A High-Linearity N-Path Passive-LNA for Direct Channel-Selection at Flexible RF

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2G/3G/LTE/NR in a Single RF Transceiver

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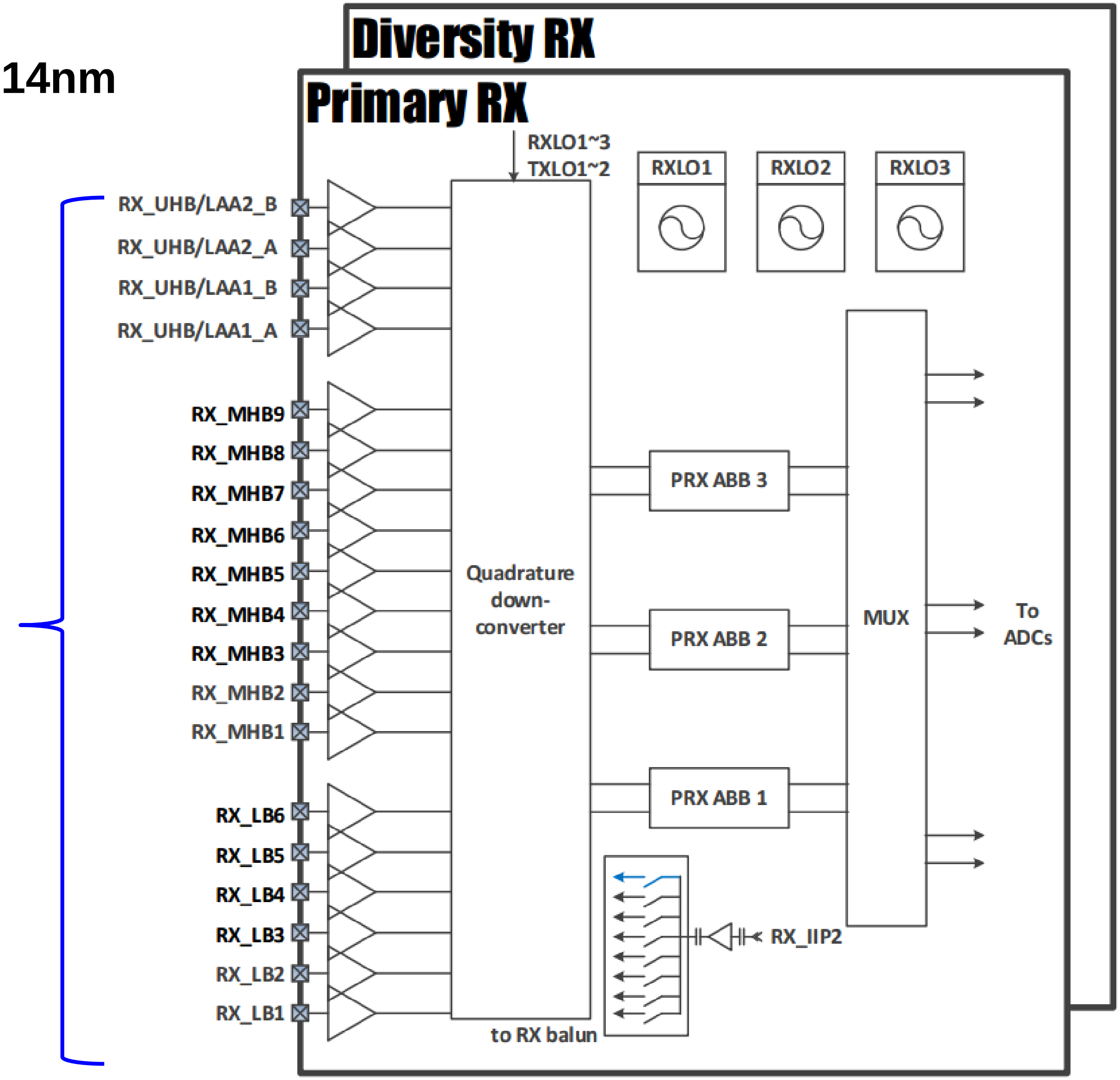
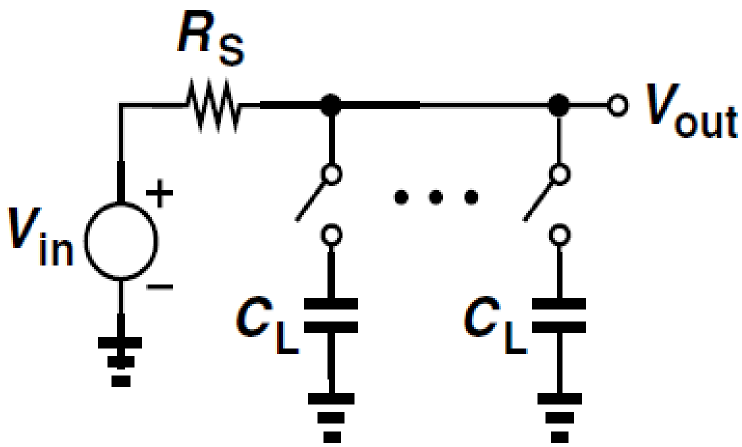
A Low-Power and Low-Cost 14nm FinFET RFIC Supporting Legacy Cellular and 5G FR1

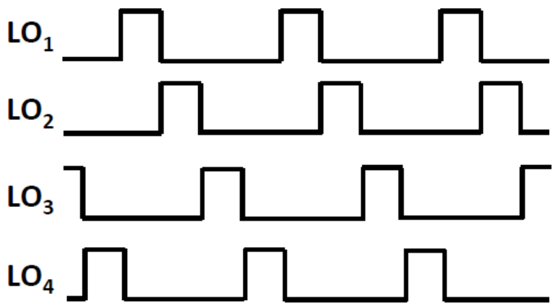
Samsung Electronics, Korea

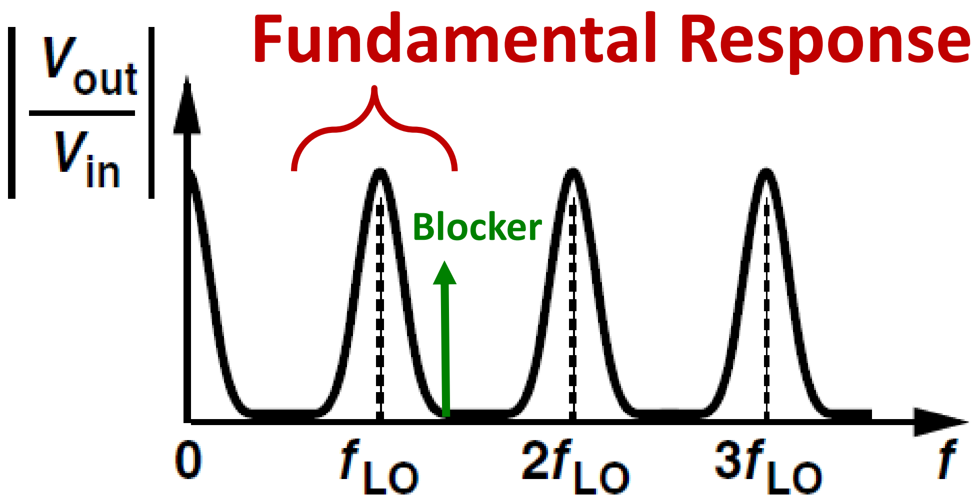
- **Dedicated gm-based LNA for each band**



