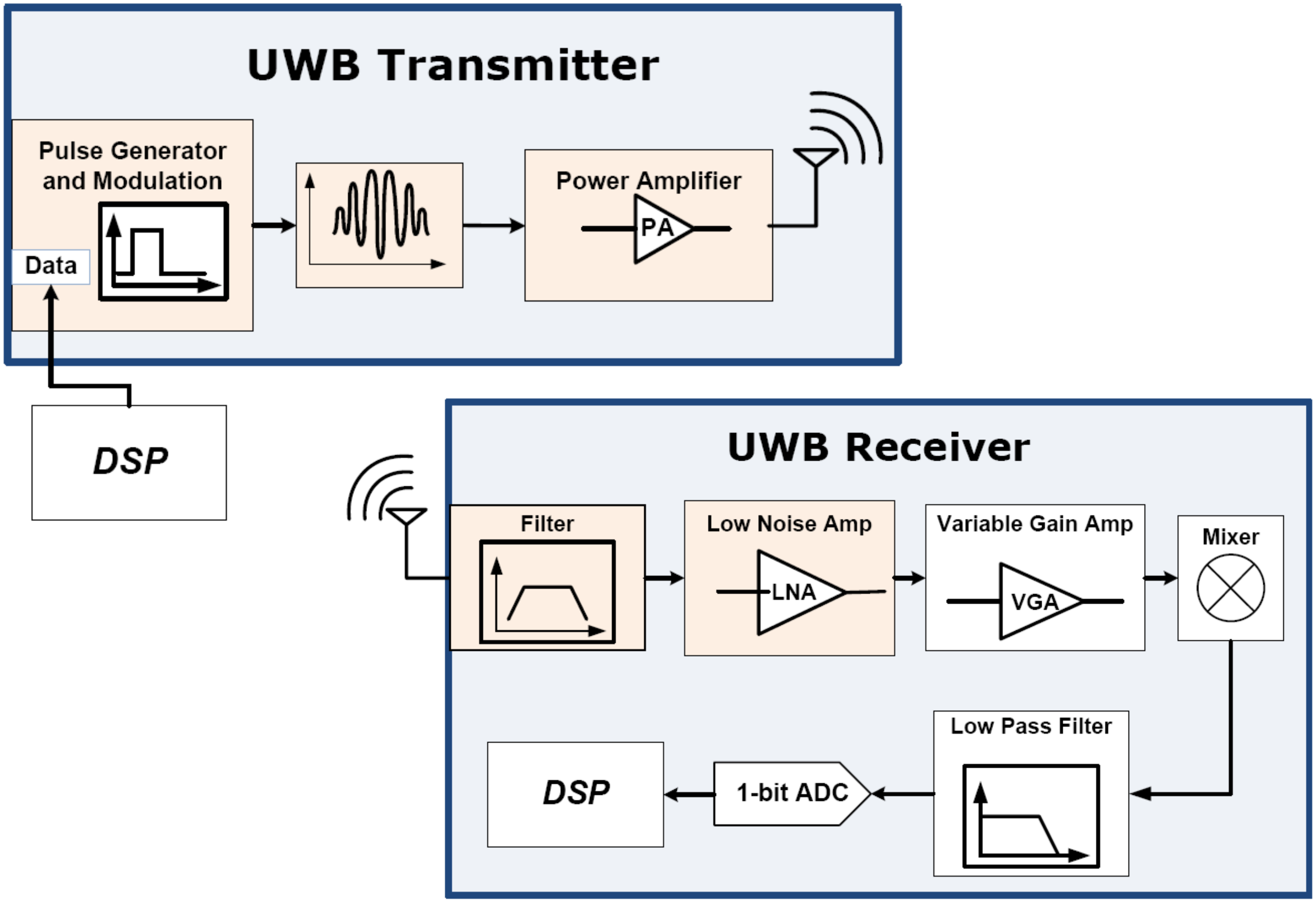
Group	Design	Frequency	Bandwidth	Data Rate	Energy/bit	Process	Size mm^2
Harrison' 04	FM	433 MHz	22 MHz	Test 300Hz	**21.2 nJ/b**	0.5 µm	1.29 mm^2
Najafi'05	FM	96.5 MHz	4 MHz	3-CH	**N/A**	1.5 µm	0.21 mm^2
Chae'08	OOK-PPM UWB	4.2 GHz	1 GHz	90 MHz	**17 pJ/b**	0.35 µm	N/A
Kuroda'09	BPSK UWB	6-10 GHz	4 GHz	750 MHz	**41 pJ/b**	0.18 µm	0.29 mm^2

New Applications?

- Low-power for more number of channels
- Less interference to other microsystem components
- Small, simple circuit for the transmission (*less area requirements*)
- ***Bio-Implants, Wireless Sensor Nodes, and Integrated Microsystems***

