CASE STUDY

INTELLIGENT TIRE SYSTEM

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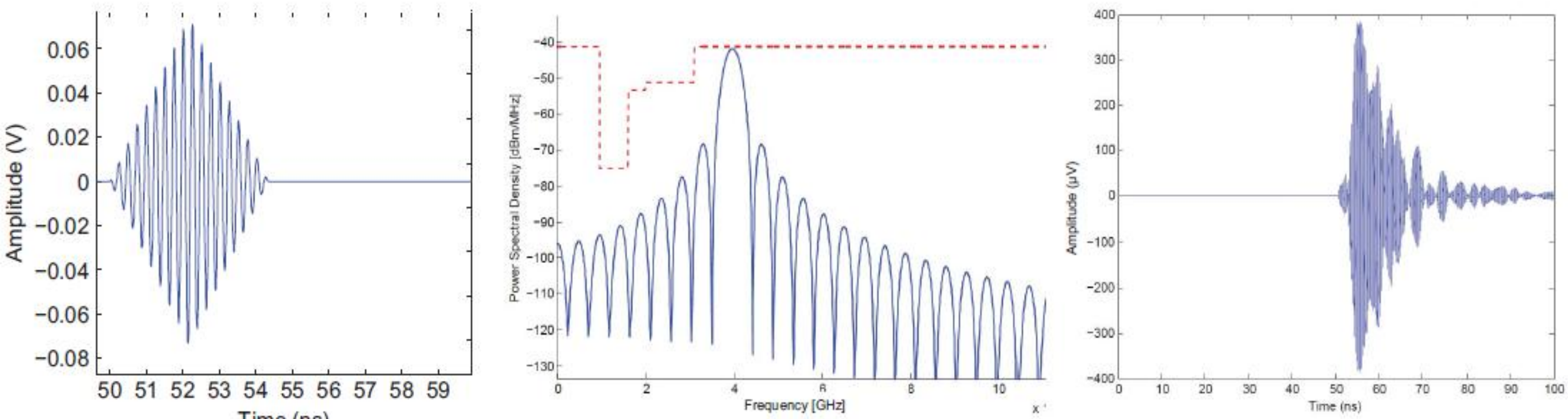
INTELLIGENT TIRE SYSTEM

Distributed architecture for real-time data acquisition of road-surface and vehicular information from sensors located inside the tire of a car

- *System Architecture*
- Personal Area Network (PAN)
- Lowest level: sensor nodes
- Upper level: PAN coordinator (communication with the sensor nodes, synchronization)
- System Control Host (the highest level coordinator of the network)
- *UWB Communication System*
- UWB radio transmission
- Preferable with respect to narrow-band transmission and spread spectrum techniques

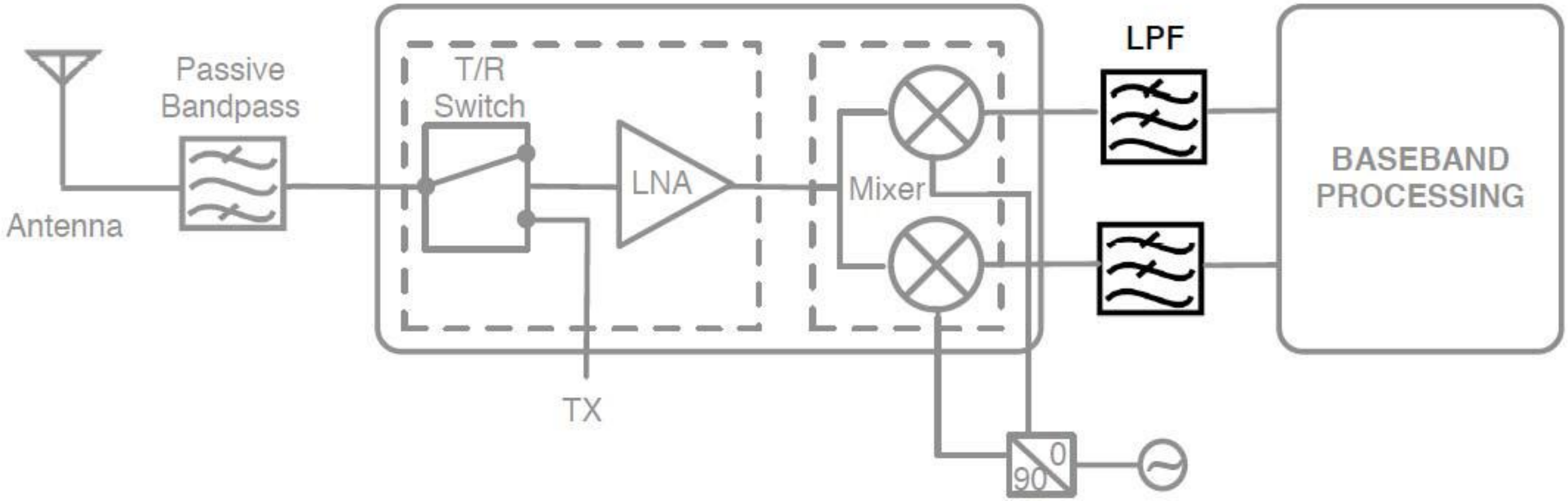
Signal Properties



(a) (b) (c)

Fig. 4. (a) Triangular transmitter pulse. (b) Pulse spectrum, showing a 500-MHz −10-dB bandwidth. (c) Received signal, including channel attenuation and multipath effect.

