

Tu01D-5

A 0.4-to-30 GHz CMOS Low-Noise Amplifier with Input-Referred Noise Reduction and Coupled-Inductive-Peaking Technique

Haitang Dong, Keping Wang, Geliang Yang,
Shiyue Ma, and Kaixue Ma
Tianjin University, Tianjin, China

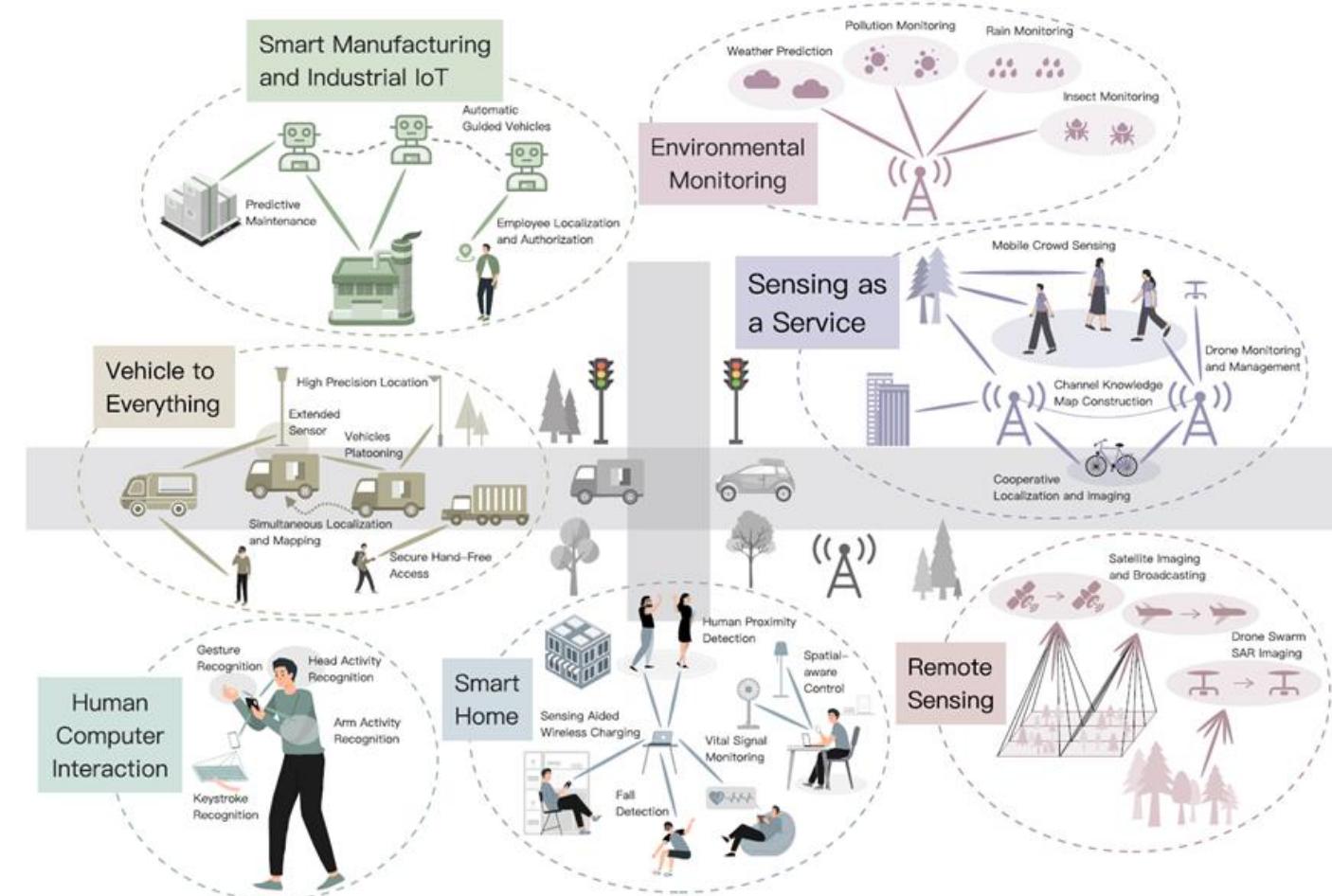
Outline

- Introduction and Motivation
- Input-Referred Noise Reduction
- Broadband Input-matching
- Coupled-Inductive-Peaking Technique
- LNA Implementation
- Measurement and Comparison
- Conclusion

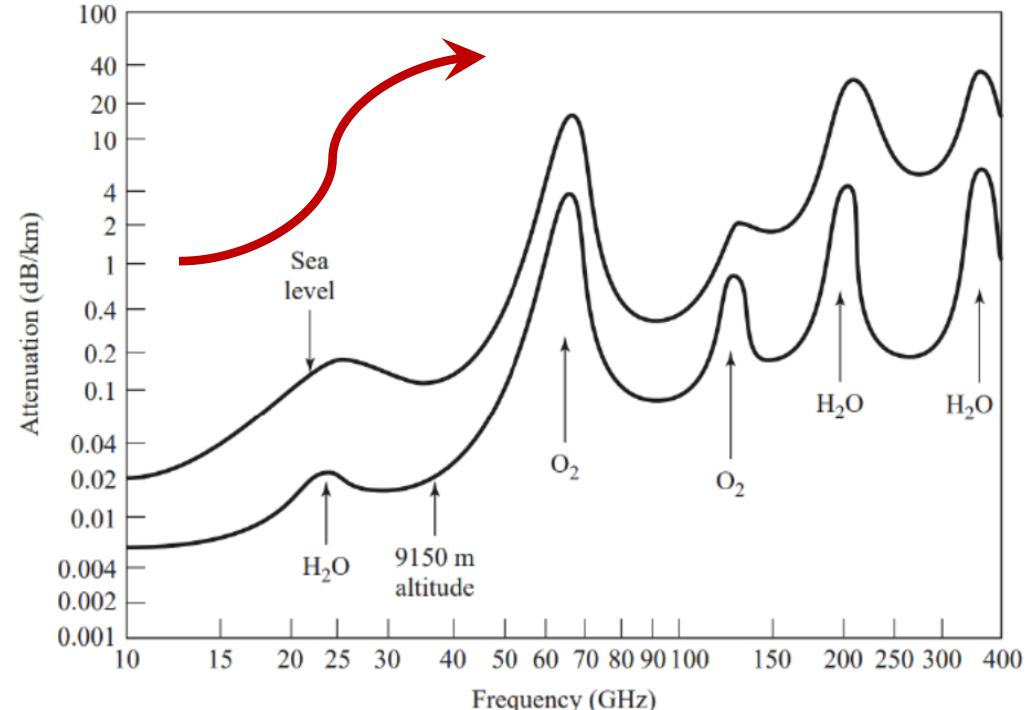
Introduction and Motivation

- Integrated sensing and communication (**ISAC**)

- The demand for channel **bandwidth** increases
- Millimeter wave** technology is a KEY technology of ISAC
- LNA** is crucial as the first part of the broadband receiver.