Overall System Architecture

Overall System Architecture

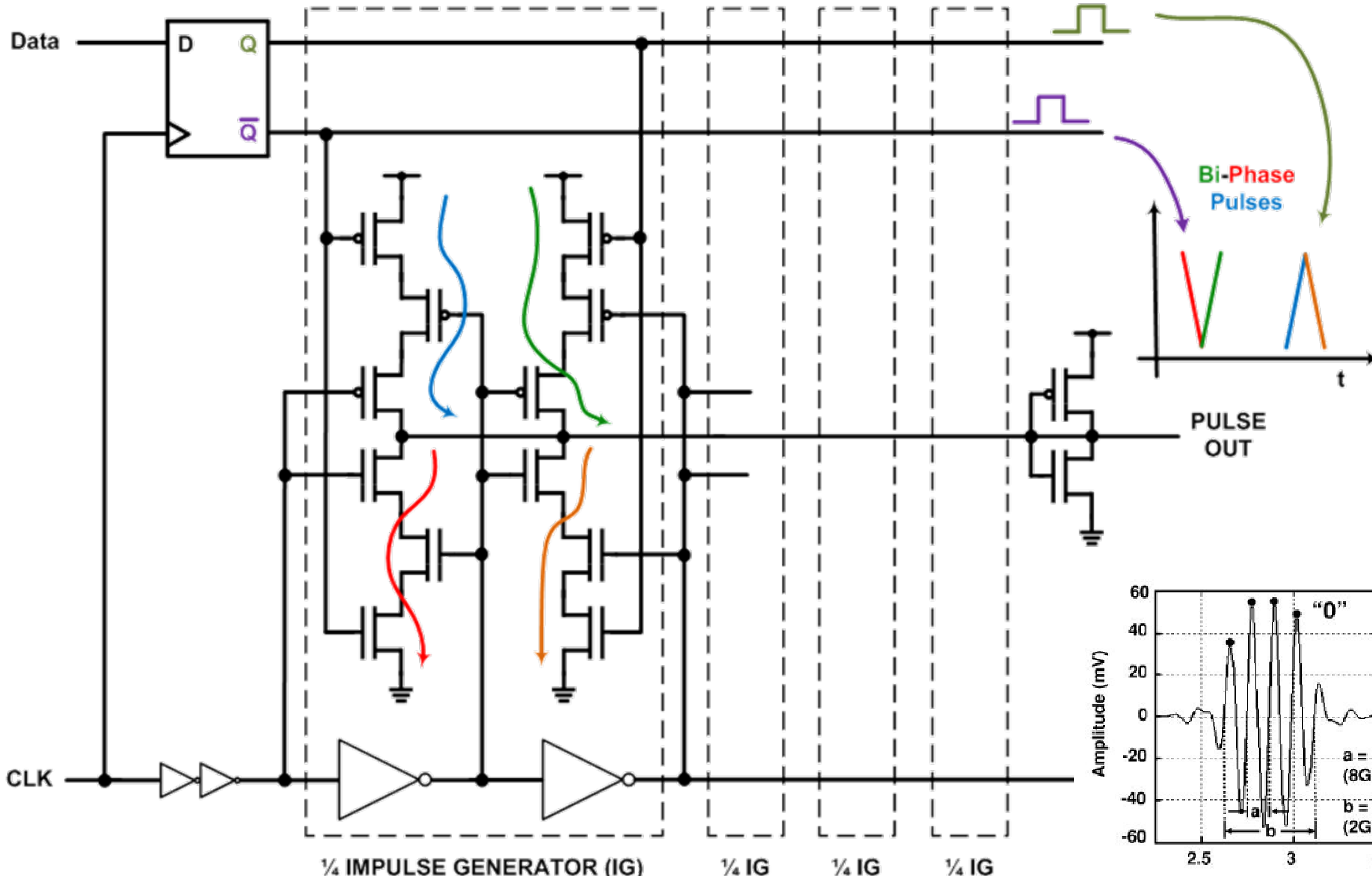


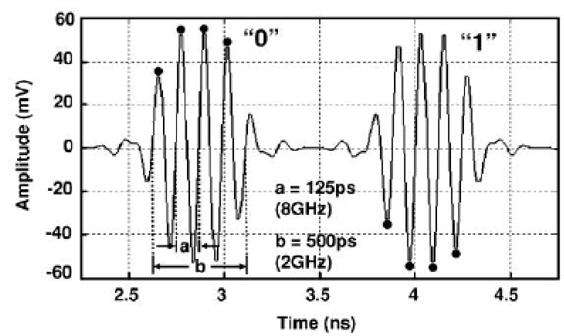
IR-UWB Transmitter

Design Choices

- **Frequency Band: 6-10GHz**
- **Why 6-10GHz?**
  - **Relatively Low Interference (WLAN Operates around 2.4/5.5GHz)**
  - **Relatively Narrow Bandwidth w.r.t. center frequency**
- **Modulation Scheme: BPSK**
- **Why BPSK?**
  - **No Discrete Spectra**
  - **3-dB Higher Modulation Efficiency compared to PPM, PAM/OOK**
- **Pulse Generation and Shaping: Digital**
- **Why Digital?**
  - **Take Advantage of Technology Scaling**
  - **Any Downside?**

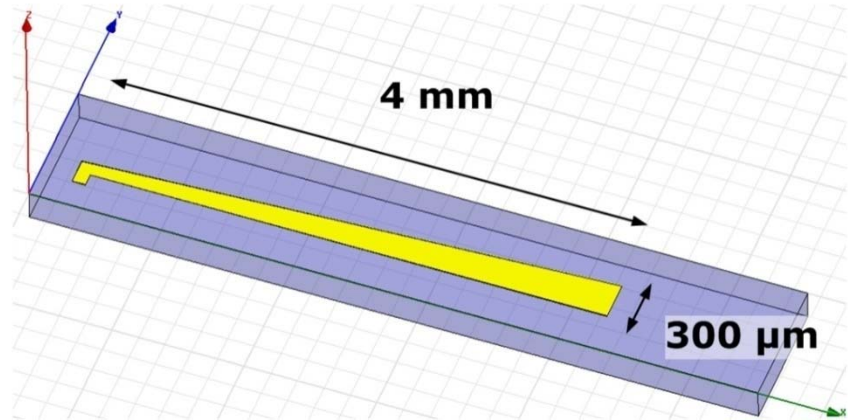
Pulse Generation/Shaping



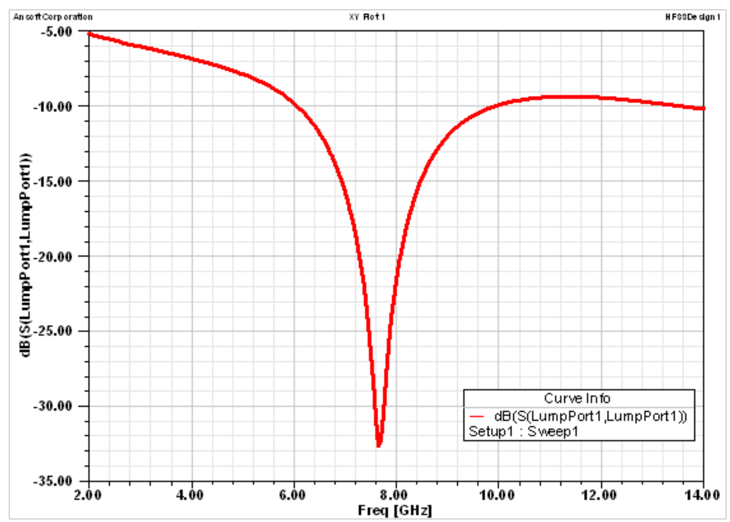


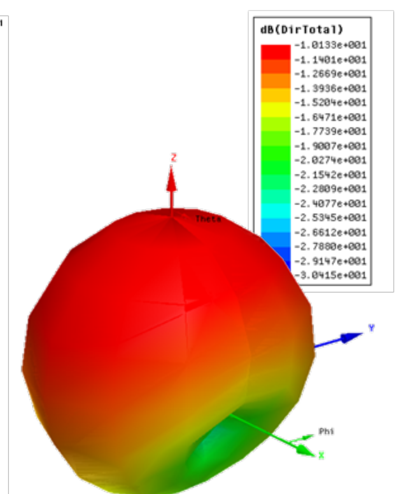
On-Chip Tapered Monopole Antenna

- Integration for short range communication
- Monopole topology
- Taper for broad bandwidth
- Matched to power amplifier



	[1]	This Work
f_c	9.0 GHz	**7.7 GHz**
Area	4.4 mm^2	**0.30 mm^2**
Directivity	5 dBi	**- 10 dBi**
Efficiency	0.6 % (-22 dB)	**4.23 % (-13 dB)**
Bandwidth	2.2 GHz	**4.0 GHz**