UWB RECEIVER FRONT-END DESIGN



A. *Receiver Requirements*
B. *RF Front-End Exploration*
C. *Low Pass Filter Abstraction*
D. *Receiver Composition and Optimization*

A. Receiver Requirements

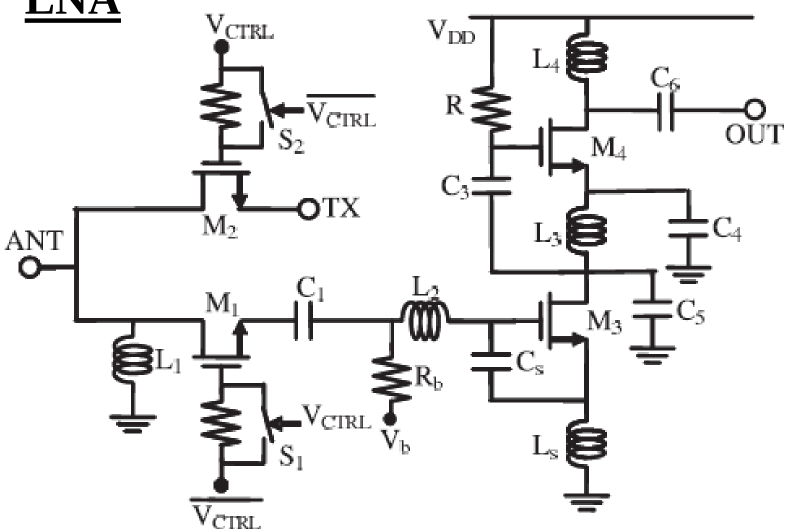
RECEIVER SPECIFICATION SET

Data rate	10 Mbps
Center frequency	3.96 GHz
Signal bandwidth (−10 dB)	500 MHz
BER	$< 10^{-3}$
Sensitivity	−60 dBm
Gain	$\geq$ 40 dB
Noise figure	$<$ 4.6 dB
$IIP3$	≥ -27 dBm
Base-band attenuation	$\geq$ 60 dB at 460 MHz

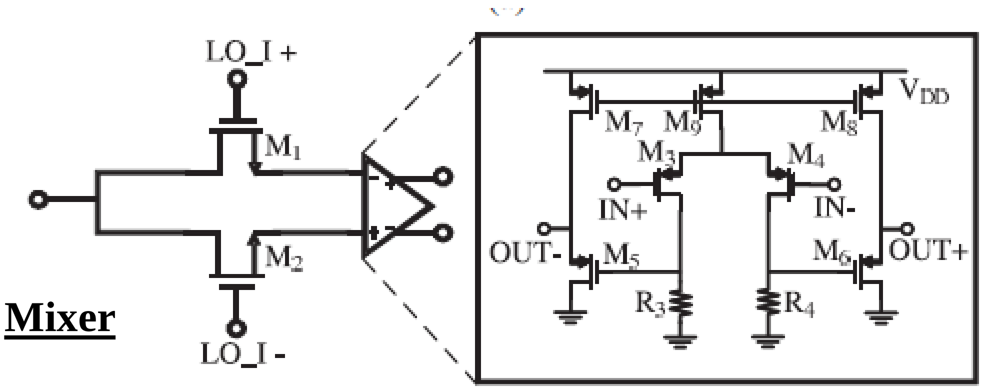
B. RF Front-End Exploration

- RF front-end: LNA + passive Mixer (M1 and M2)+low noise gain stage (M3-M8)

LNA



Mixer



1. **AP components and contracts**
2. **RF Front-End Composition**

1. AP components and contracts

- ***LNA component***
- Specify the related variables
- **Assumptions** & **Guarantees** *(A_{LNA}, G_{LNA})*