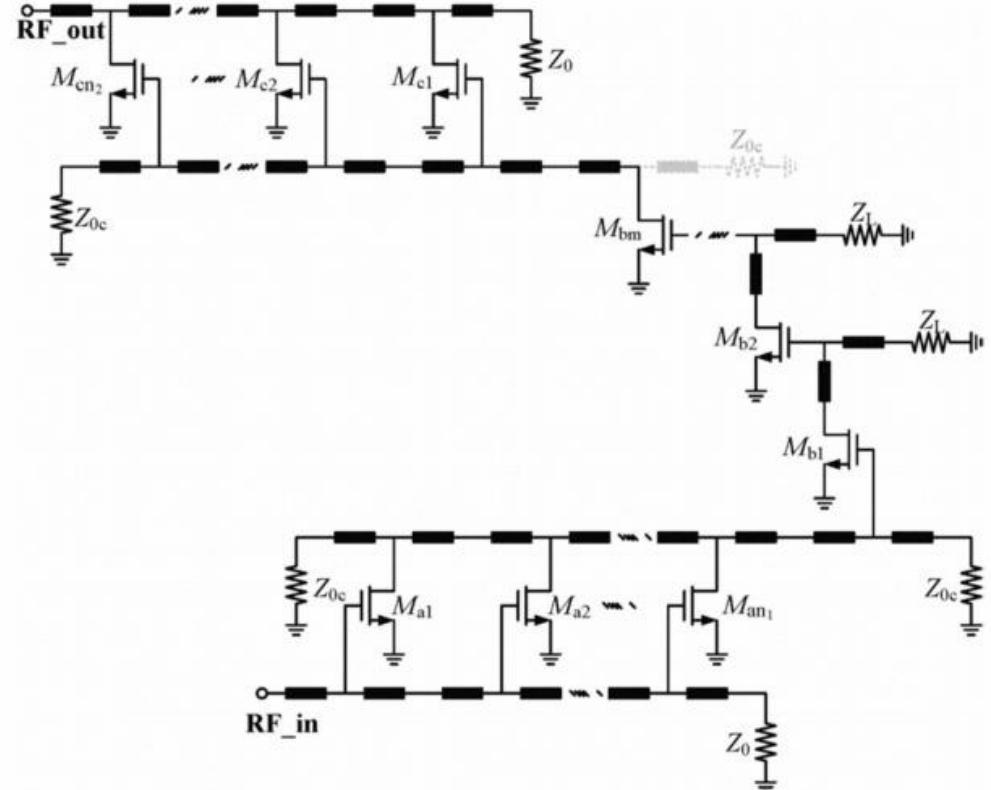
- Design challenges for Broadband LNA
 - Broadband circuits are **more difficult** to design than narrowband circuits
- Design challenges for mm-wave LNA
 - Transmission line loss 😞
 - Limited signal transmission 😞
 - Complex parasitic situations 😞



Introduction and Motivation

- Distributed amplifiers (DAs)

- High gain 
- Bandwidth up to tens of GHz 
- Large chip area 
- High power consumption 



[Ping Chen, et al., MTT-S'11]

Introduction and Motivation

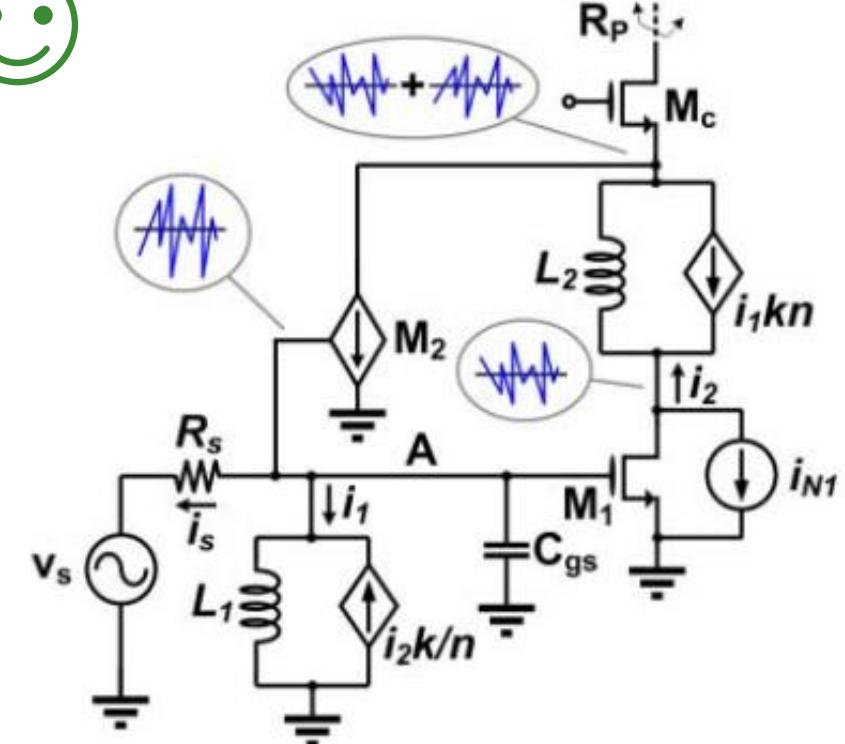
- **Wideband Input Matching and Noise Cancellation LNA**

- Break the bottom-line of the NF ($\sim 3\text{dB}$) 