Passive N-Path SC Filter



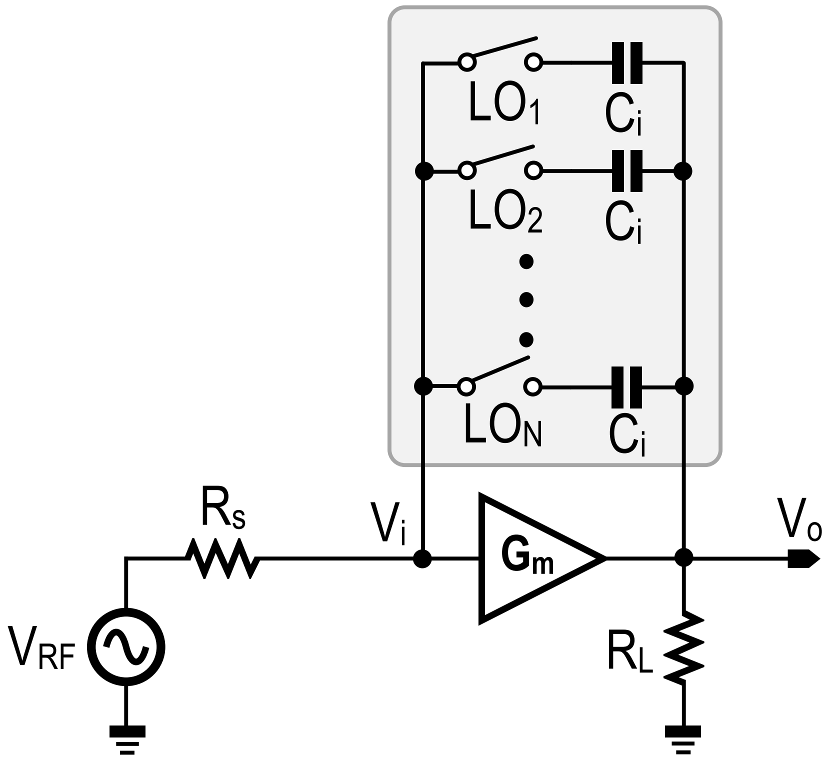


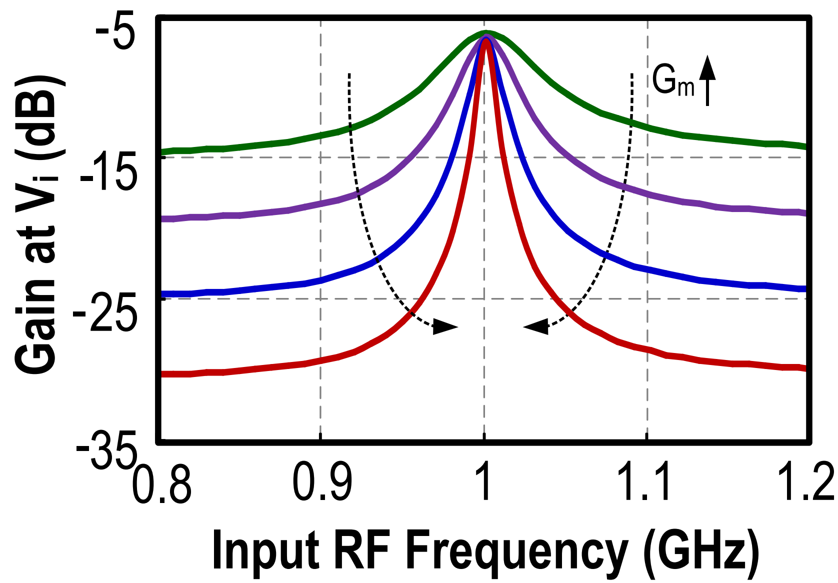


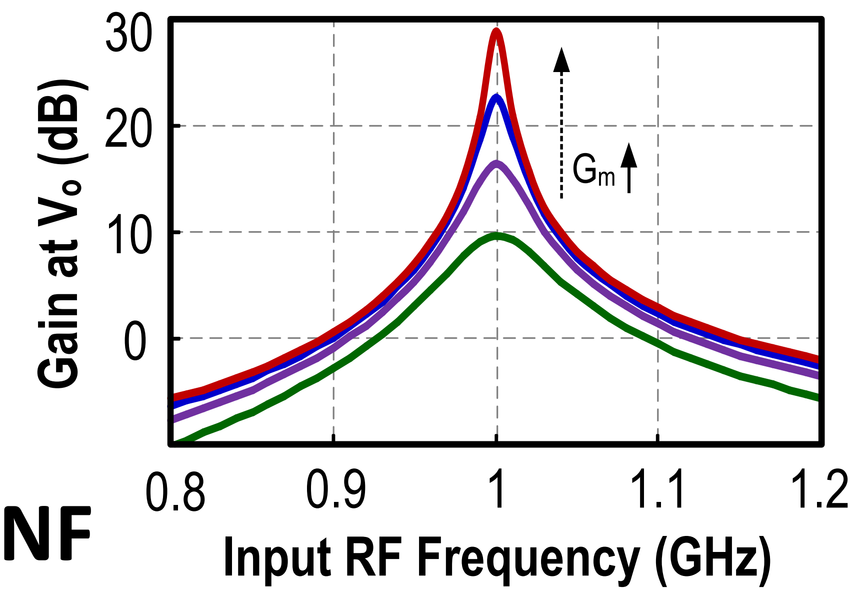
$$Q = \text{Center Freq./BW}$$
$$= 2\pi \times R_s C_L \times N \times f_{LO}$$

- Center Frequency defined by f_{LO}
- There is no gain and no input impedance matching
- A "sharp" response entails big switches & caps

G_m + N-path Filter [Z. Lin TCAS-I'14]

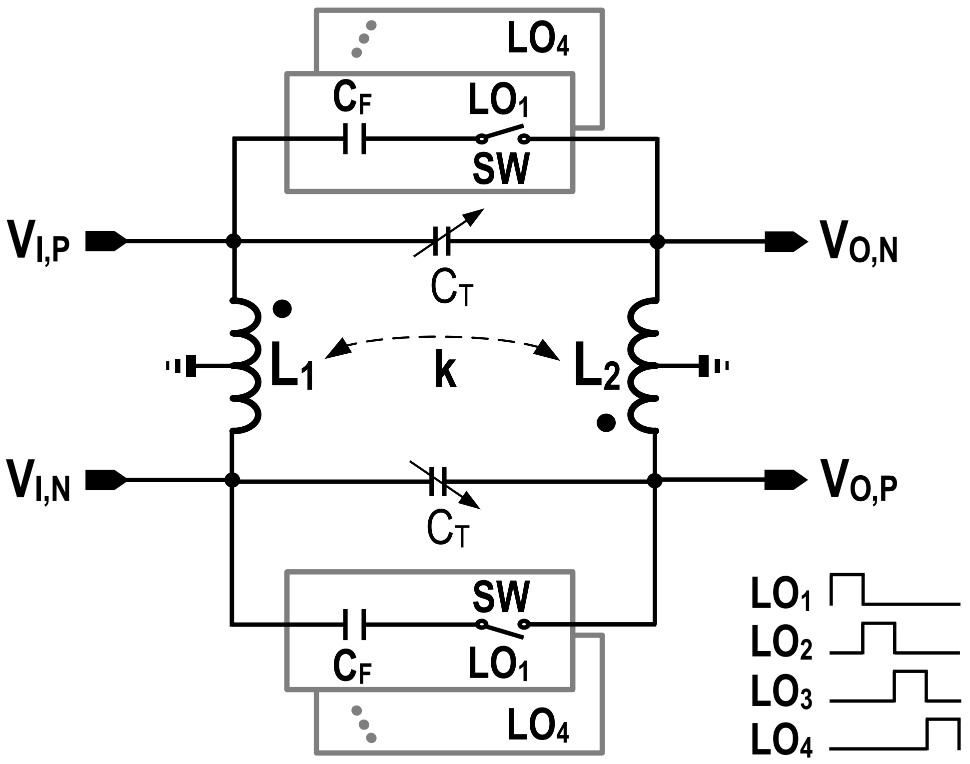


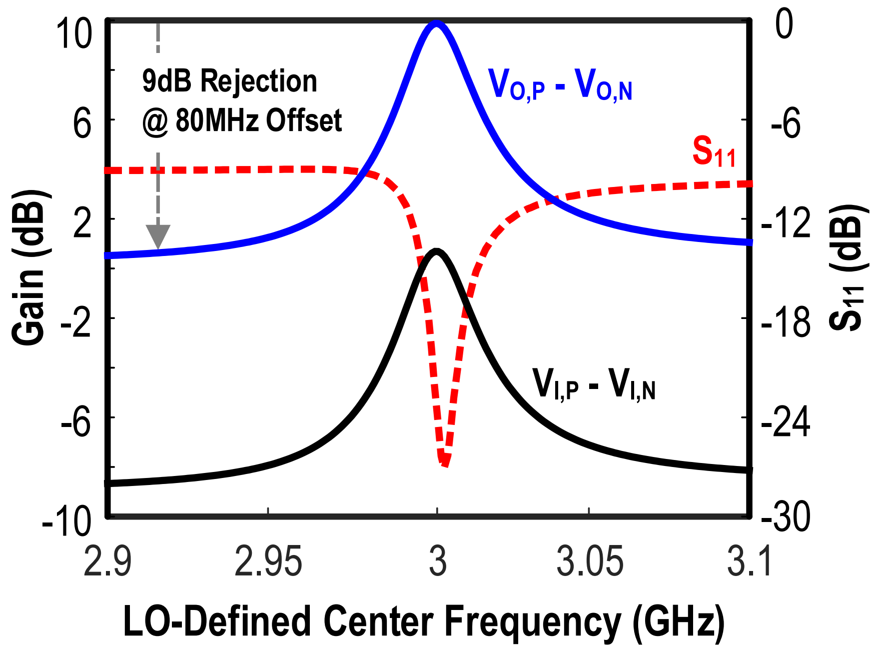




- G_m-controlled stopband rejection (small switches & capacitors are possible)
- Large G_m benefits gain and NF