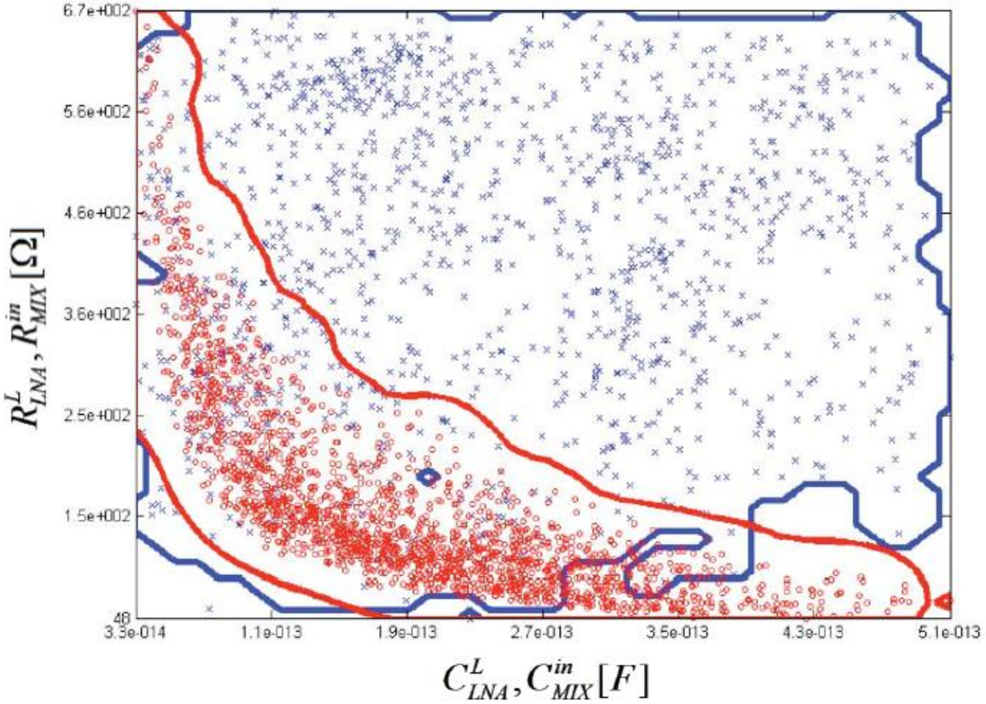
A_{LNA}= {(R_L ,C_L) : $R_L \in$ [85, 520] ,$C_L \in$ [0.03, 0.25] pF}

- G_{LNA} is the set of performance figures ζ_{LNA} that satisfy $P_{LNA}(\zeta_{LNA}) = 1$ and are obtained by evaluating the mapping φ_{LNA} on the input, configuration and interface variables in A_{LNA}.
- **Mixer component**
- C_{LNA} and C_{MIX}: horizontal contracts

2. RF Front-End Composition

- $C_{RF} = C_{LNA} \otimes C_{MIX}$

- The intersection between the set of configurations assumed by the LNA and the set of configurations offered by the Mixer is non-empty.



Design Exploration Via Optimization

$$\min_{\zeta_{LNA},\zeta_{MIX}} \quad \omega_1 \cdot P_{RF} + \omega_2 \cdot \Theta(NF_{RF})$$

$$\text{s.t.} \begin{cases} IIP3_{RF} \geq -35 \text{ dBm} \\ K_{RF} \geq 15 \text{ dB} \\ NF_{RF} \leq 5 \text{ dB} \\ \zeta_{RF} = \phi_{RF}(u_{RF}; \zeta_{LNA}, \iota_{LNA}, \zeta_{MIX}, \iota_{MIX}) \\ \mathcal{P}_{LNA}(\zeta_{LNA}) = 1, \quad \mathcal{P}_{MIX}(\zeta_{MIX}) = 1 \\ Z_{MIX}^{in} \in A_{LNA}^{L}, \quad Z_{LNA}^{out} \in A_{MIX}^{S} \\ Z_{RF}^{S} \in A_{LNA}^{S}, \quad Z_{RF}^{L} \in A_{MIX}^{L} \end{cases}$$