- Ultra wideband 

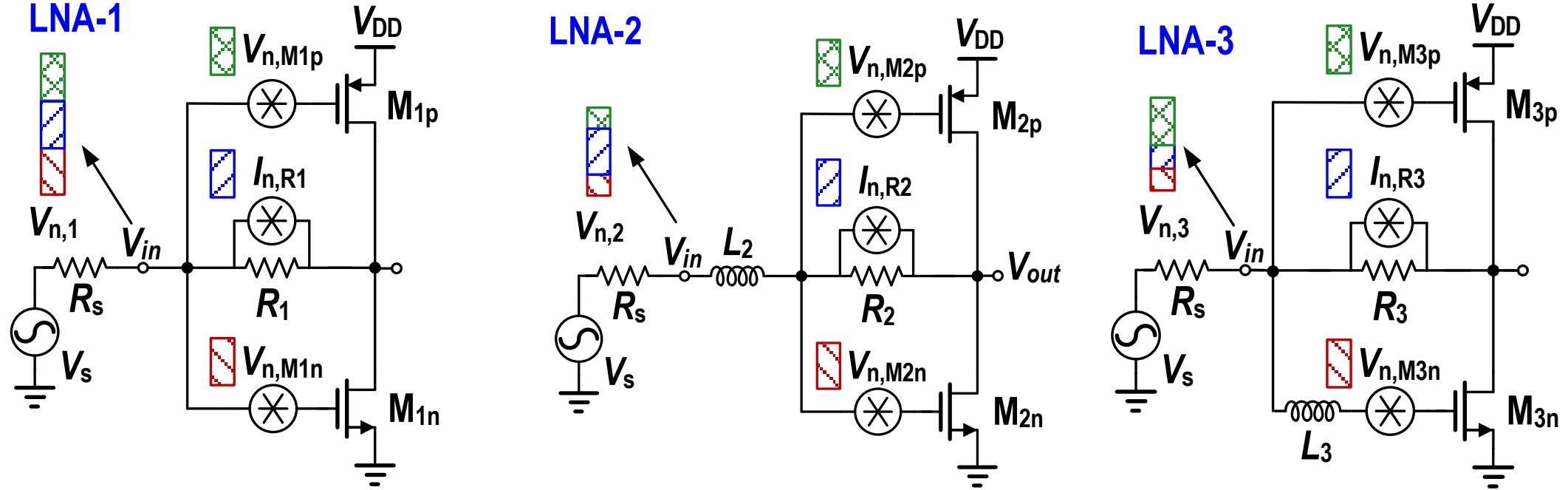
- Low power consumption 

- The gain is not as good as DAs 



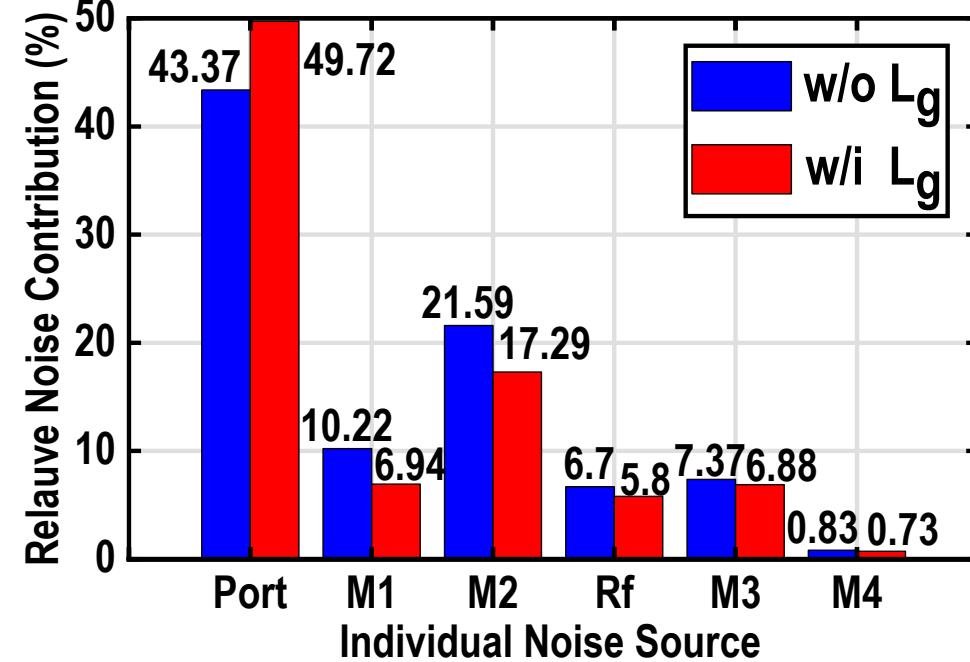
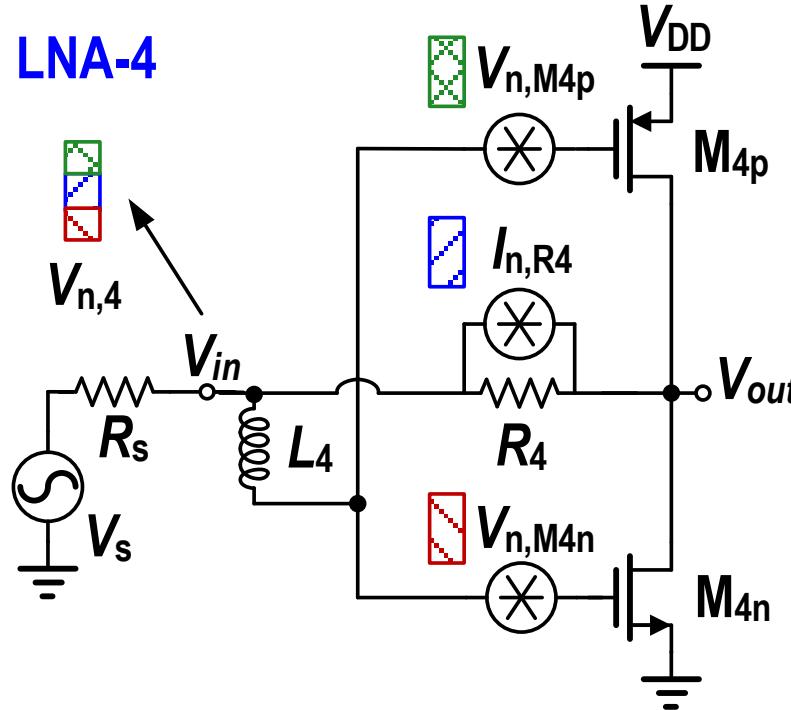
[Liang Wu, et al., TCAS-I'17]

Input-Referred Noise Reduction



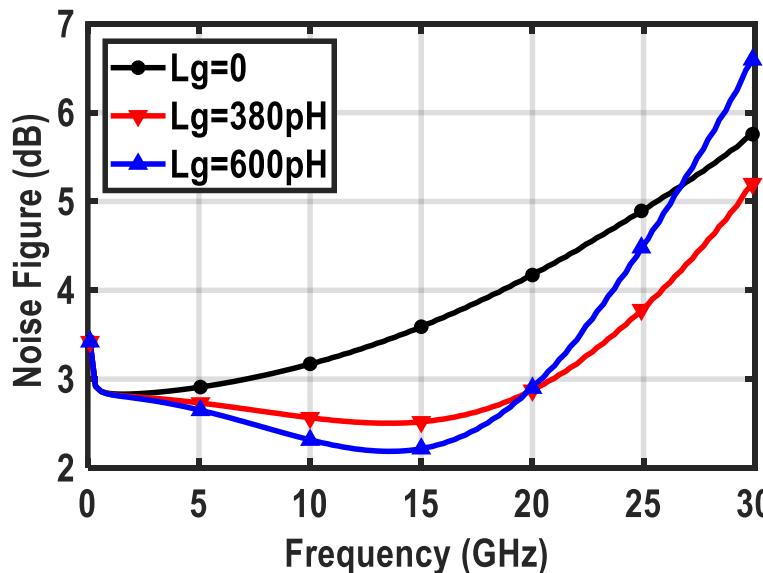
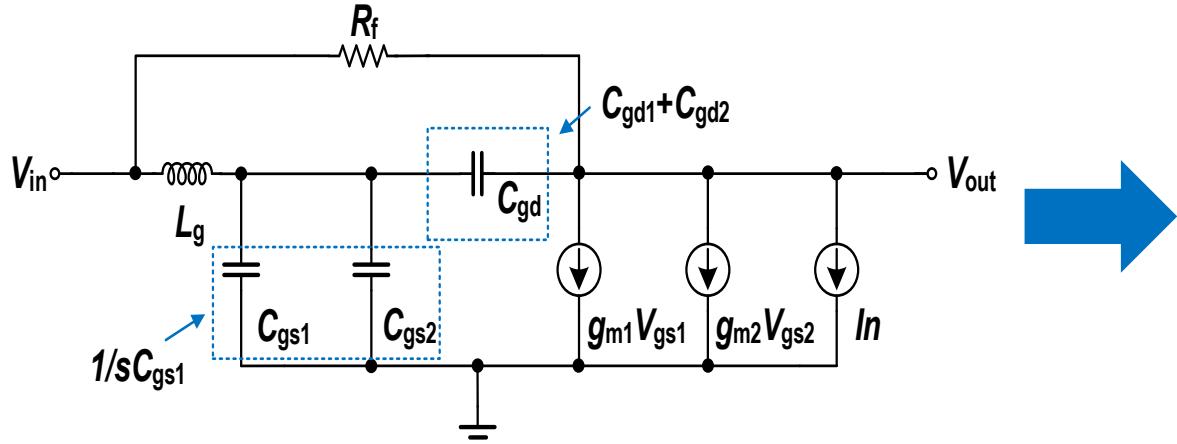
- LNA-1: Traditional inverter-based LNA
- LNA-2: Inverter-based LNA with inductive matching of L2
- LNA-3: Inverter-based LNA with inductive matching of L3