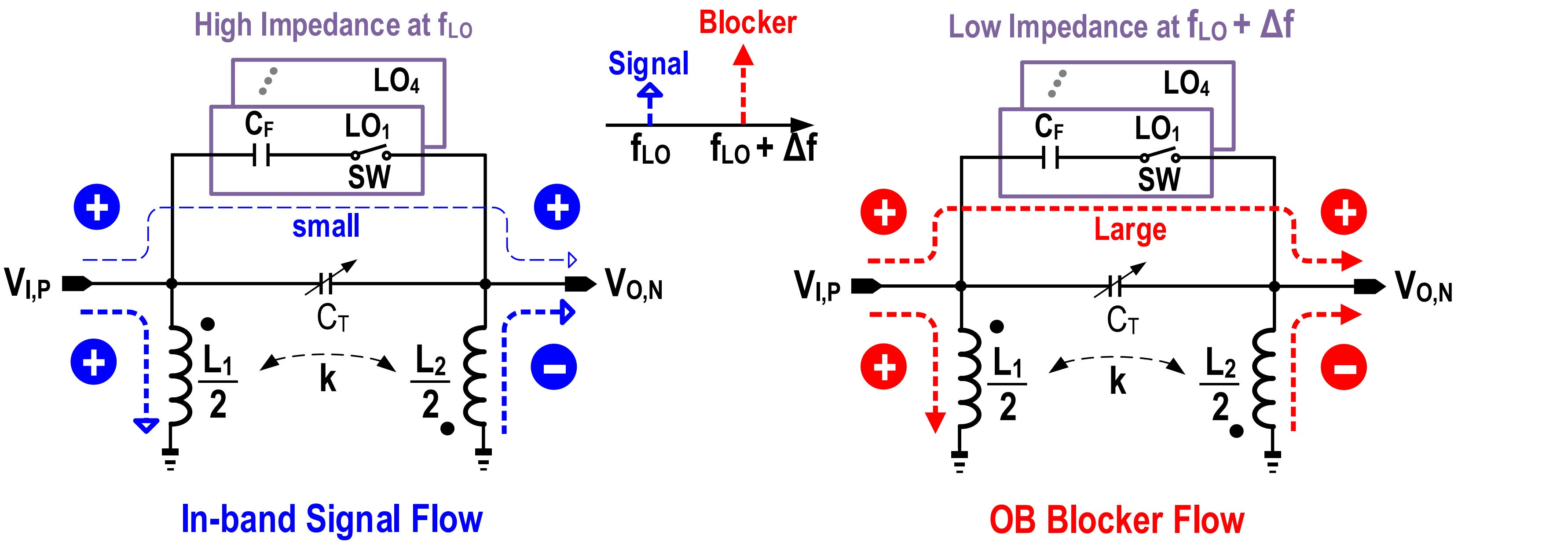
Proposed N-Path Passive-LNA (pLNA)

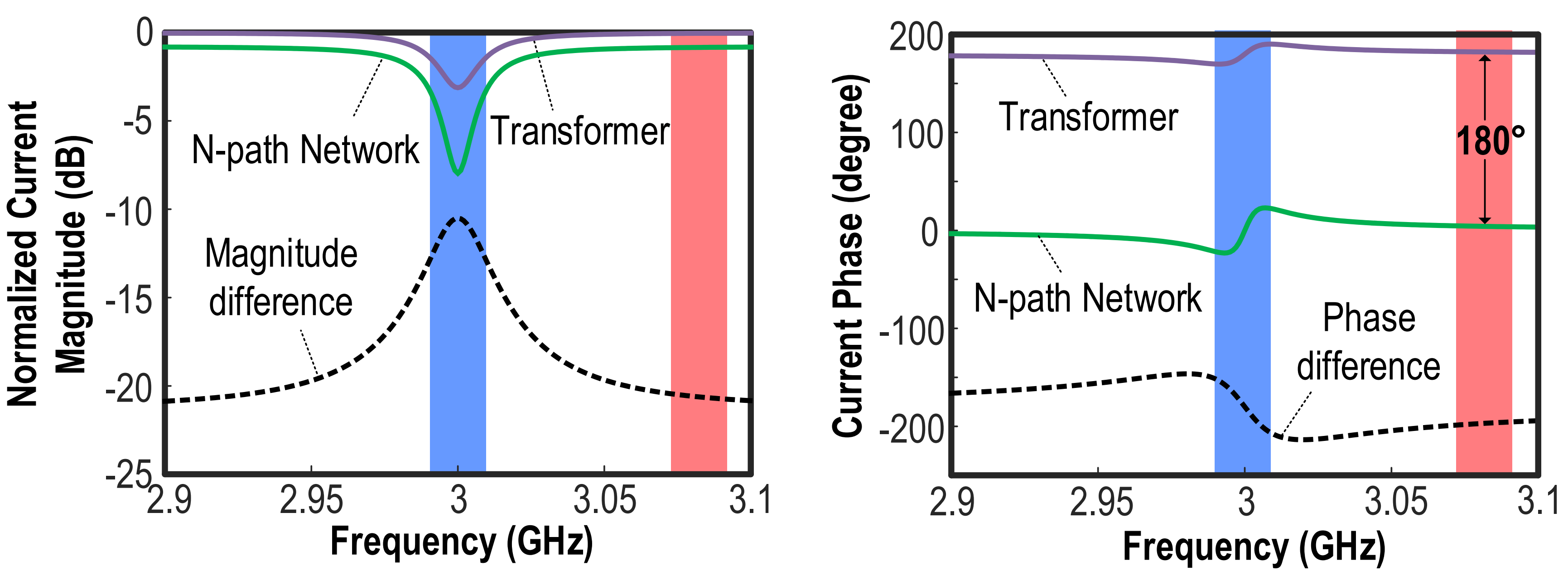




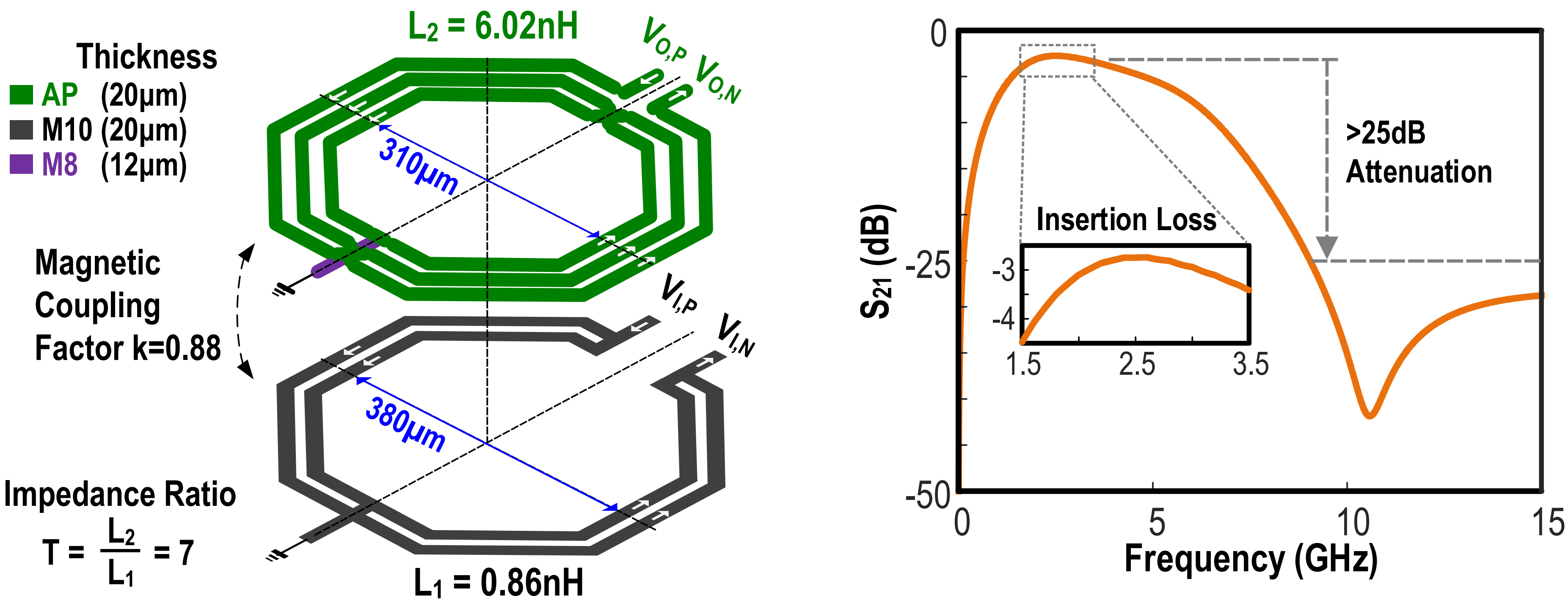
- Step-up transformer to replace G_m → **better in-band and out-of-band linearity**
- Easy differential implementation → **better IIP2**
- No static power consumption