7186/20730 satisfied the contracts

21 minutes on a 3.16 GHz Intel Core2 Duo Workstation to obtain the optimum

Optimization Results

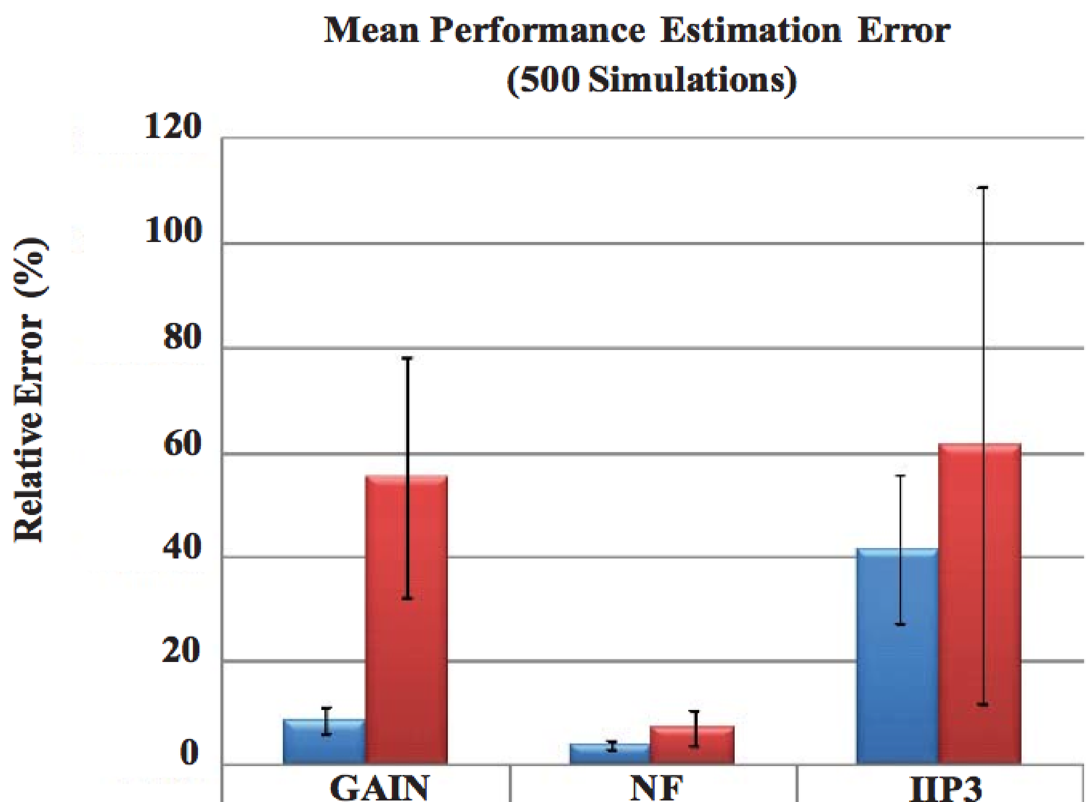
TABLE II

OPTIMIZATION AND SIMULATION RESULTS

Performance (3.96 GHz)	LNA (Optimal)	Mixer (Optimal)	RF front-end Estimation	RF front-end Simulation
NF (dB)	3.49	13.3	3.7	3.89
Gain (dB)	23.5	−3.57	19.9	18.74
IIP3 (dBm)	−13.7	−7.37	−30	−27.96
Power (mW)	5.4	1.67	7.07	7.07

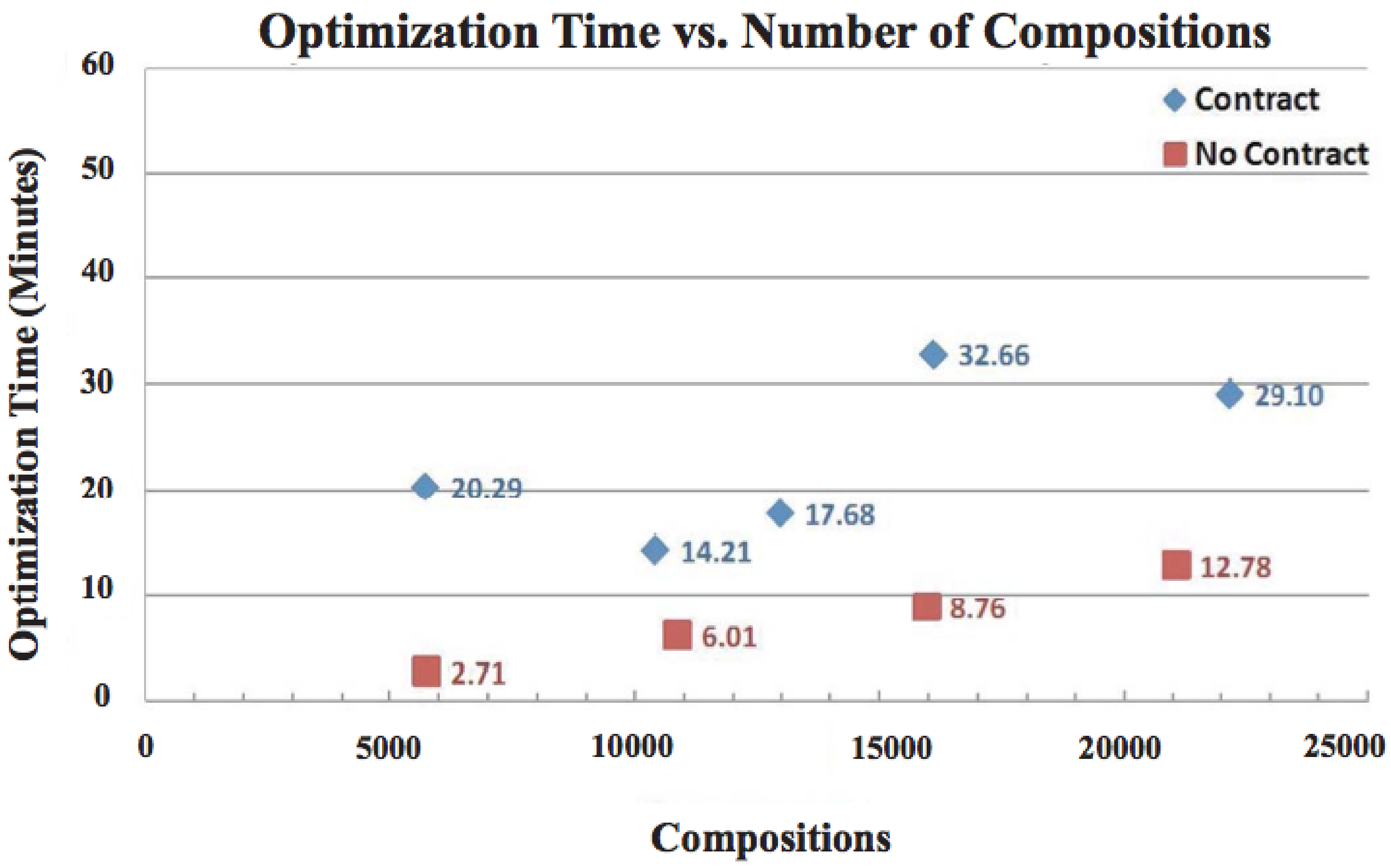
Transistor-level simulation using the nearest neighbors