Input-Referred Noise Reduction



- Proposed the LNA-4 by using the **input-referred noise reduction technique**.
- The equivalent voltage noises of M_{4n} and M_{4p} are divided by L_4 .
- The current noise of feedback resistor R_f is shunted to the ground by the series resonant path composed of the C_{gs} and inductor L_4 .

Input-Referred Noise Reduction



The NF can be expressed:

$$NF = 1 + \frac{V_{n,out}^2}{A_o^2} \cdot \frac{1}{4kTR_s} \quad (1)$$

Using the simplified small-signal equivalent circuit, the $V_{n,out}^2$ can be derived as:

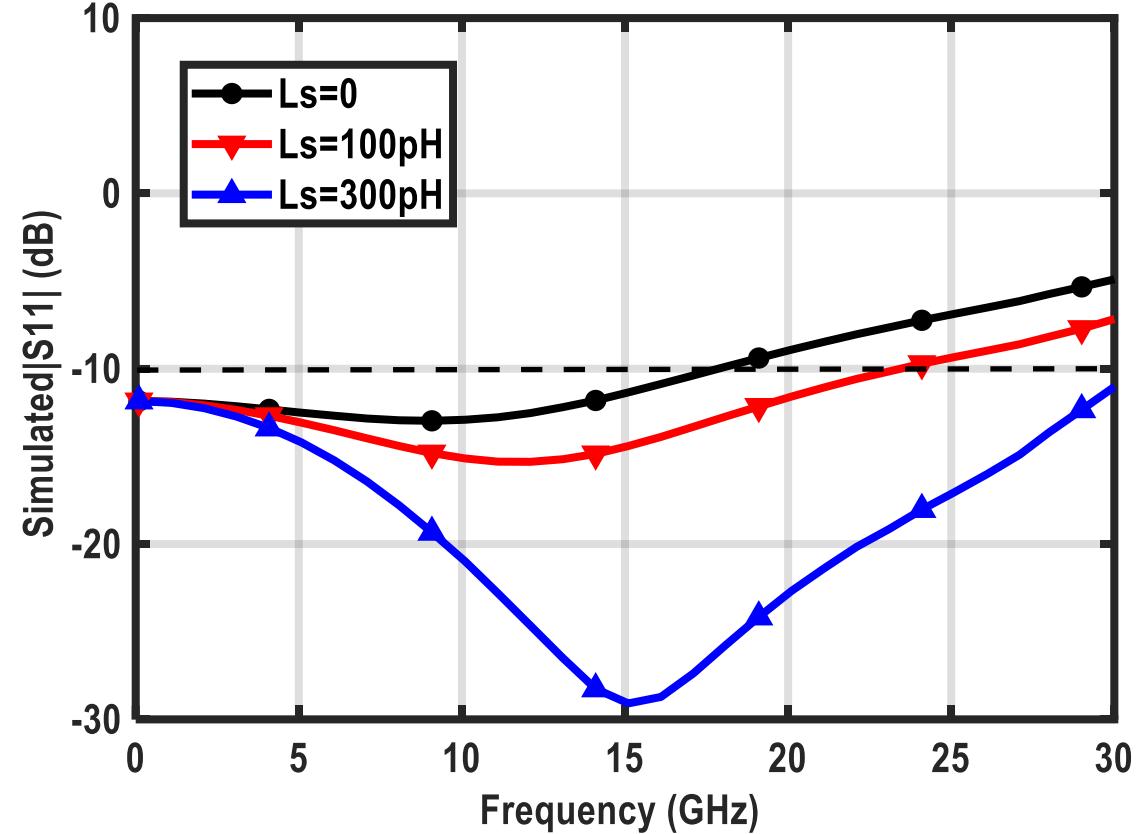
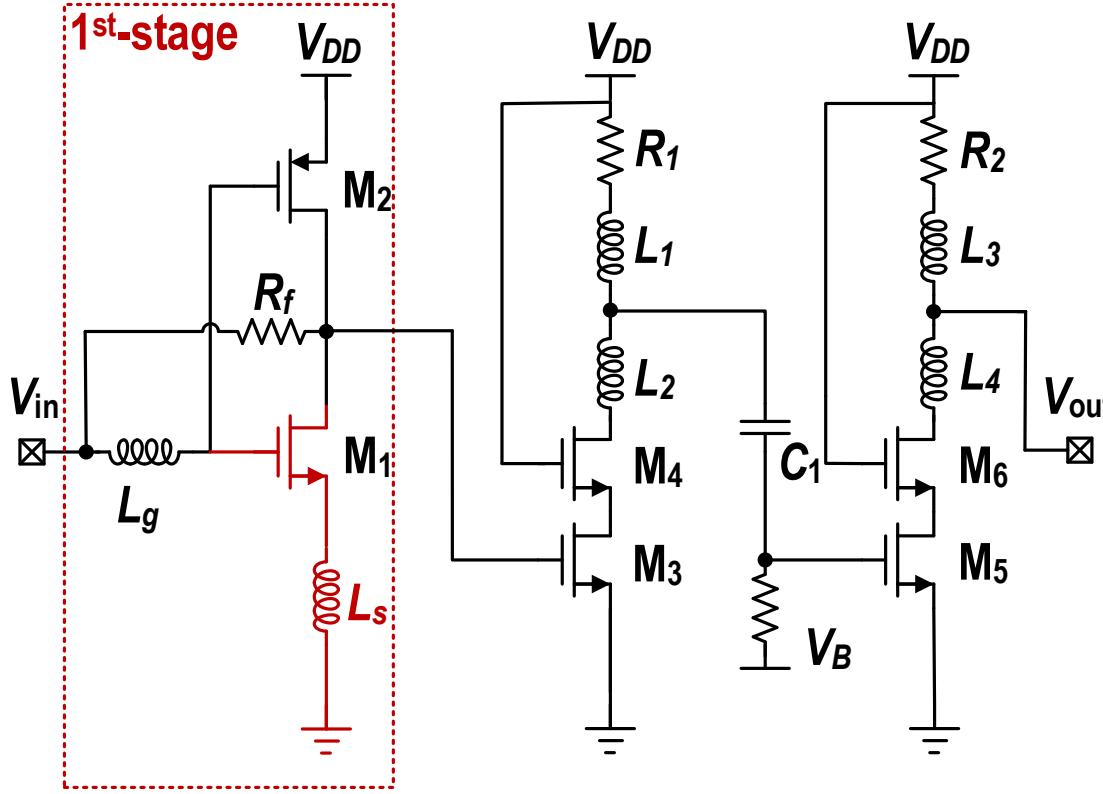
$$\overline{V_{n,out}^2} = 4kT \left[R_f + \gamma g_m \cdot \left(\frac{V_{out}}{I_n} \right)^2 \right] \quad (2)$$