Operation Principle of the N-path pLNA



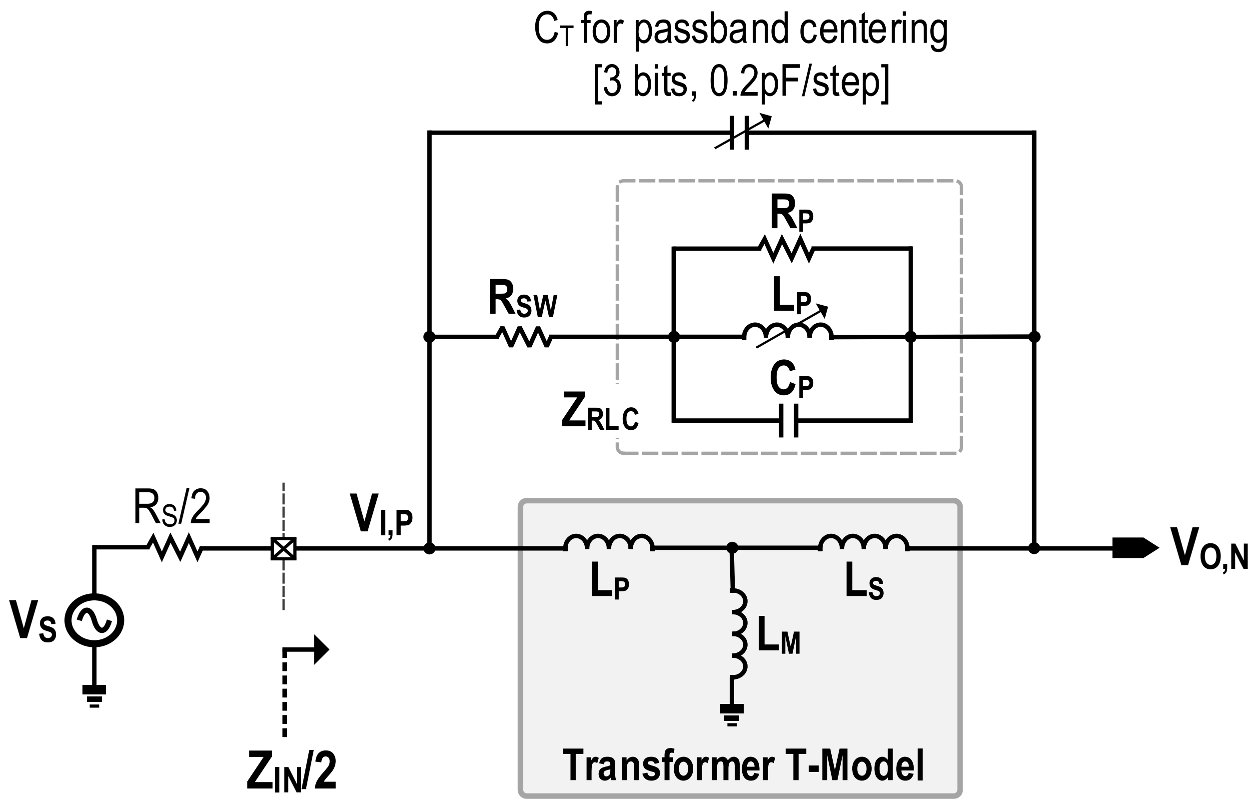


Step-Up Spiral Transformer



- Vertical-coupling spiral transformer with different metallization allows a high impedance ratio of 7
- Reasonable insertion loss and wideband coverage
- Intrinsic lowpass response suppresses the harmonic folding terms

N-path pLNA LTI Model



k : Magnetic Coupling Factor

T : Impedance Ratio

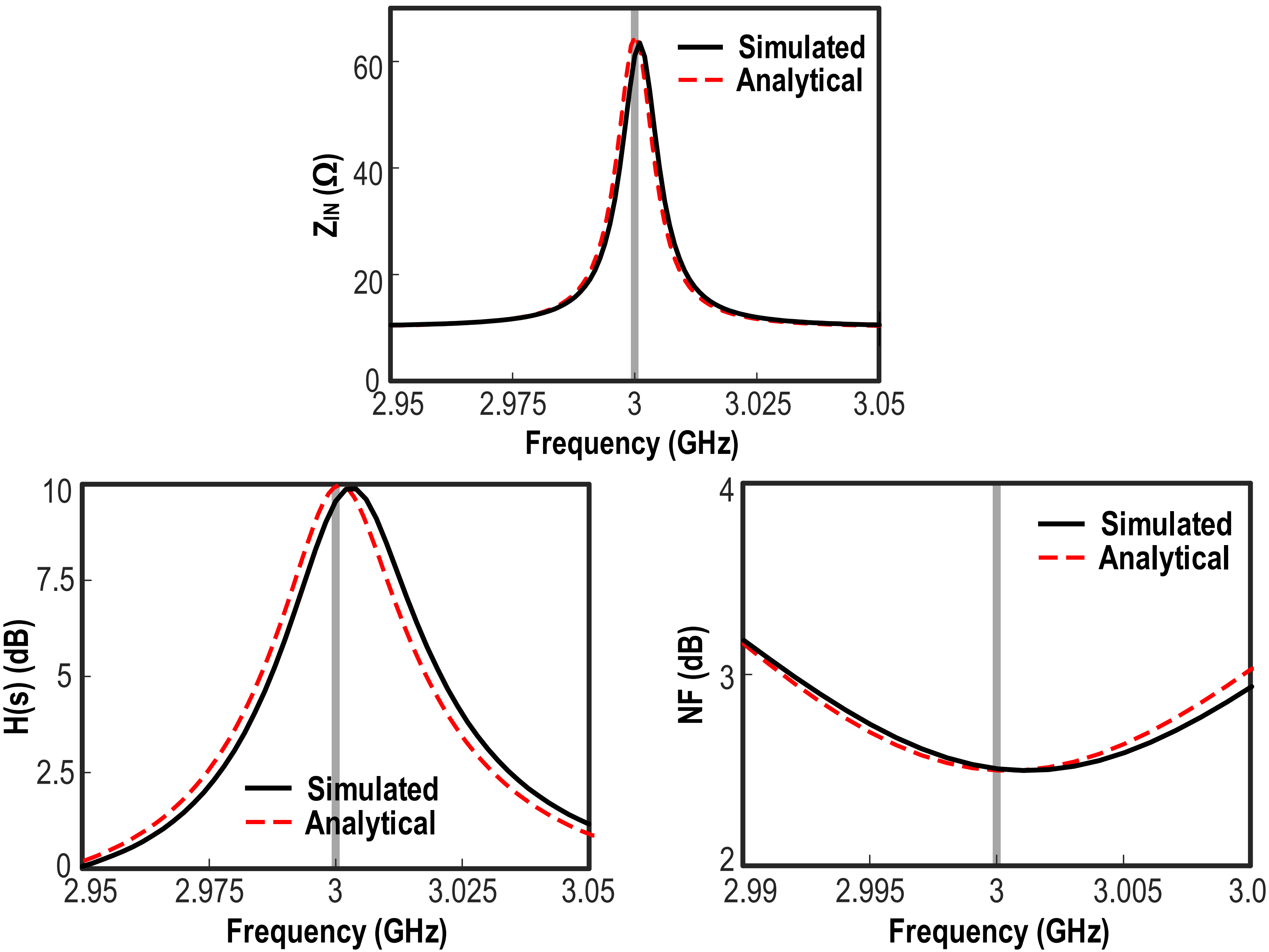
$$L_P = \frac{L_1 + k \cdot L_1 \cdot \sqrt{T}}{2}$$