Contract-based vs. No Contract

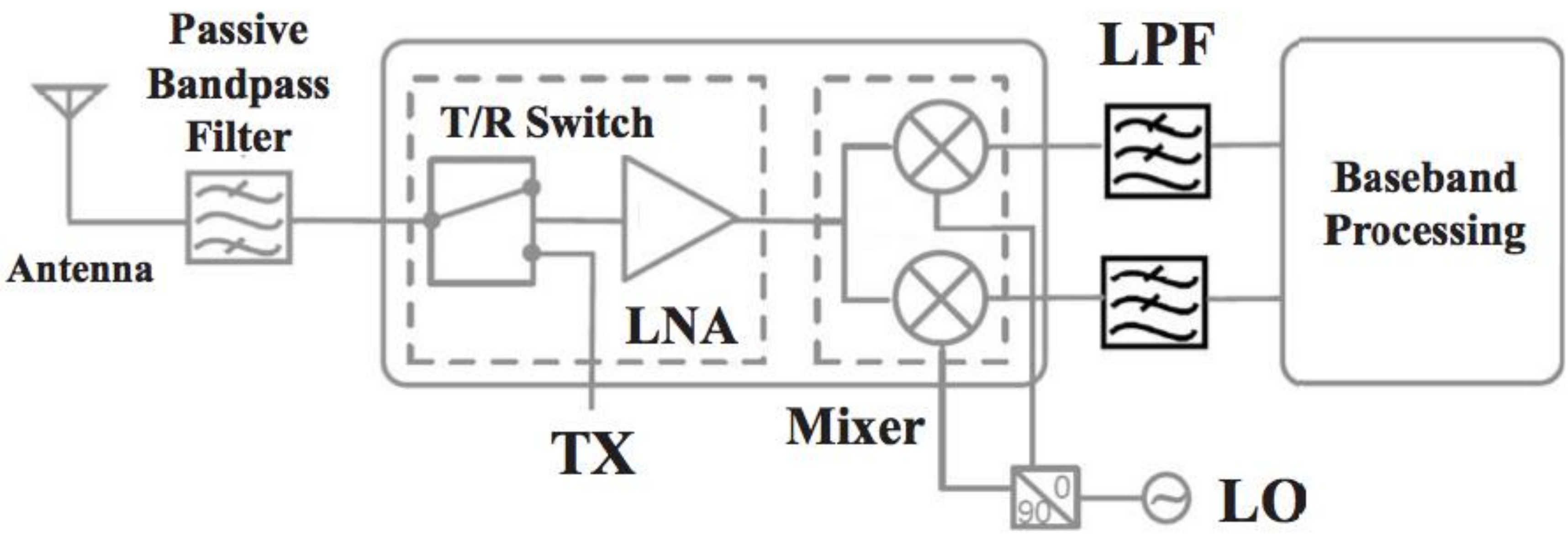


	GAIN	NF	IIP3
Contract	8.38%	3.76%	41.29%
No Contract	55.14%	7.07%	61.04%

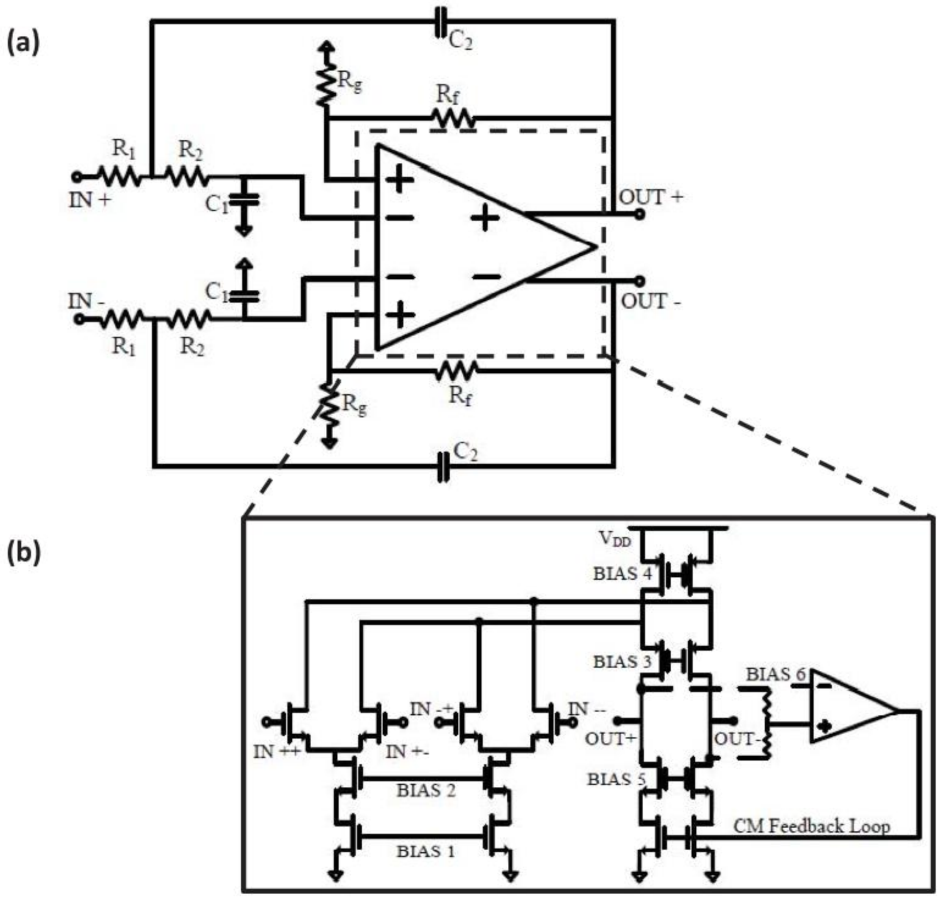
Optimization Computation Cost



Low Pass Filter



Low Pass Filter Abstraction



$$H_{SK}(s) = \frac{K_{SK}}{\frac{s^2}{\omega_0^2} + \frac{s}{Q\omega_0} + 1}$$