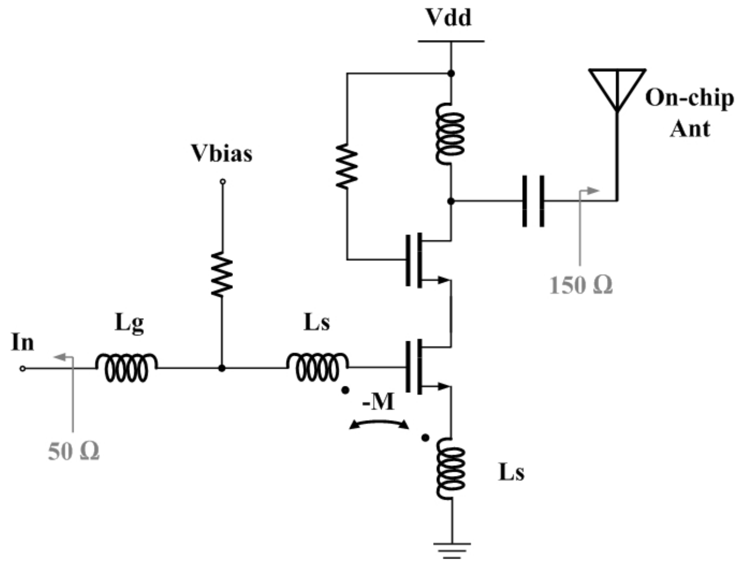
UWB Power Amplifier

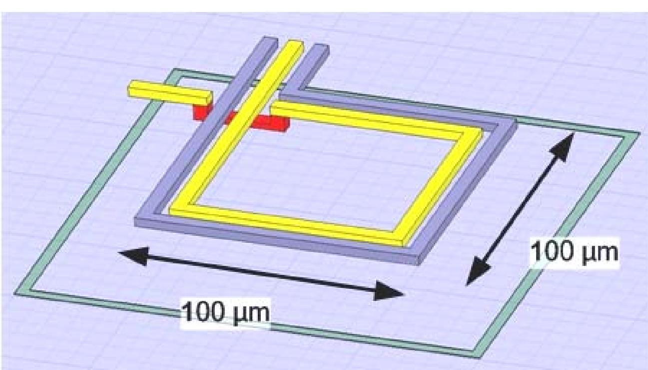
- **Transformer feedback to increase bandwidth**

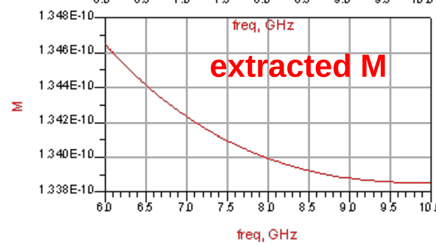
$$Zin = \frac{gmLs}{Cgs} + j\left[\omega(Lg + Ls) - \frac{1}{\omega Cgs}\right]$$

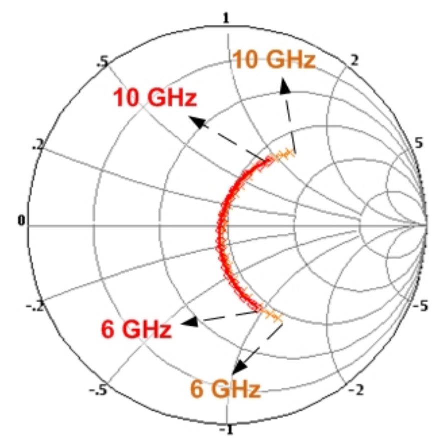
$$Zin_{FB} = \frac{gm(Ls - M)}{Cgs} + j\left[\omega(Lg + 2Ls - 2M) - \frac{1}{\omega Cgs}\right]$$