Where

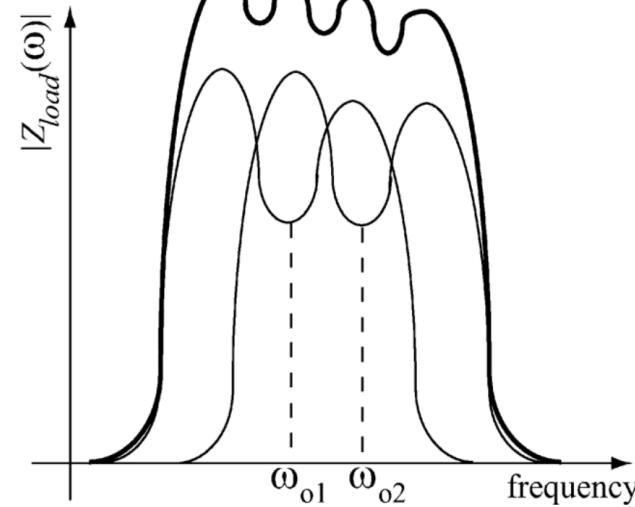
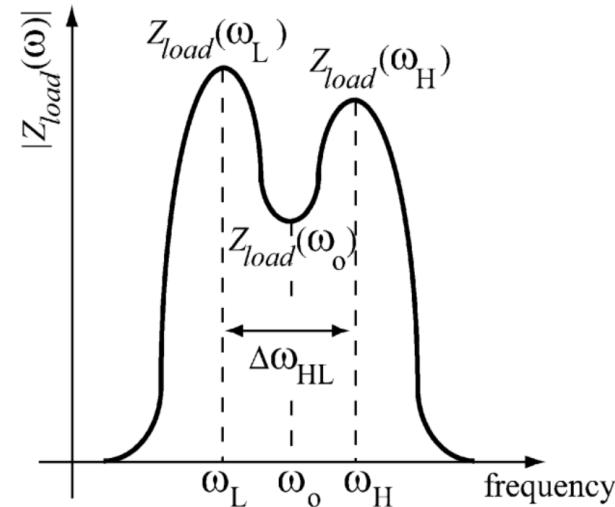
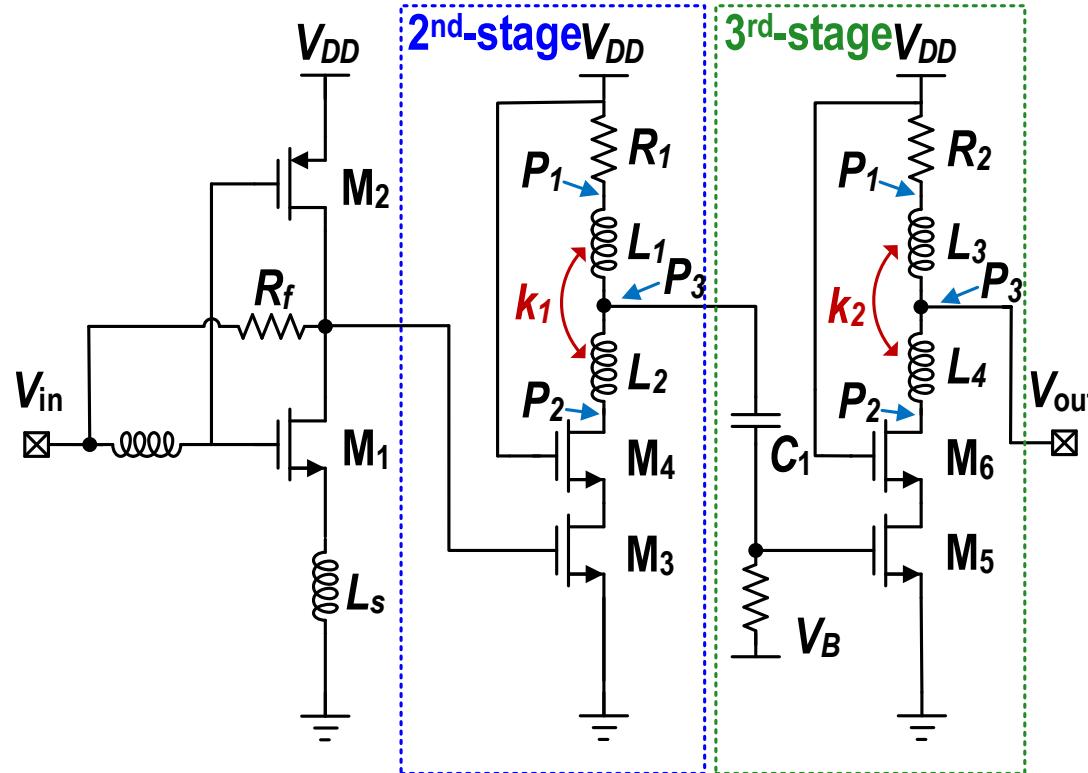
$$\frac{V_{out}}{I_n} = \frac{A \cdot R_f}{A + R_f \cdot [sC_{gd} \cdot (1 + s^2 L_g C_{gs}) + g_m \cdot s^2 L_g C_{gd}]} \quad (3)$$