Filter Behavioral Model

$$\omega_0 = \frac{1}{\sqrt{R_1 R_2 C_1 C_2}}$$

$$Q = \frac{\sqrt{R_1 R_2 C_1 C_2}}{C_1(R_1 + R_2) + R_1 C_2(1 - K_{SK})}$$

Performance and Interface Parameters

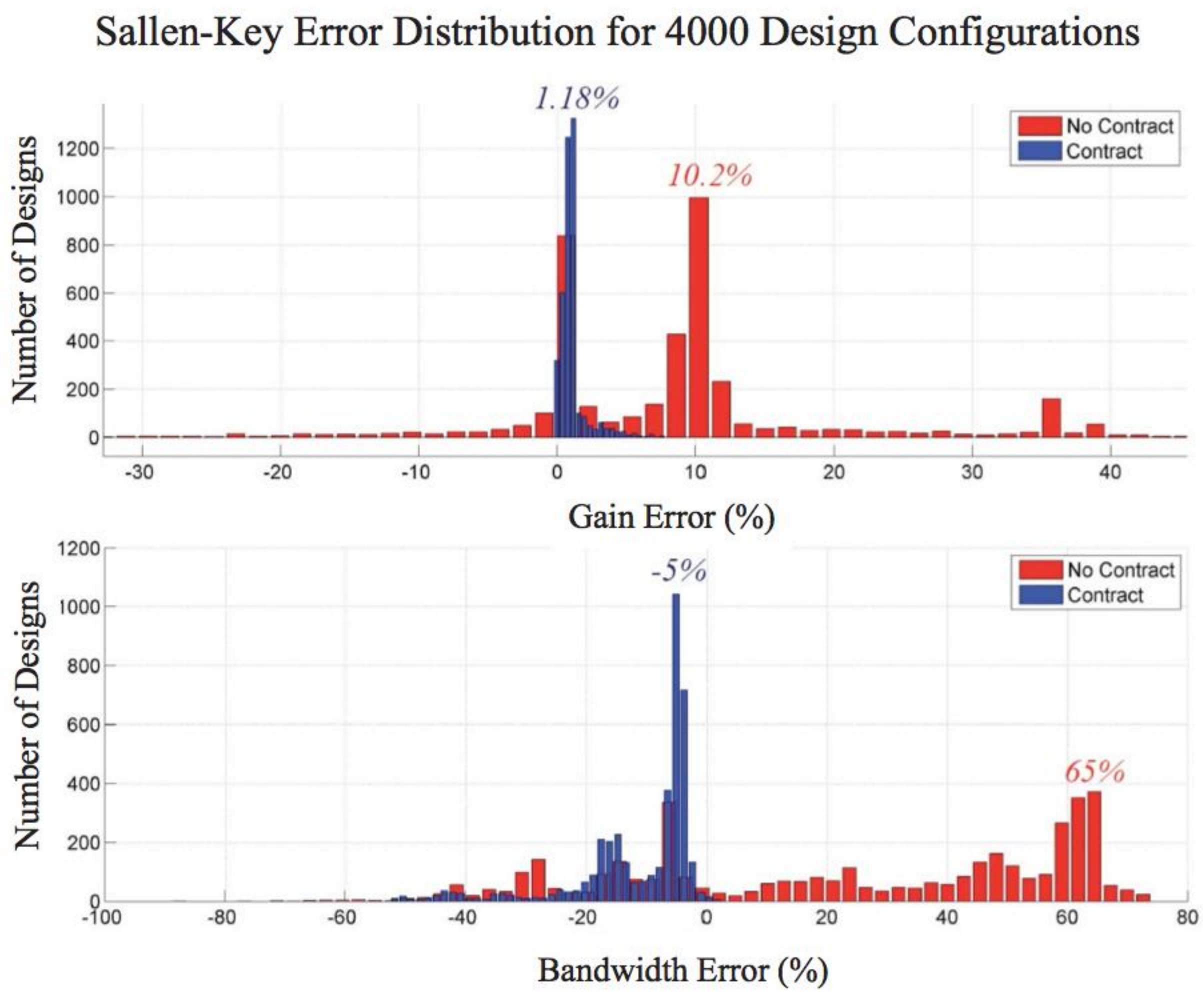
$$(P_{SK}, Q, \omega_0, N_{SK}, K_{SK}, HD_3, Z_{in}, Z_{out})$$

Power consumption
Cell quality-factor