$$L_S = \frac{L_2 + k \cdot L_1 \cdot \sqrt{T}}{2}$$

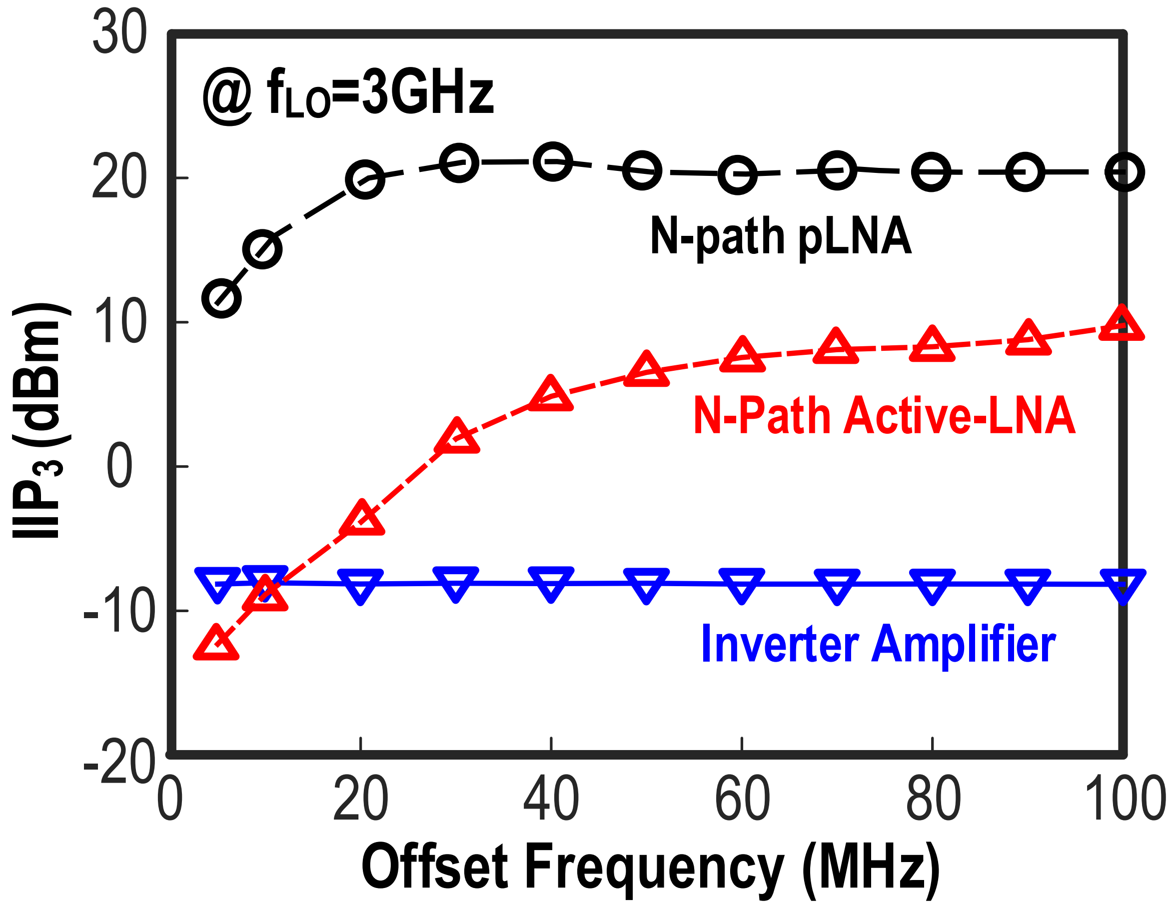
$$L_M = \frac{-k \cdot L_1 \cdot \sqrt{T}}{2}$$

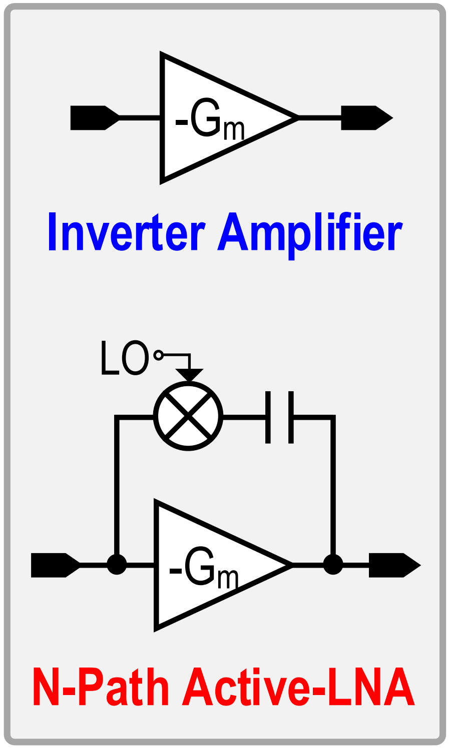
- **A transformer T-model is used**
- **The N-path SC network is replaced by a paralleled RLC network**
- **The 3-bit C_T bank enables passband centering**