$$\text{Where } A = 1 + s^2 L_g (C_{gs} + C_{gd}) \quad (4)$$

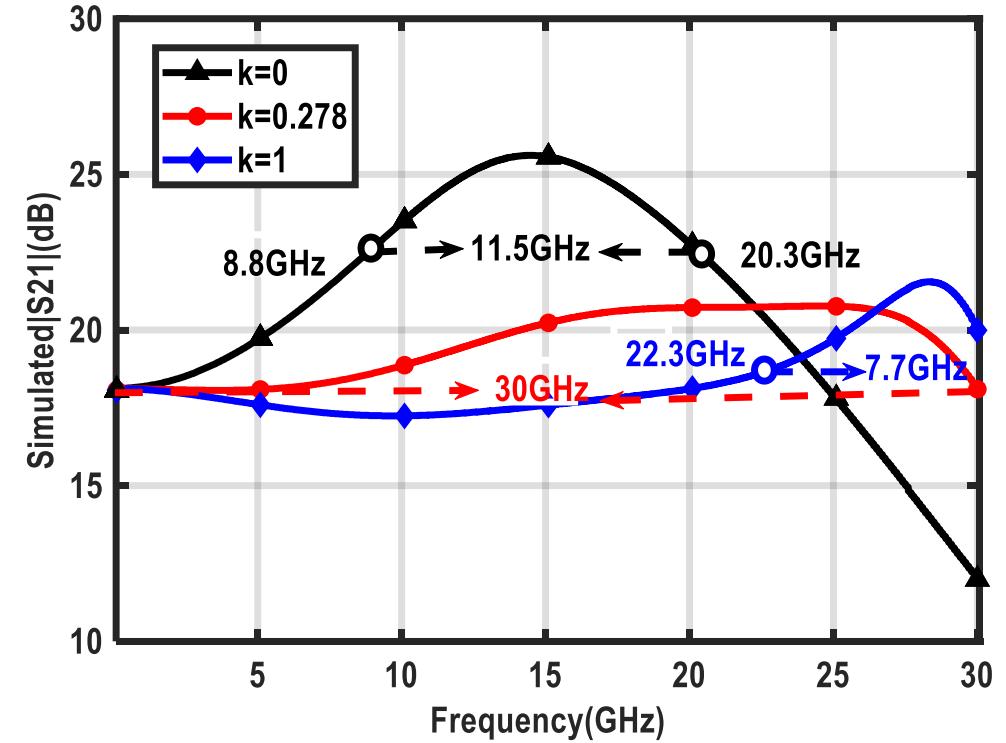
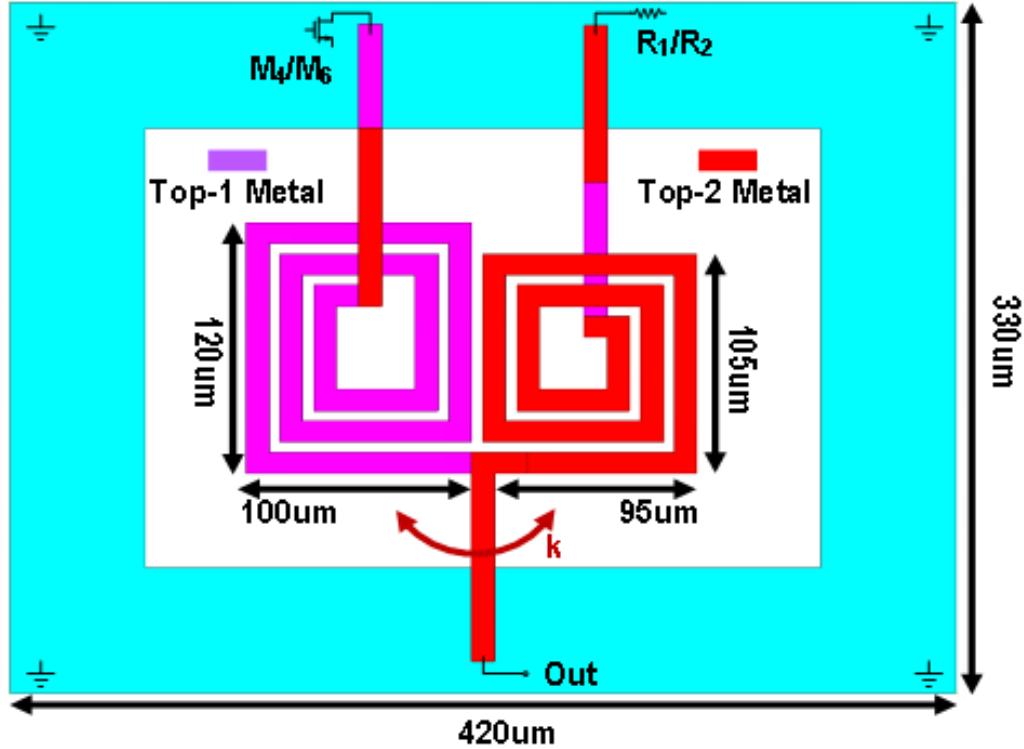
Broadband Input-matching



- Inductor L_s is used to form source inductance degradation structure LNA to achieve **broadband input matching** in the millimeter wave broadband
- $L_s=300\text{pH} \rightarrow S_{11}<-10\text{dB}$



- **Cascode** amplifiers provide better reverse isolation and higher power gain over a broadband bandwidth.
- **Coupled-inductive-peaking technique** to achieve broadband load.



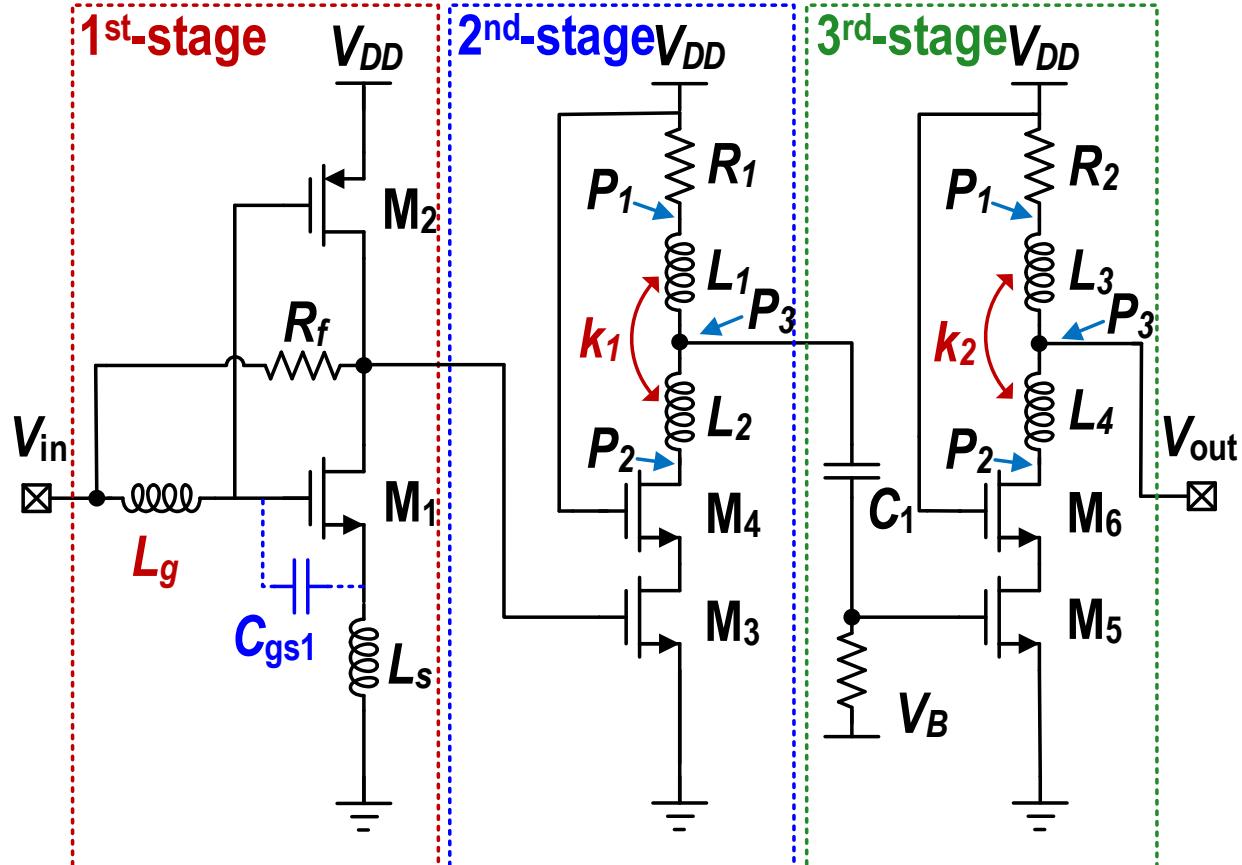
- Two different top layer metals are used to further reduce the insertion loss
- Based on the EM simulation, k is designed to be 0.278, and the 3-dB bandwidth of LNA can reach 0.4-30 GHz