- **No additional output matching network for efficiency**





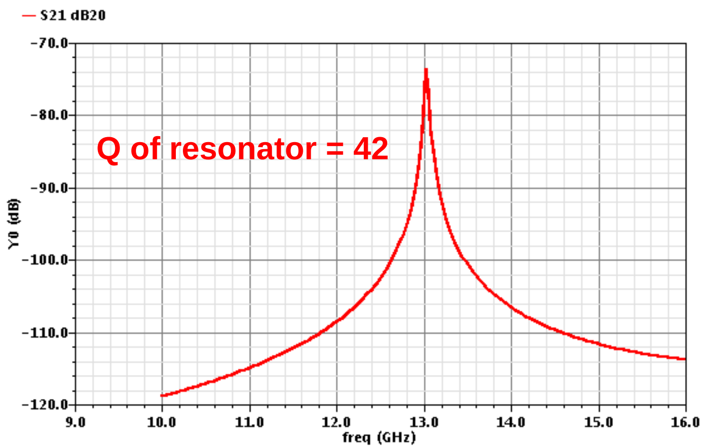


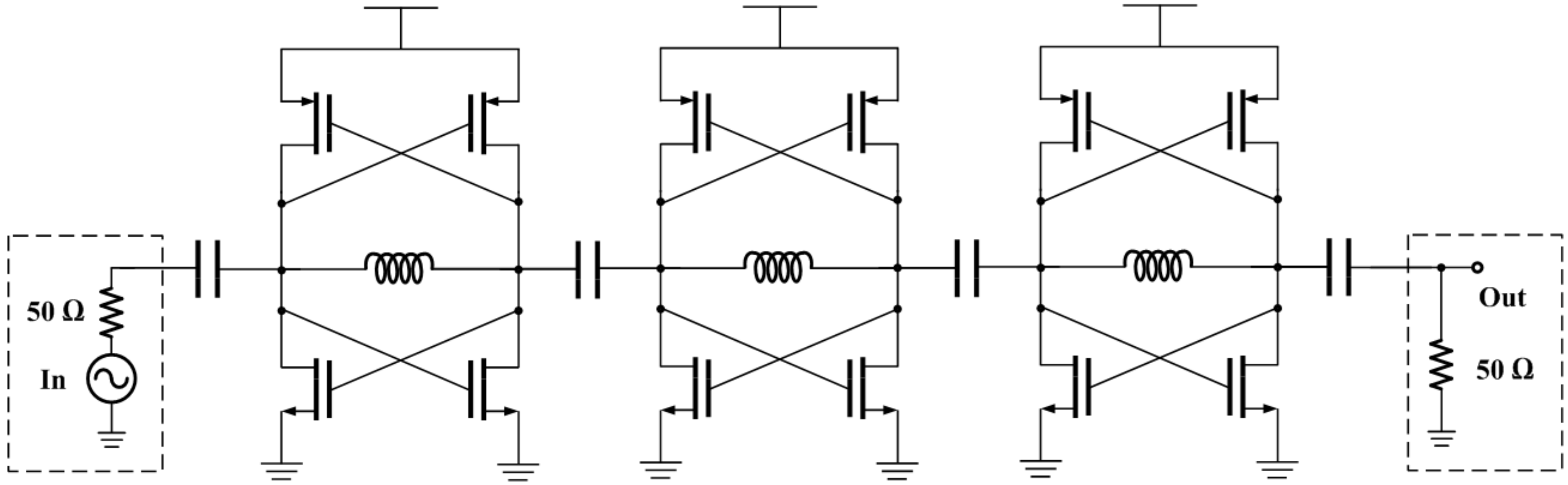


IR-UWB Receiver

On-Chip Active Bandpass Filter

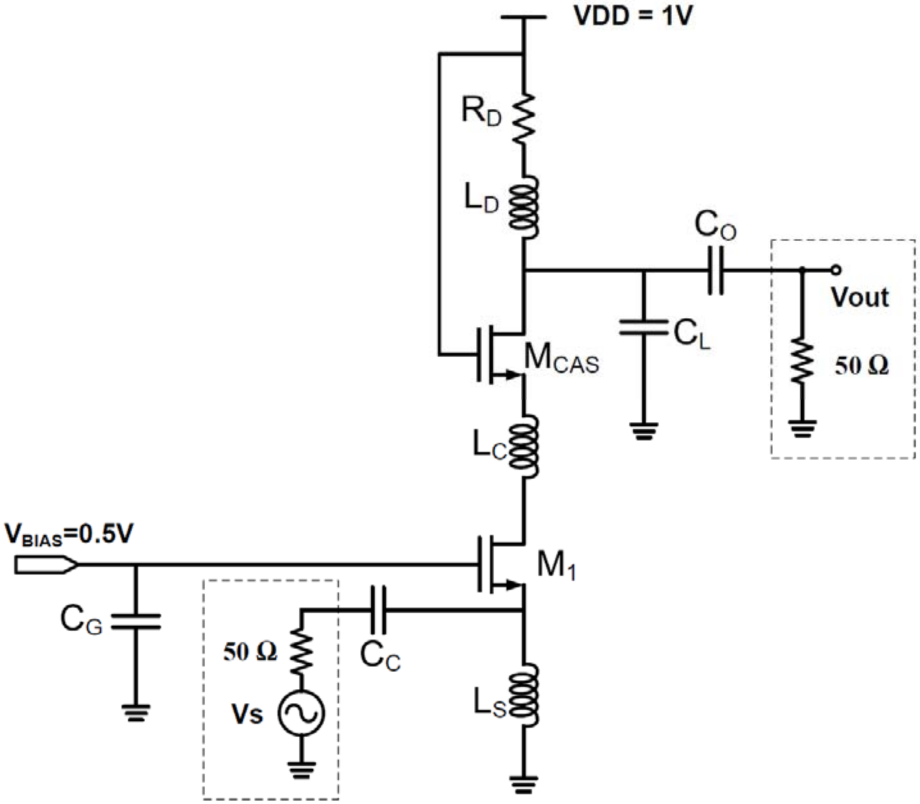
- On-chip solution for pre-select bandpass filter
- 3rd order shunt-type resonance capacitive coupled bandpass filter
- Efficient loss compensation for Q-factor boosting





Low-Power Low-Noise Amplifier

Schematic



Biased in Moderate Inversion

Account for Gate-Induced Noise

$$F = 1 + \frac{\gamma}{\alpha g_{m1} R_s} + \frac{\delta \alpha}{5 g_{m1} R_s} \left(\frac{\omega}{\omega_T}\right)^2$$

$\gamma = 1.9$ $\alpha = 0.9$ $g_{m1} = 26mS$

$I_{ds} = 2.56mA$ $C_{gs1} = 100\,fF$

$\left(\frac{\omega}{\omega_T}\right)^2 = 0.037$ $NF \approx 4.2dB$

Low-Power Low-Noise Amplifier

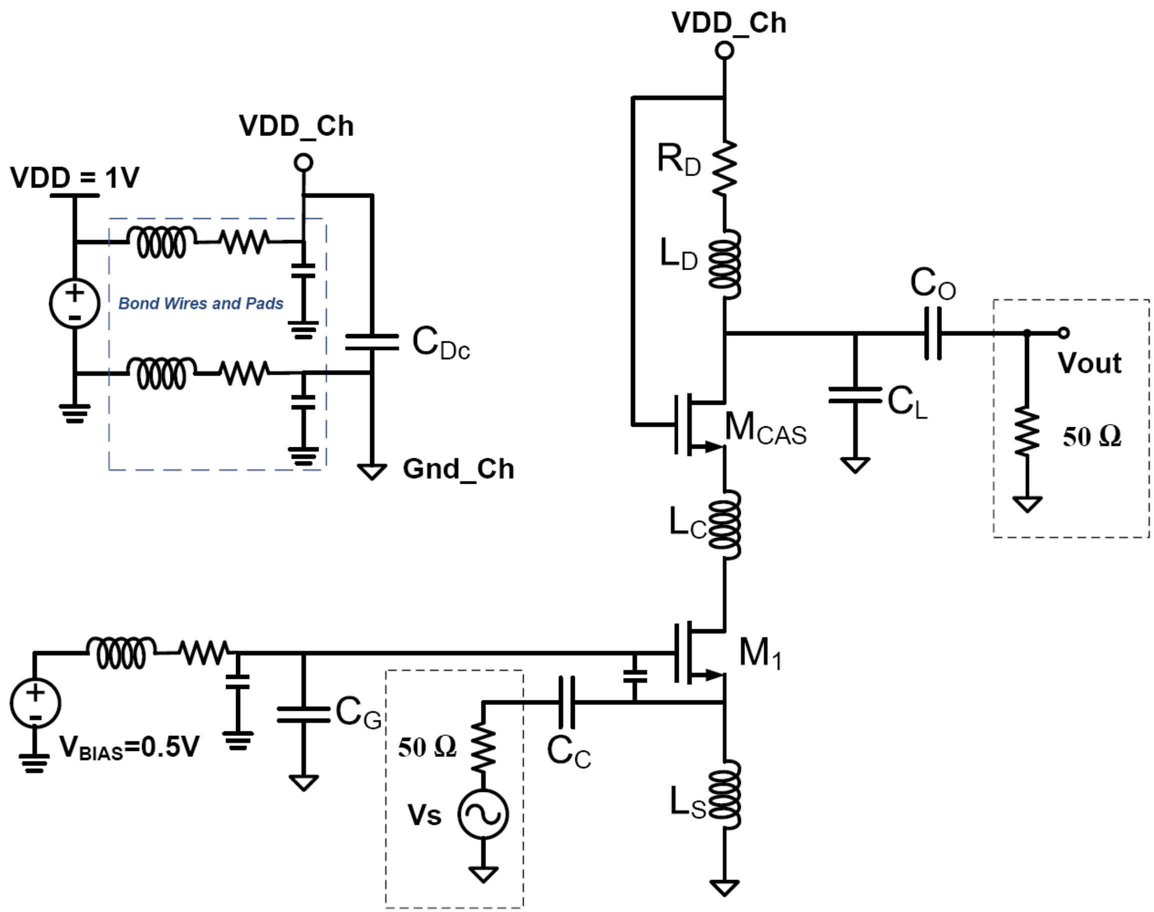
Schematic

(more practical)