N-path pLNA LTI Model



Simulated IIP3 for Different Implementation

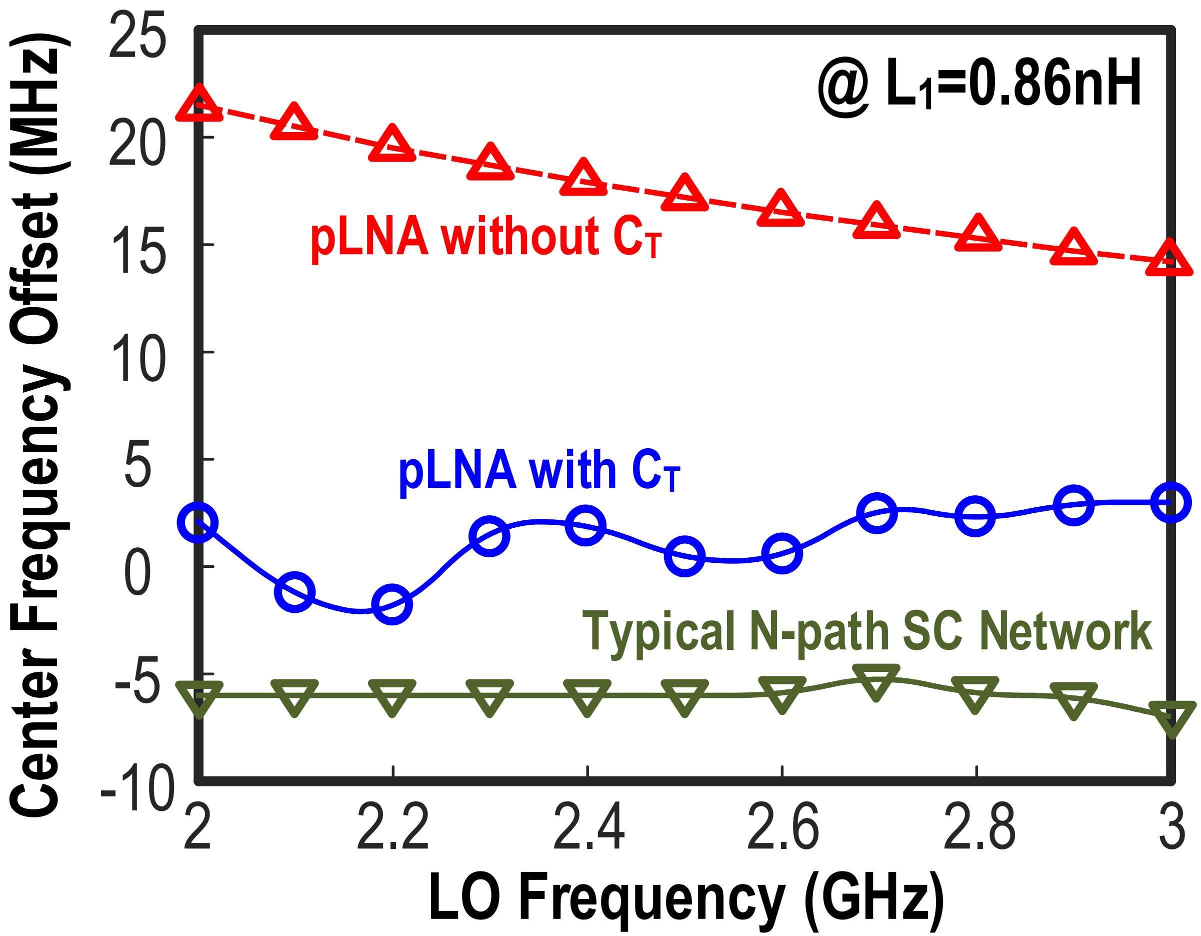




G_m= -18mS
voltage gain= 10 dB

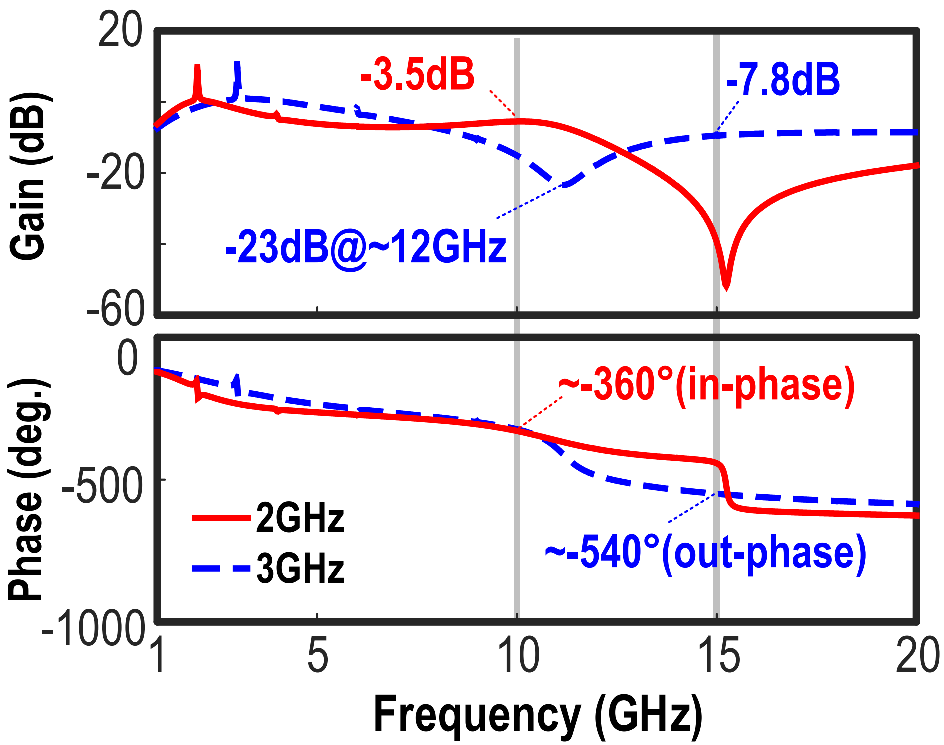
- N-path pLNA shows better IB and OB IIP3
- Linearity is upper-limited by the MOS switches in the N-path network

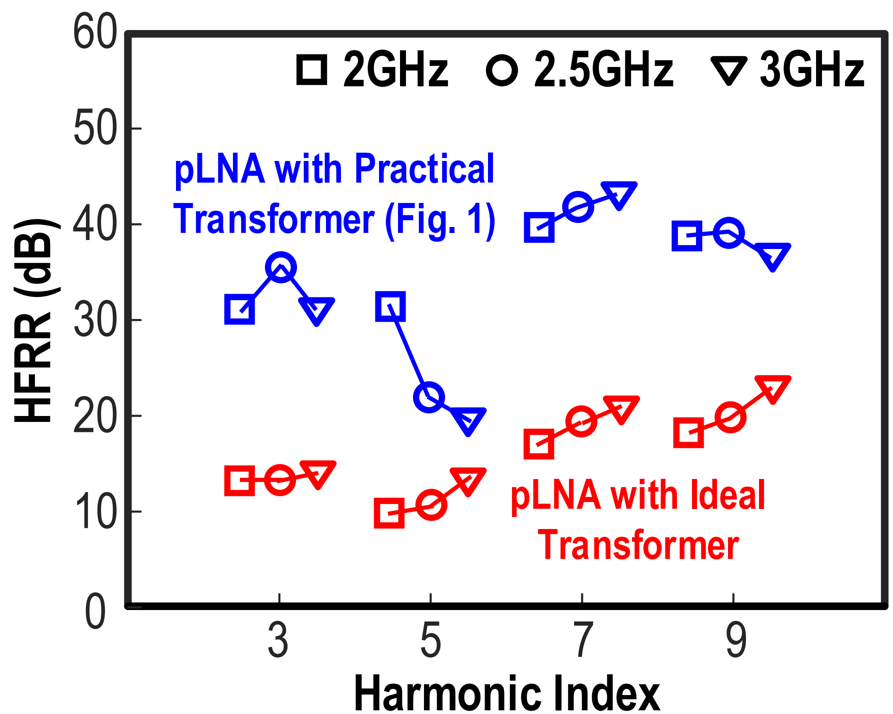
Center Frequency Shifting and Correction



- Typical N-path SC network has a left-shift center Frequency
- Our pLNA shows a right-shift center frequency due to the inductive effect of the transformer, C_T is added for correction

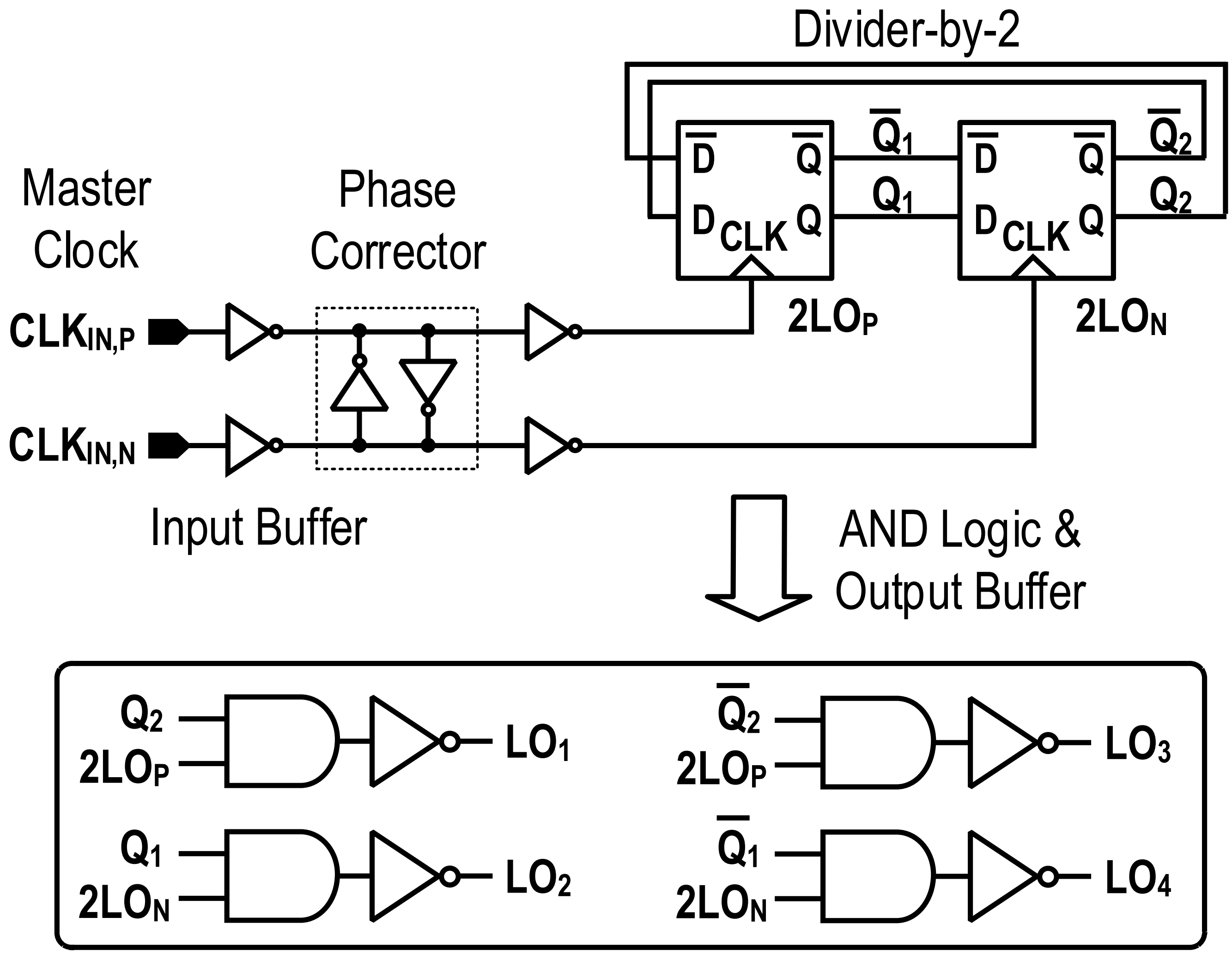
Gain and Phase Responses and $HFRR_{3,5,7,9}$





- Wide-range view of gain and phase responses at 2 and 3GHz show different behaviors at high frequency
- With the tunable C_T, the lowpass characteristic of the transformer also changes the HFRR results at different RF