Resonant angular frequency
Output noise power
Gain
Third-order harmonic distortion
Input impedance
Output impedance

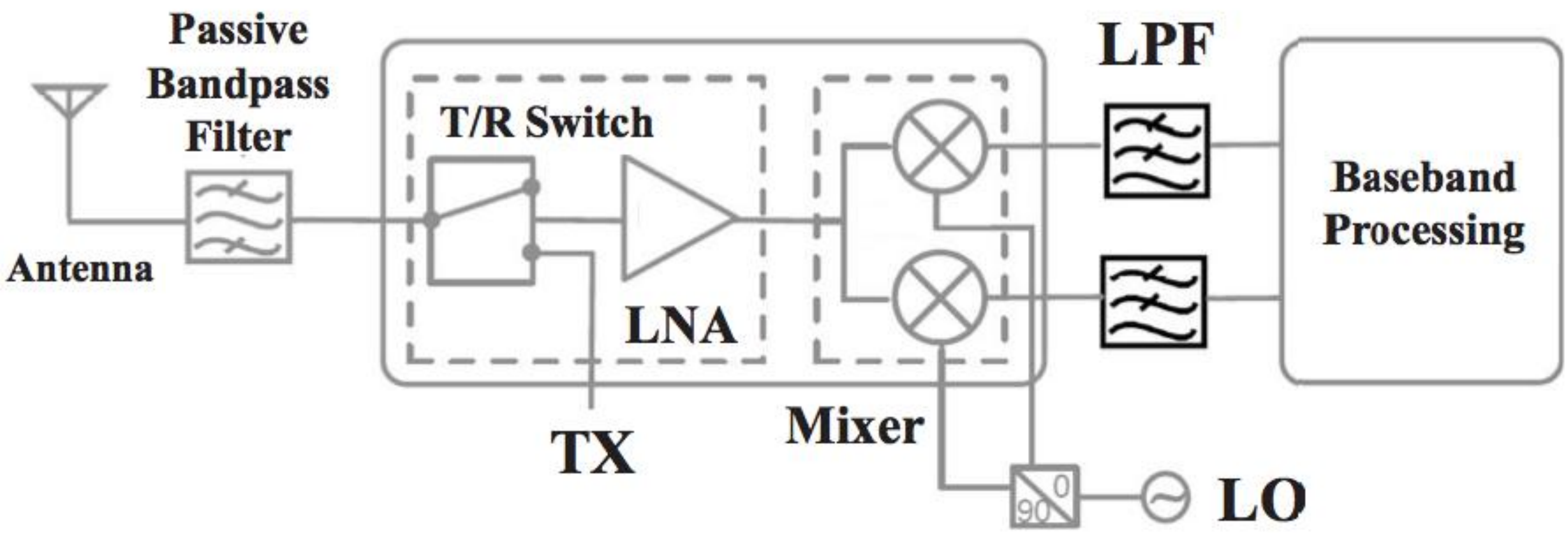
$$A_{SK}^{S,L} = \{(R_S, C_S, R_L, C_L) : R_S \in [100, 1000]\ \Omega,$$
$$C_S \in [0.01, 1]\ \text{pF},\ R_L \in [1, 1000]\ \text{K}\Omega,\ C_L \in [0.1, 10]\ \text{pF}\}$$