Fully-Integrated

Account for Pads and Bond Wires

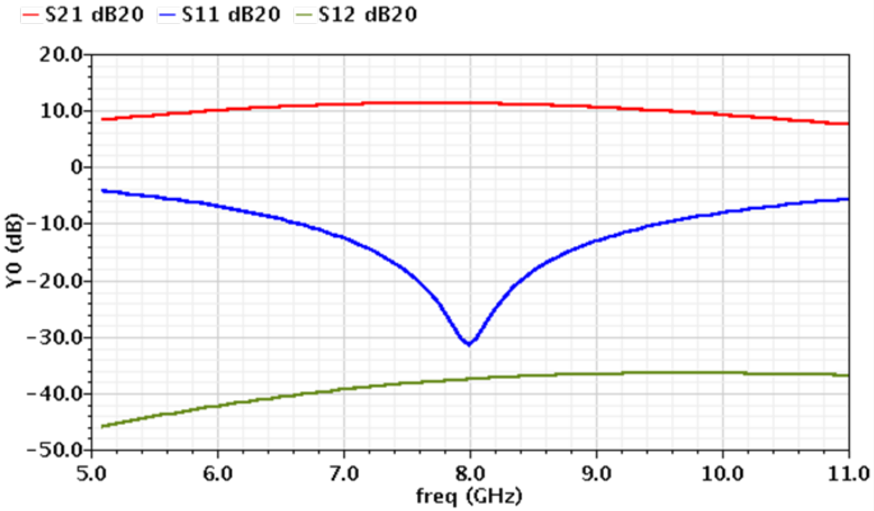
Account for Parasitics from Inductors



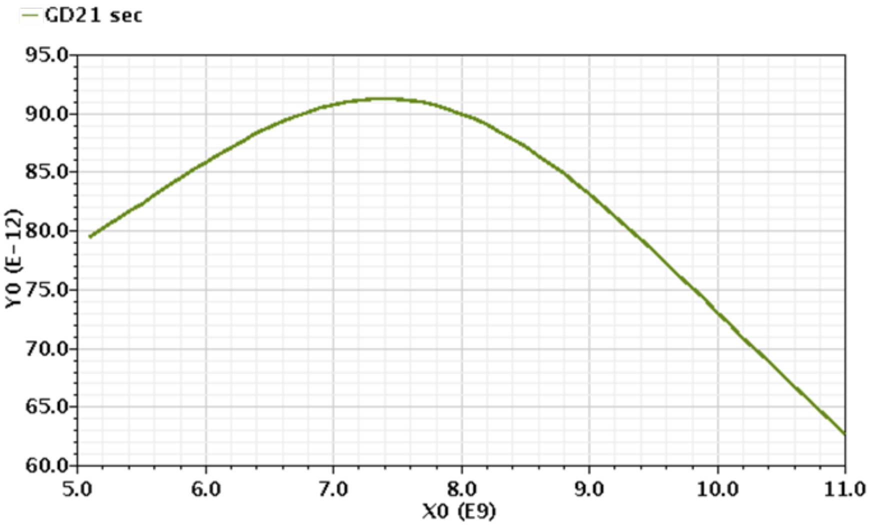
Results and Performance Comparison with previous work

Simulation Result - UWB Power Amplifier

S-parameters



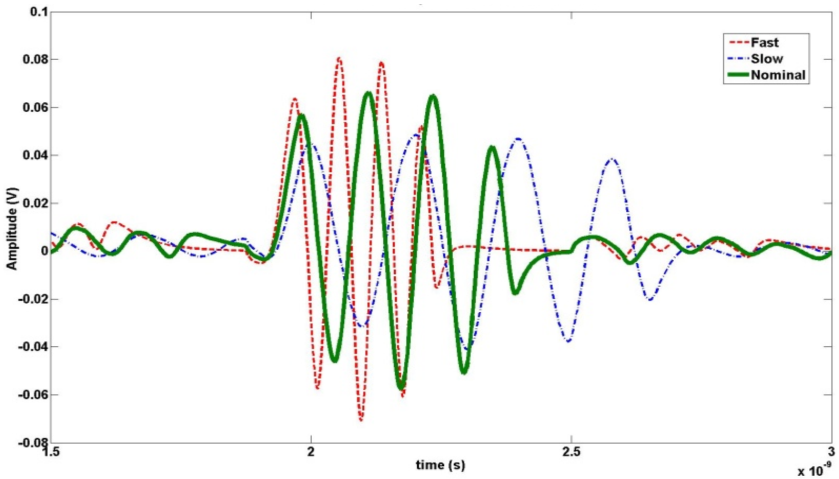
Group Delay of S21



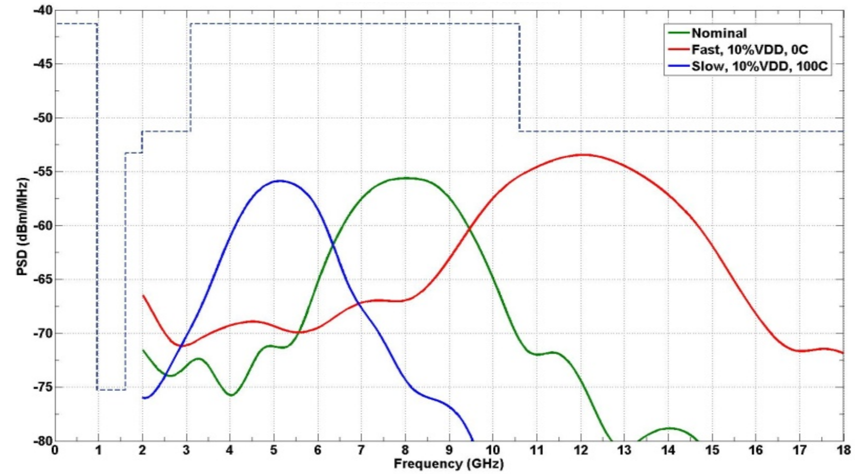
Reference	CMOS Tech.	Bandwidth	Avg. Gain	Avg. OP_{1dB}	Group Delay Variation	Power Consumption	Avg. PAE
[1]	0.18 µm	8 - 10 GHz	13.2 dB	N/A	N/A	20.0 mW	N/A
[8]	0.18 µm	3.1 – 4.8 GHz	19.0 dB	-4.2 dBm	N/A	25.0 mW	1.5 %
[9]	0.18 µm	6 - 10 GHz	8.5 dB	5.0 dBm	N/A	18.0 mW	14.4 %
This Work	**0.13 µm**	**5.1 – 10.5 GHz**	**10.1 dB**	**0.1 dBm**	**18.6 % from 90 ps**	**4.2 mW**	**21.6 %**