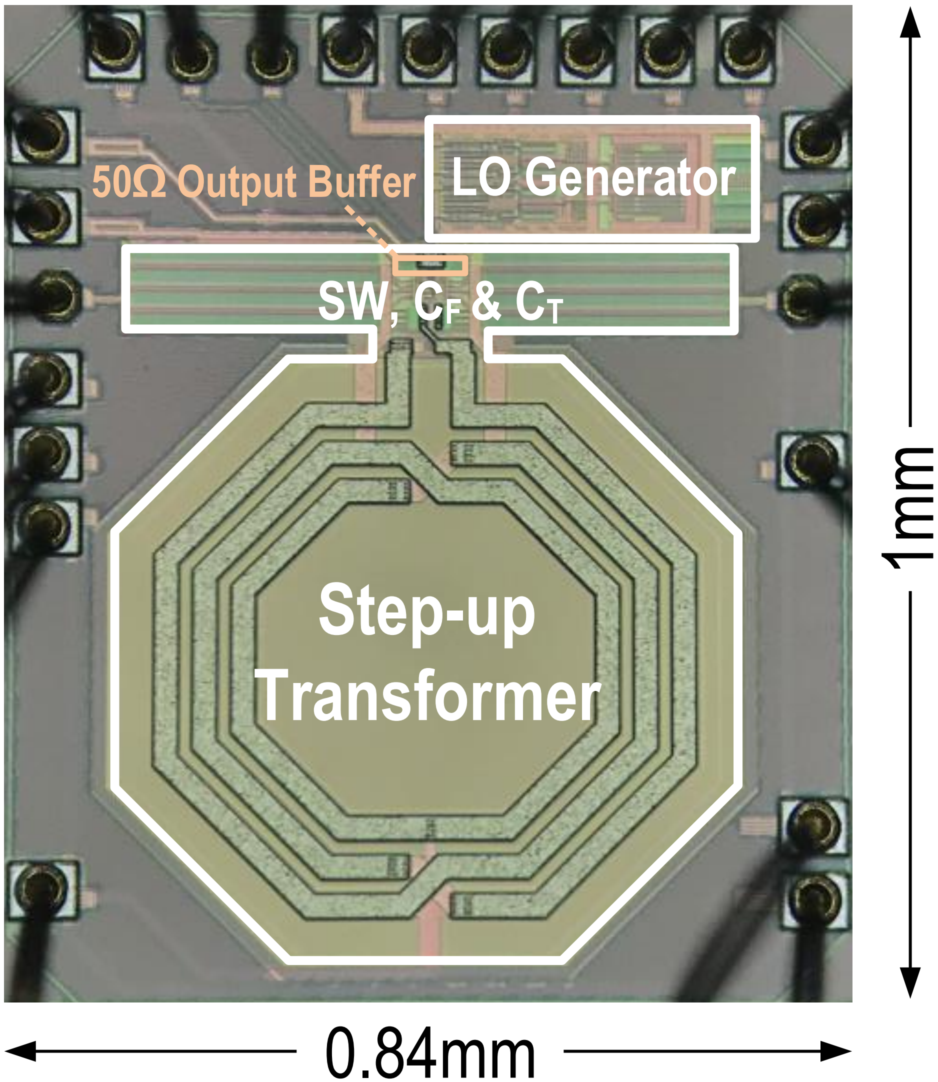
4-Phase 25%-Duty-Cycle LO Generator



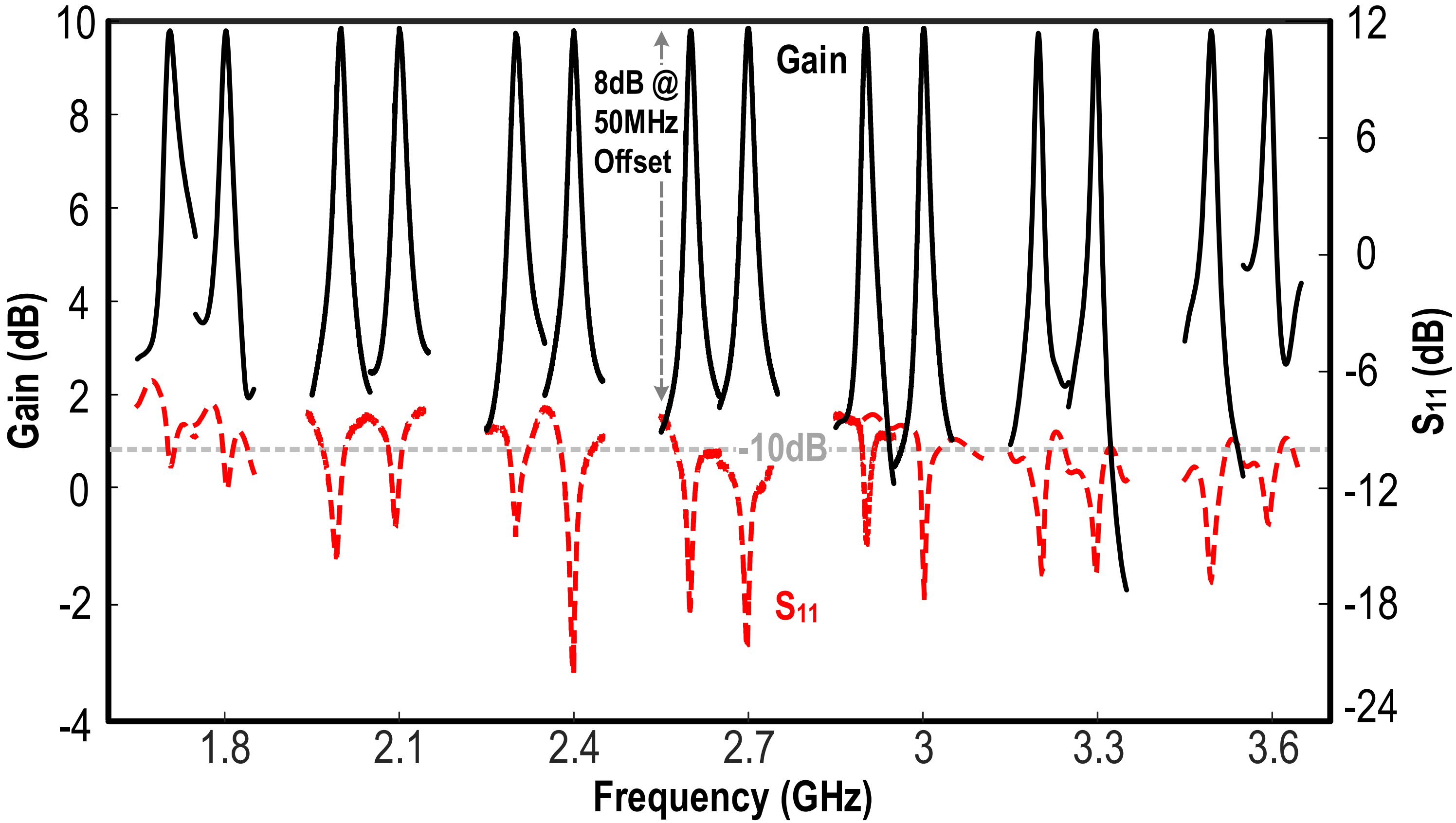
Power: 31.5mW at 3GHz, 29mW due to the output buffer

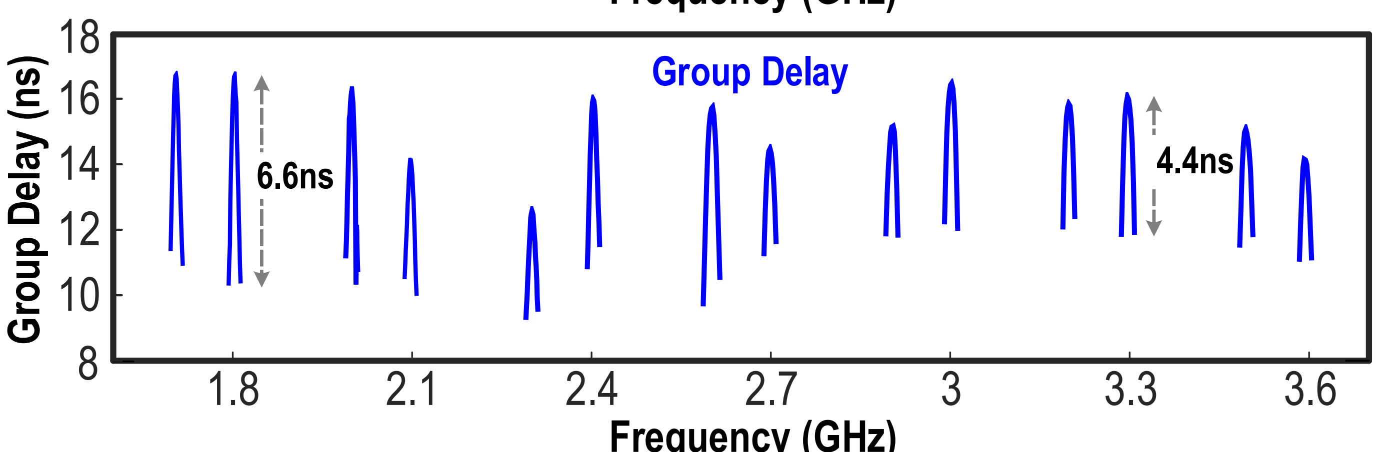
Simulated PN at 3GHz: -170dBc/Hz@80MHz Δf