- Schematic of the Ultra wideband LNA

 $V_{DD}=1.5V$
 $K_1=0.278$
 $R_f=308.8\Omega$
 $R_2=40.8\Omega$
 $M_1=0.06\times 14\times 4\mu m^2^*$ $L_g=380pH^{\#}$
 $M_2=0.06\times 16\times 4\mu m^2^*$ $L_s=200pH^{\#}$
 $M_3=0.06\times 16\times 4\mu m^2^*$ $L_1=800pH^{\#}$
 $M_4=0.06\times 16\times 4\mu m^2^*$ $L_2=600pH^{\#}$
 $M_5=0.06\times 16\times 4\mu m^2^*$ $L_3=820pH^{\#}$
 $M_6=0.06\times 16\times 2\mu m^2^*$ $L_4=600pH^{\#}$

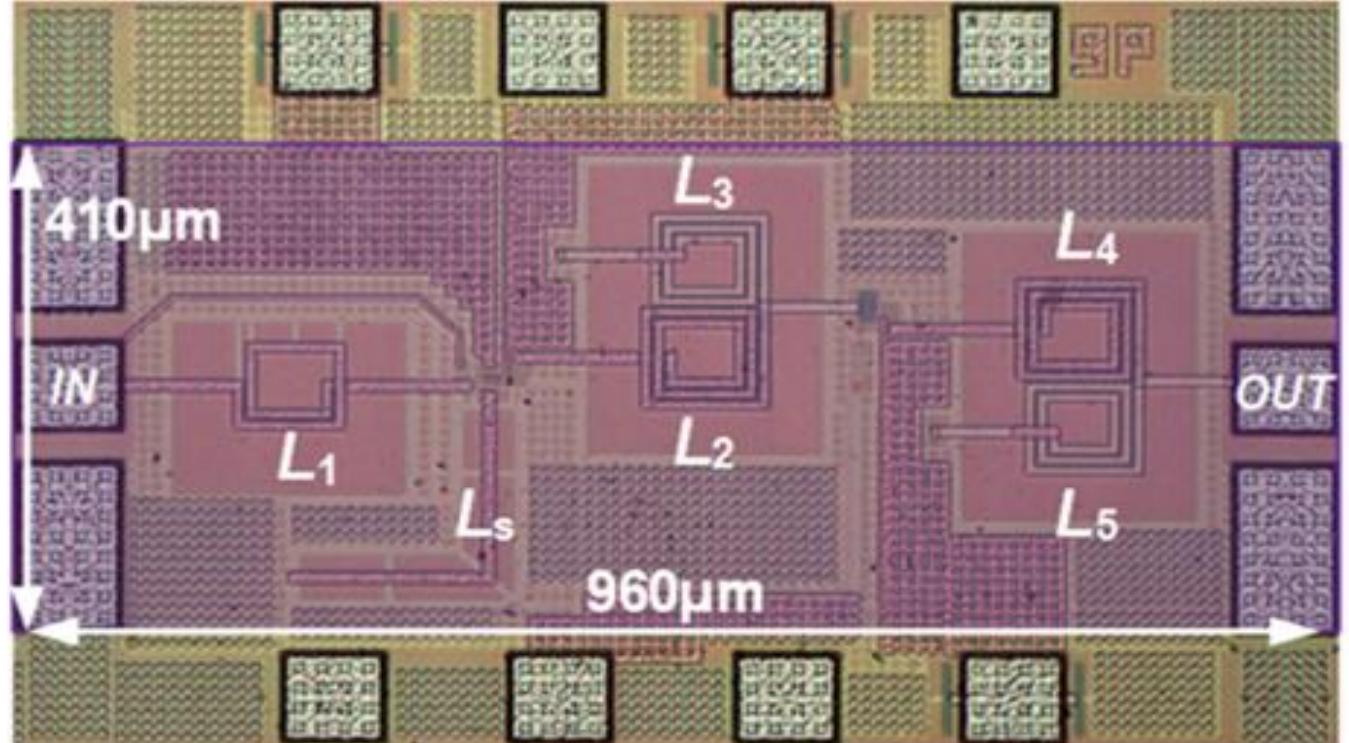
*The process scales 0.9x during manufacturing