Simulation Result - UWB Transmitter

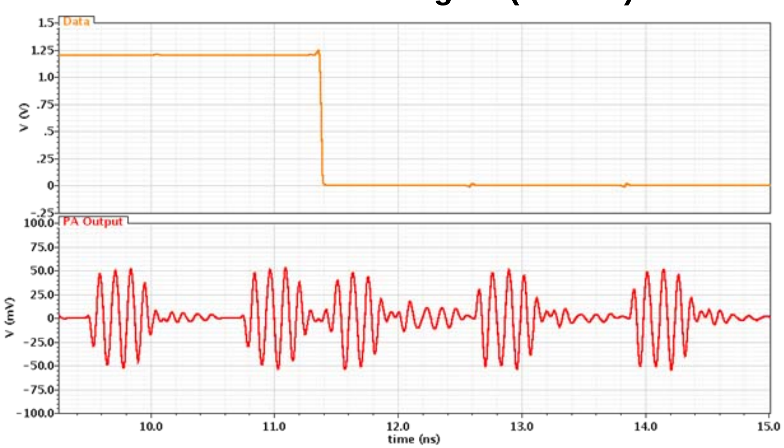
Transient Response [PVT]



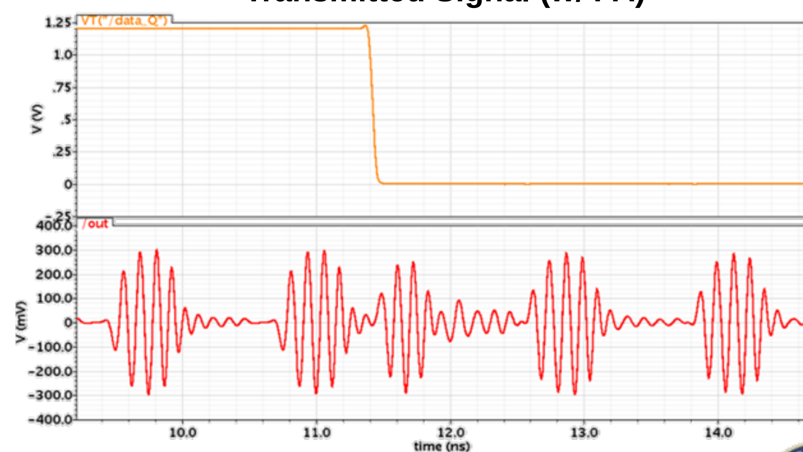
Power Spectral Density [PVT]



Transmitted Signal (w/o PA)

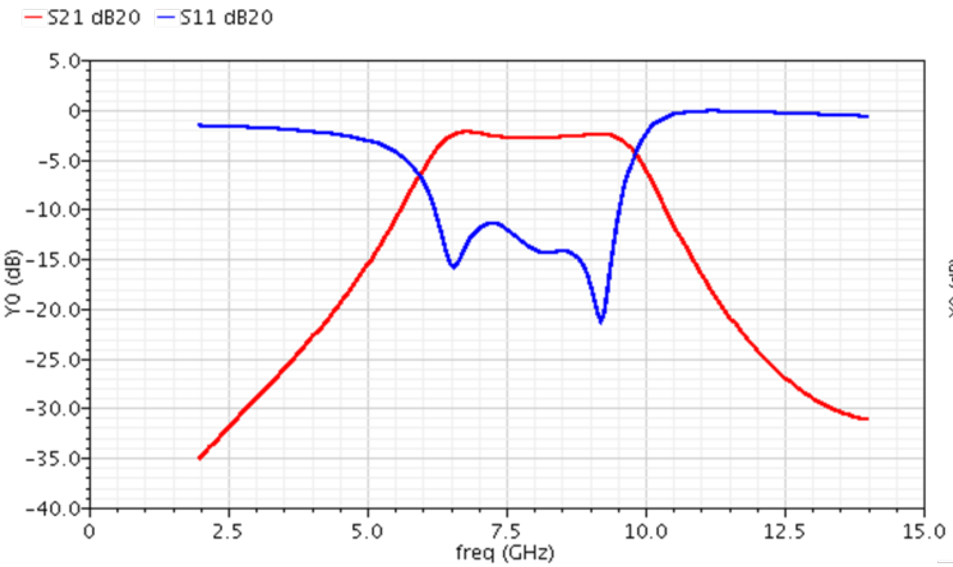


Transmitted Signal (w/ PA)