$$R_S \leq 0.1 \cdot R_1 \qquad R_L \geq 10 \cdot R_{out}^{SK}$$

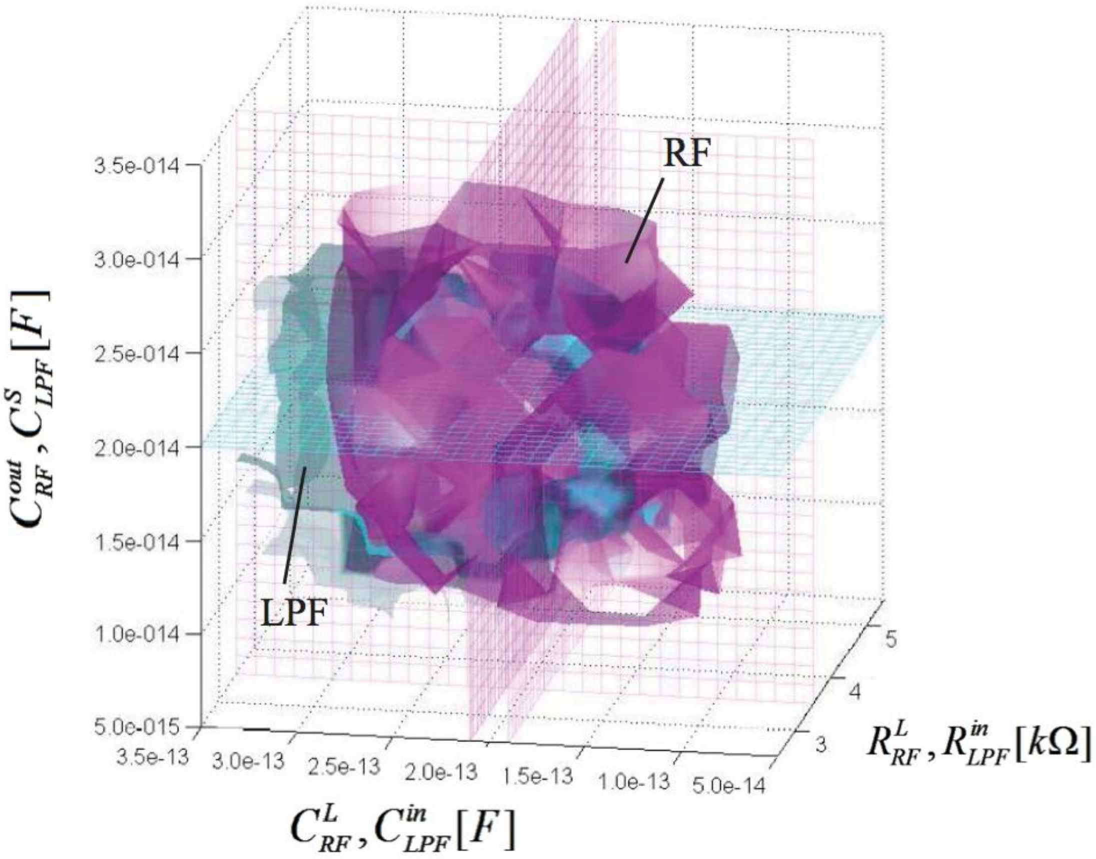
Benefit of contracts



Receiver


Passive
Bandpass
Filter
Antenna
T/R Switch
LNA
TX
Mixer
LPF
Baseband
Processing
0
90
LO

Receiver Composition



Receiver Optimization

$$C = \sum_i \omega_i \Theta_i(\zeta_{RX}^i)$$

Data rate	10 Mbps
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Receiver Optimization Results

	Gain (dB)	Power (mW)	NF (dB)	IIP3 (dBm)
Min. Noise	42	18.6	3.46	−19
Min. Power	45.8	13.6	4.14	−21
Max. IIP3	40	14.5	4.58	−11.6
Max. Gain	51	20.0	3.88	−19.2

	Gain (dB)	Power (mW)	BW (MHz)	NF (dB)	IIP3 (dB)
Mean	0.6	0.2	14	0.18	2.06
Variance	1.24	0.3	18	0.15	1.66