#@15GHz

 $V_B=0.65V$
 $k_2=0.278$
 $R_1=60.1\Omega$
 $C_1=557fF$


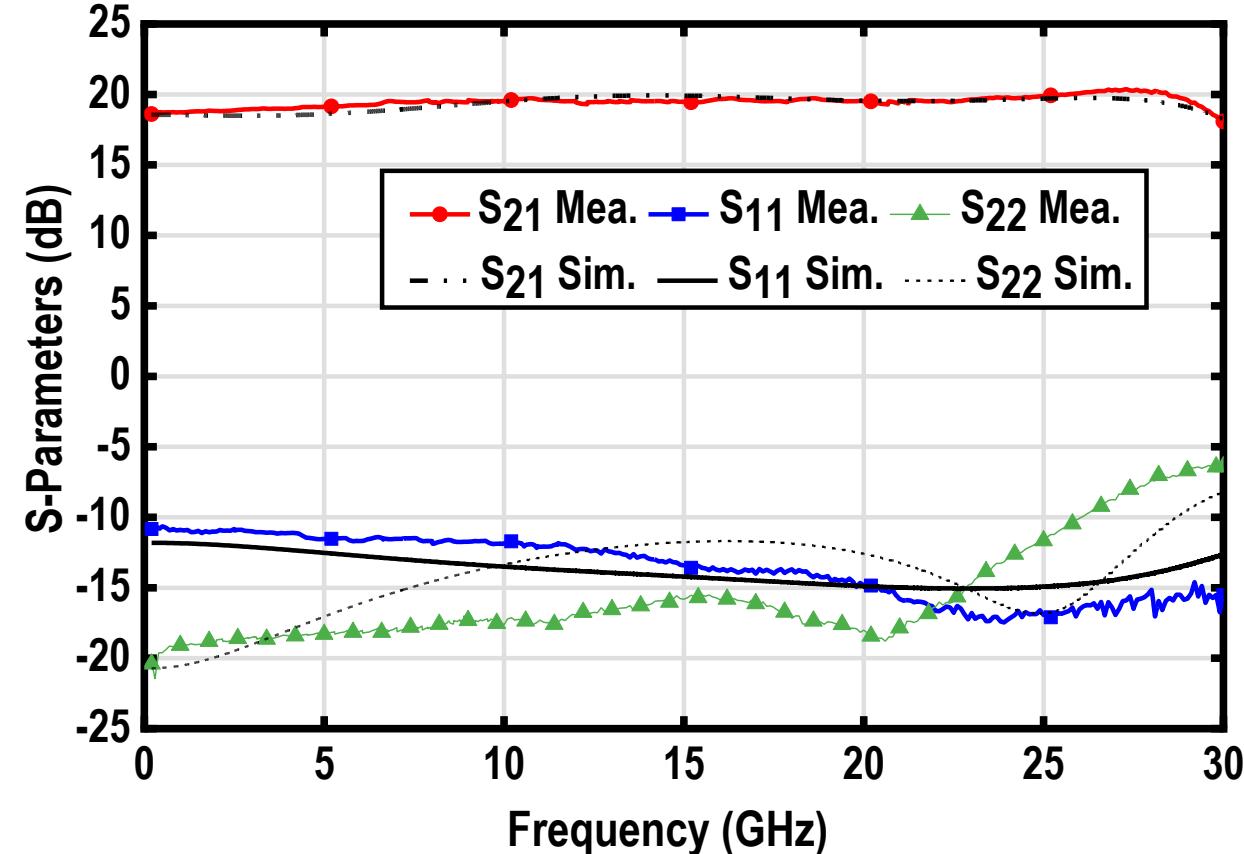
Chip Micrograph

- In 55-nm CMOS technology
- Chip size: 0.39 mm^2
- Supply: 1.5V



Measurement

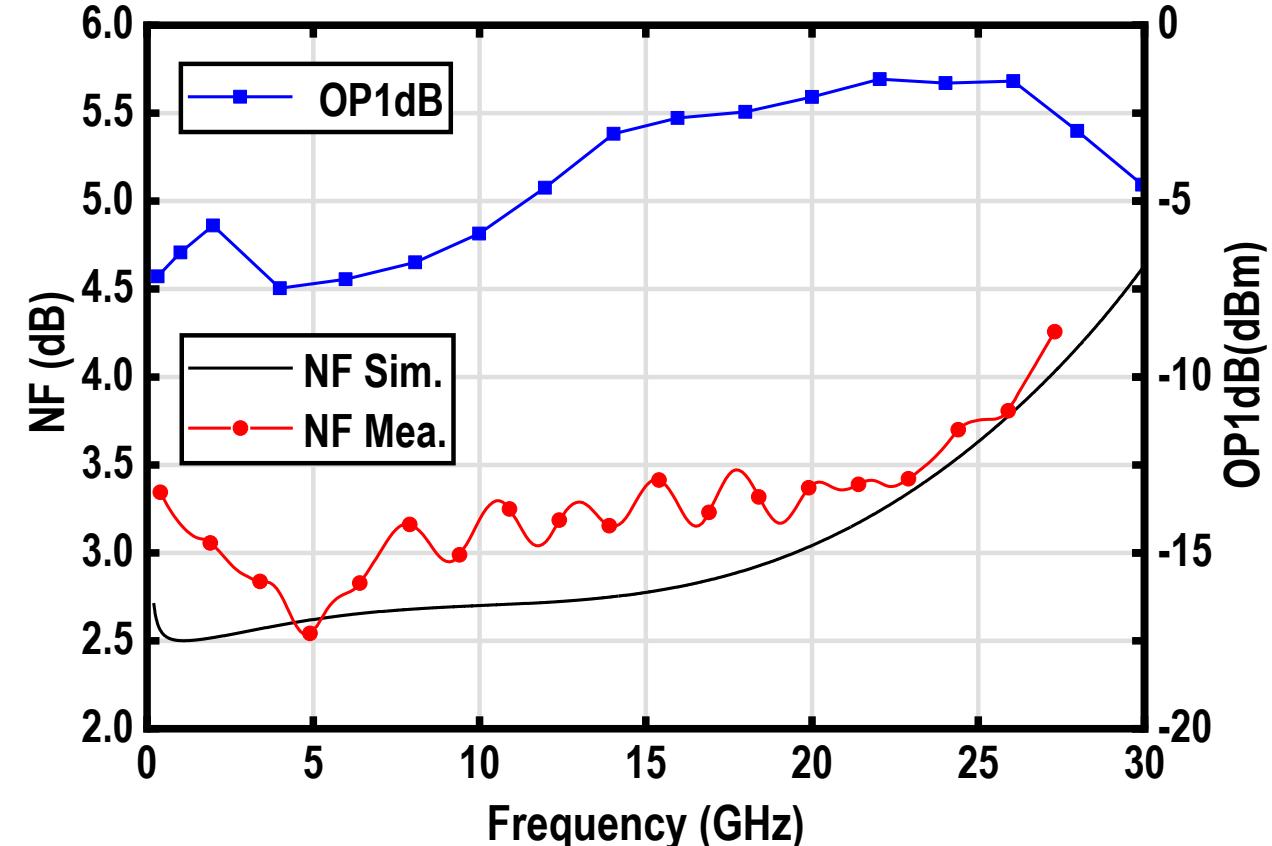
- S-parameter measurements



- $S_{11} < -10 \text{ dB}$ from 0.4 to 30 GHz.
- S_{21} : 18.2 to 20.3 dB from 0.4 to 30 GHz.

Measurement

- Noise figure and OP_{1dB} measurements



- NF < 4.3 dB from 0.4 to 26.5 GHz.
- Output $P_{1dB} > -8$ dBm from 0.4 to 26.5 GHz.

Performance comparison

Ref.	Techn.	Freq. (GHz)	Gain (dB)	NF (dB)	OP _{1dB} (dBm)	IIP3 (dBm)	P _{DC} (mW)	V _{DD} (V)	Size (mm ²)	FoM
[1] IMS'11	0.18um CMOS	0-35	20.5&	6.8-8#	8.6*	N/A	250	2.8	0.78	0.33
[3] TMTT'20	65nm CMOS	1-20	12.8	3.3-5.3	N/A	5.8	20.3	1.6	0.096	2.42
[5] JSSC'15	40nm CMOS	24-54	7	<6.2	-0.5-2	10-13	34	N/A	0.15	0.75
[6] RFIC'19	65nm CMOS	24.9-32.5	18.33	3.25-4.2	-24	N/A	20.5	1.2	0.11	2.25
[7] RWS'14	90nm CMOS	1.9-22.5	13.52	2.74-3.74	N/A	-1.8	9.96	1.2	0.72	8.85
[8] MWCL'17	65nm CMOS	7.6-29	10.7	4.5-5.6	N/A	1.4	12.1	1	0.3	2.76
[9] TMTT'22	65nm CMOS	7.2-27.3	16.6	3.3-3.72	N/A	-6^	13.2	1.2	0.14	8.28
This Work	55nm CMOS	0.4-30	20.3	2.5-4.3	>-8	-15.9	23.5	1.5	0.39	10.98

&minimum Gain, #<18GHz, *@5GHz, ^@20 GHz

$$FoM = \frac{Gain_{max}[abs.] \times BW[GHz]}{(F_{mean} - 1) \times P_{DC}[mW]}$$

Conclusion

- Proposed a ultra wideband LNA with:
 - Input-referred noise reduction → Low NF
 - Broadband Input-matching → -3dB bandwidth
 - Coupled-inductive-peaking technique → High gain
- It achieves:
 - Ultra wideband -3dB bandwidth: 0.4-30GHz
 - Low noise NF < 4.3 dB
 - High gain Peak gain: 20.3dB
 - High linearity OP_{1dB} > -8dBm
 - High FoM The best FoM

Thank you!