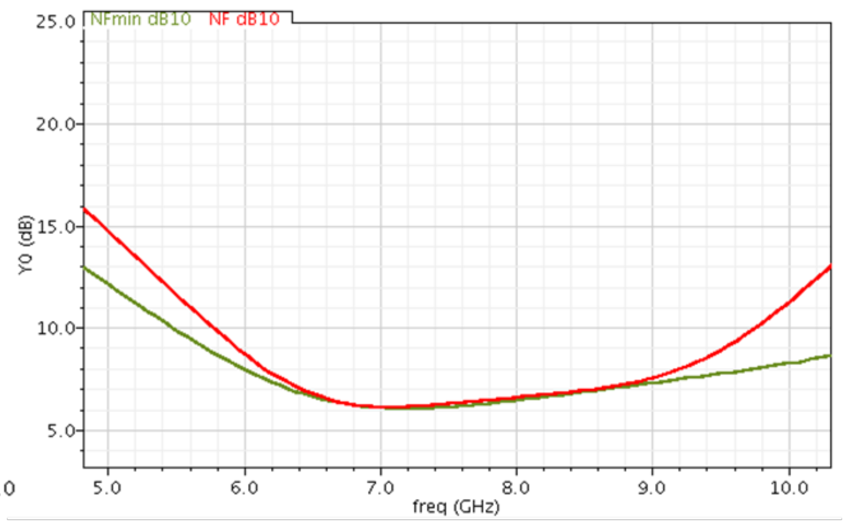


Simulation Result - Active Bandpass Filter

S-parameters



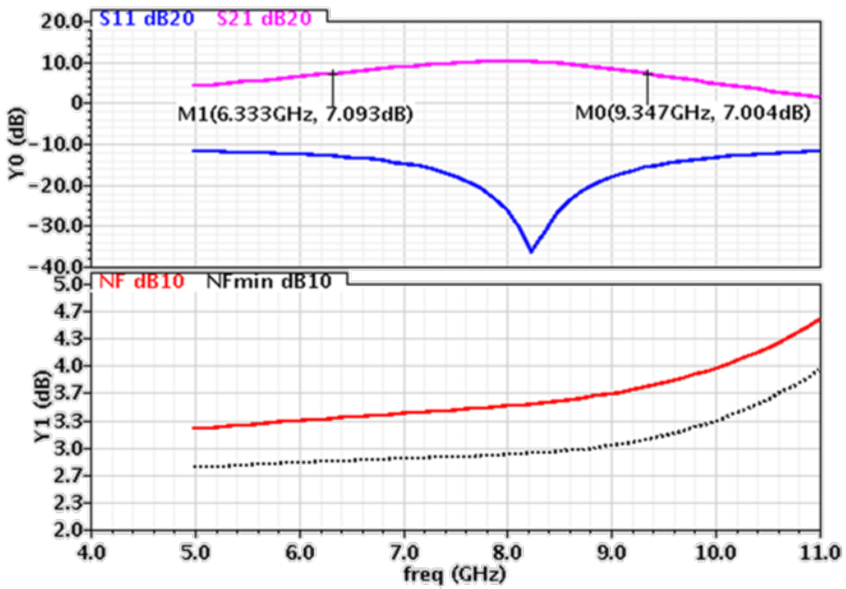
NF and NFmin



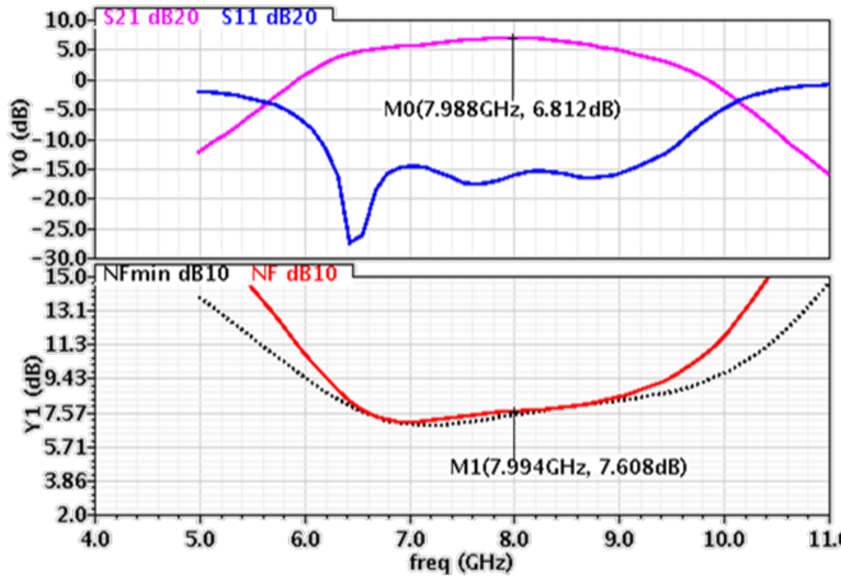
Bandwidth	Insertion Loss	Return loss	Noise Figure	Out-of-Band Attenuation	Power Consumption
3.9 GHz	2.9 dB	-11.2 dB	6.2 dB @ 7 GHz	30 dB @ 3 GHz 28 dB @ 13 GHz	0.4 mW

Simulation Result – LNA and Filter

S-parameters and NF of LNA only



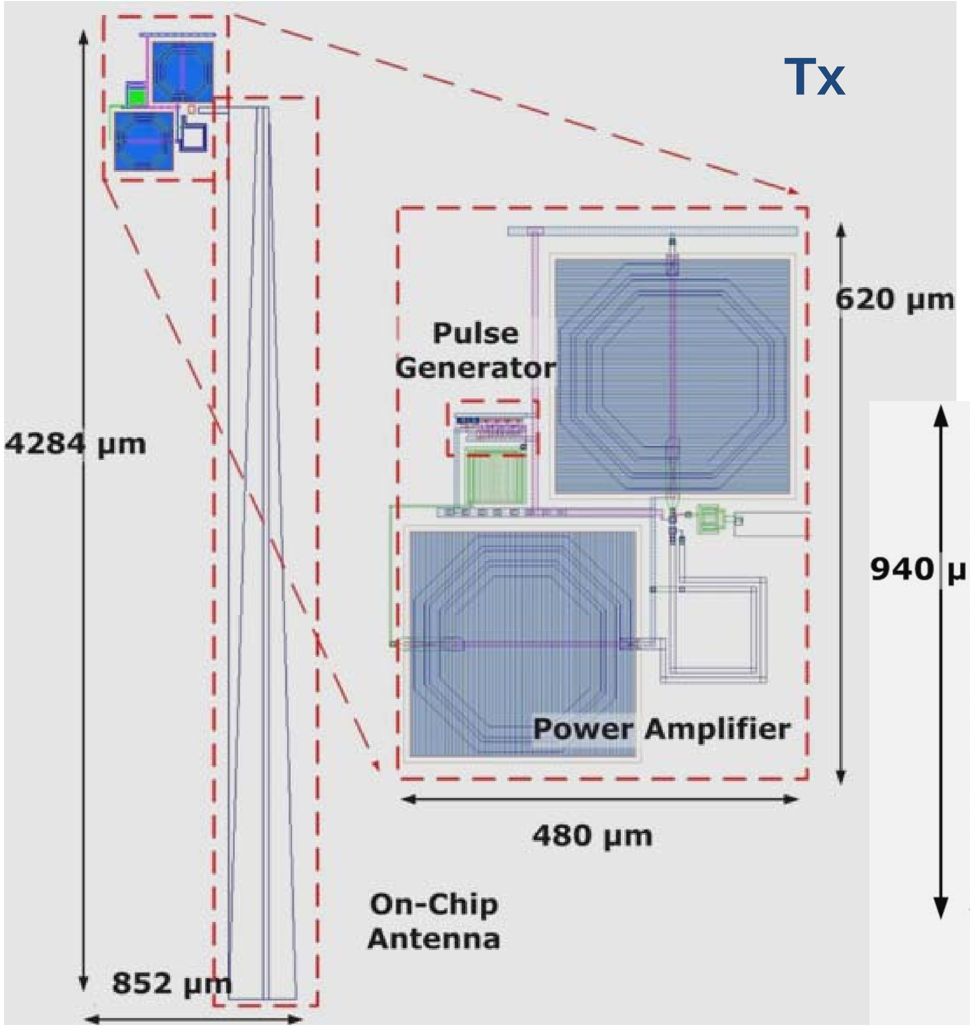
S-parameters and NF of LNA + Filter



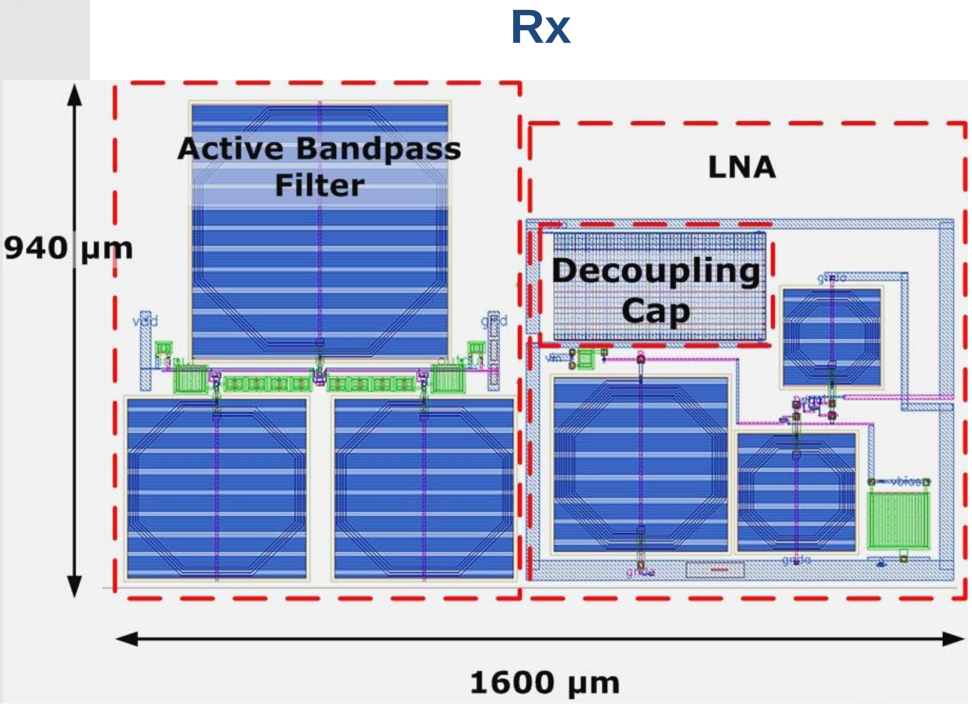
Reference	Technology	BW [GHz]	NF [dB]	S_{21} [dB]	S_{11} [dB]	IIP3 [dBm]	Supply [V]	Power [mW]	Area [mm^2]
[10]	130 nm	3-5	3.5 - 5.5	6.4 - 9.5	< -10.0	- 0.8	1.2	16.5	~ 1.08
[11]	90 nm	0.5-5	2.3-2.6	21-22*	< -10.0	- 8.8	1.8	12.0	0.012
[12]	180 nm	6-10	4.8	11.6	<-9	1.2	1.8	11.6	0.81
This Work	**130 nm**	**6.3-9.4**	**3.3-3.7**	**7-10**	**<-13**	**-6.8**	**1**	**2.56**	**0.51**

*Voltage Gain

Layout View of UWB Transmitter and Receiver



	Area
Tx w/o Antenna	0.29 mm^2
Tx w/ Antenna	3.65 mm^2
Rx w/ Decoupling Cap	1.50 mm^2



Results and Comparison with previous work

Parameter	[1]	[2]	[3]	[4]	This Work
Supply Voltage [V]	1.8-2.2	1	1.8	1	**1.2 (Tx)/1(Rx)**
Process Technology	180 nm	90 nm	180 nm	180 nm	**130 nm**
BW [GHz]	6 - 10	3.2 - 5	3.3 – 4.8	3.1 - 10	**6 -10**
Data Rate	750 Mb/s	10 Mb/s	1 Gb/s	1.8 Gb/s	**1Gb/s**
Modulation	BPSK	Delay-based BPSK	BPSK	BPSK	**BPSK**
Radiated Power [dBm/MHz]	-62.49	-42	-42	-42	**-55**
FOM [pJ/b]	41	47	108	126	**7**

Conclusions and Future Directions

Tailoring Designs up to what the application needs

Conclusion

- **Low-power implementation of IR-UWB transmitter for short range (7 pJ/bit)**
- **Broadband power amplifier and on-chip antenna**
- **Transmitter can be a part of fully-integrated wireless microsystems**
- **Low-power, low-noise analog front-end for IR-UWB receiver**
- **On-chip active bandpass filter reducing the Impact of out band interferers**
- **The performances of all implemented blocks is comparable and outperforms state-of-the-art publications**
- **Future work should include implementing the remaining blocks (inc PLL) as well as testing the real chip performance**

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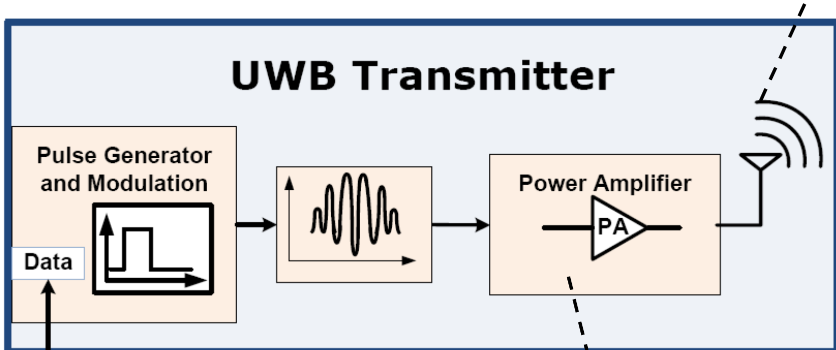
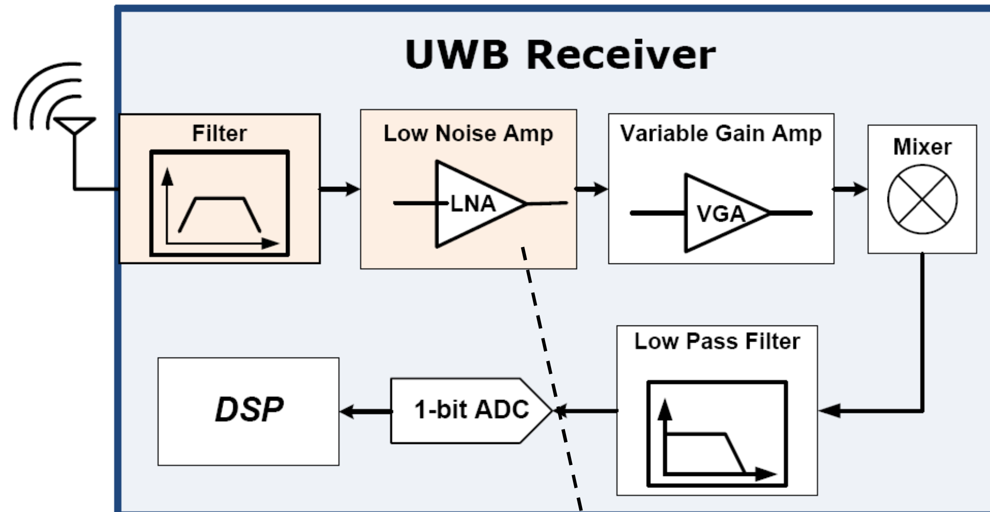
Thank you

Questions?

Overall System Architecture

Antenna	Limit
Gain	-15 dBi
Bandwidth	4 GHz (6 to 10 GHz)
Center Frequency	8 GHz
Efficiency	-20 dB





Modulator /Pulse Generator	Limit
Center Frequency	8 GHz
Bandwidth	4 GHz (6 to 10 GHz)
Max. Data Rate	1 Gbps
Modulation Type	Bi-Phase
Pulse Type	Multi-Cycle Gaussian
Energy/bit	< 12 pJ/bit

Power Amp	Limit
Power Gain	15 dB
Bandwidth	4 GHz (6 to 10 GHz)
IIP3	> 5 dBm
IIP2	> 10 dBm
P_{1dB}	> -5 dBm
Power Consumption	< 20 mW

Low-Noise Amp	Limit
Gain	>12 dB
Bandwidth	4 GHz (6 to 10 GHz)
Noise Figure	<4 dB
IIP3	> -14 dBm
Power Consumption	< 3 mW