Chip Photo of the N-Path pLNA in 28nm CMOS

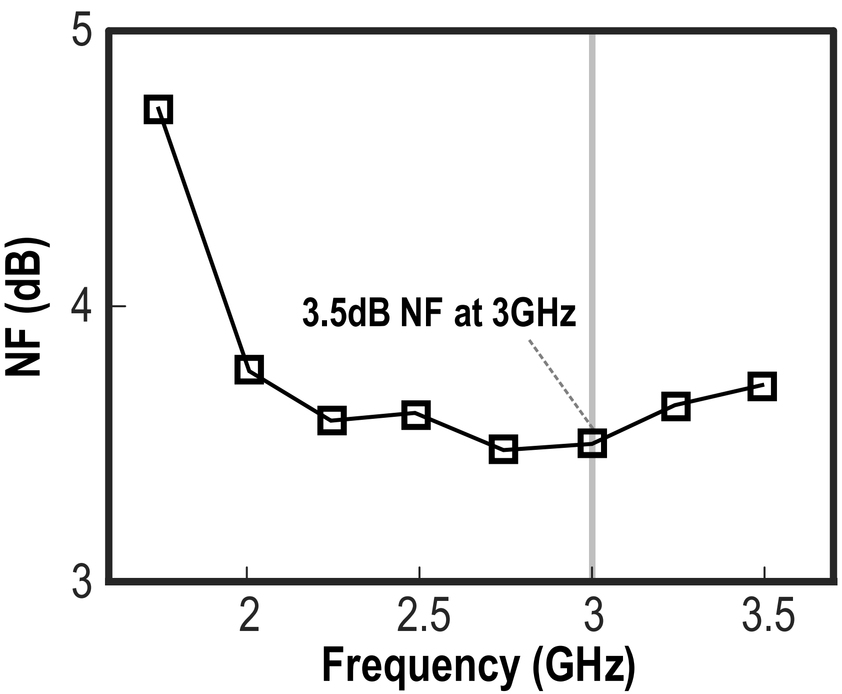


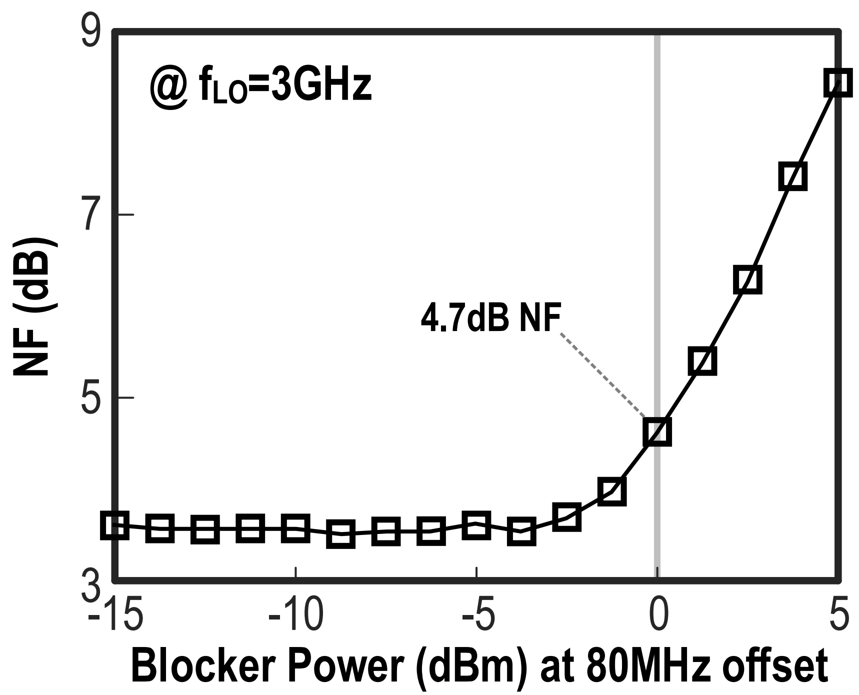
Measured Gain, S_{11} and Group Delay





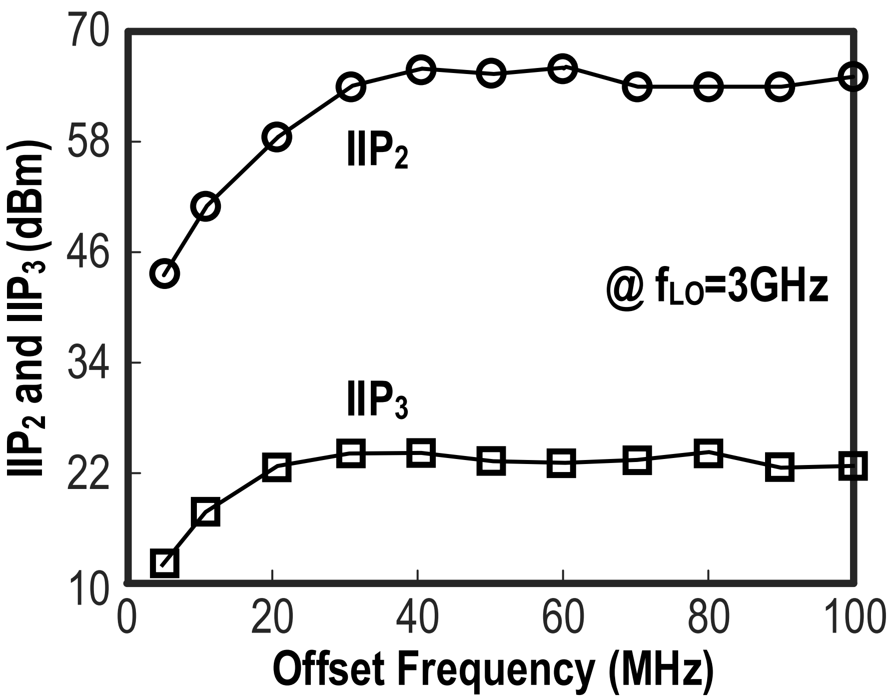
Measured NF and Blocker NF

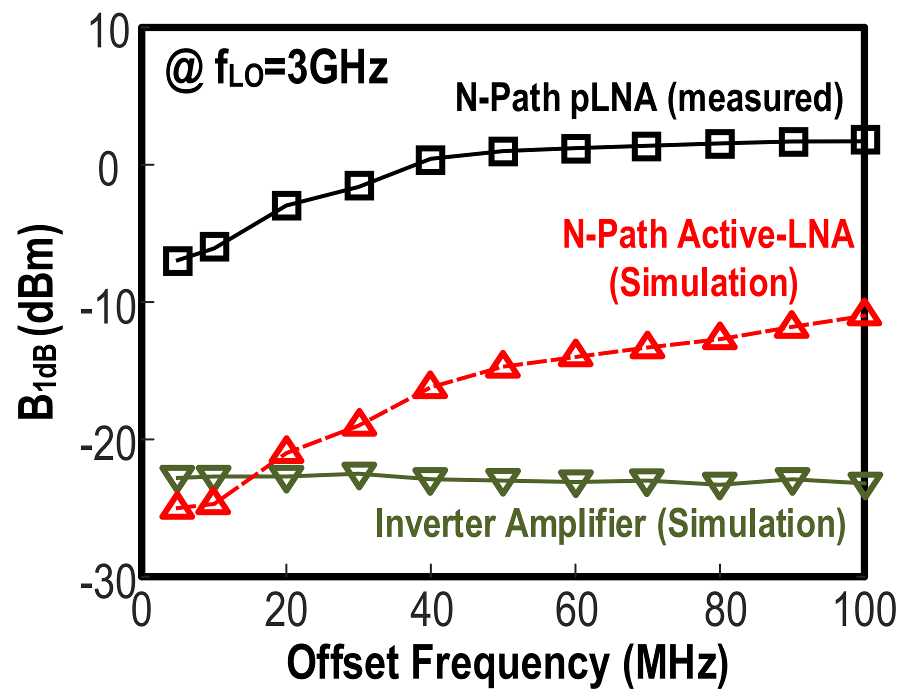




- **NF: 3.5dB at 3GHz RF**
- **0dBm-Blocker NF: 4.7dB at 3GHz RF**

Measured OB-IIP_2/IIP_3 and B_{1dB}

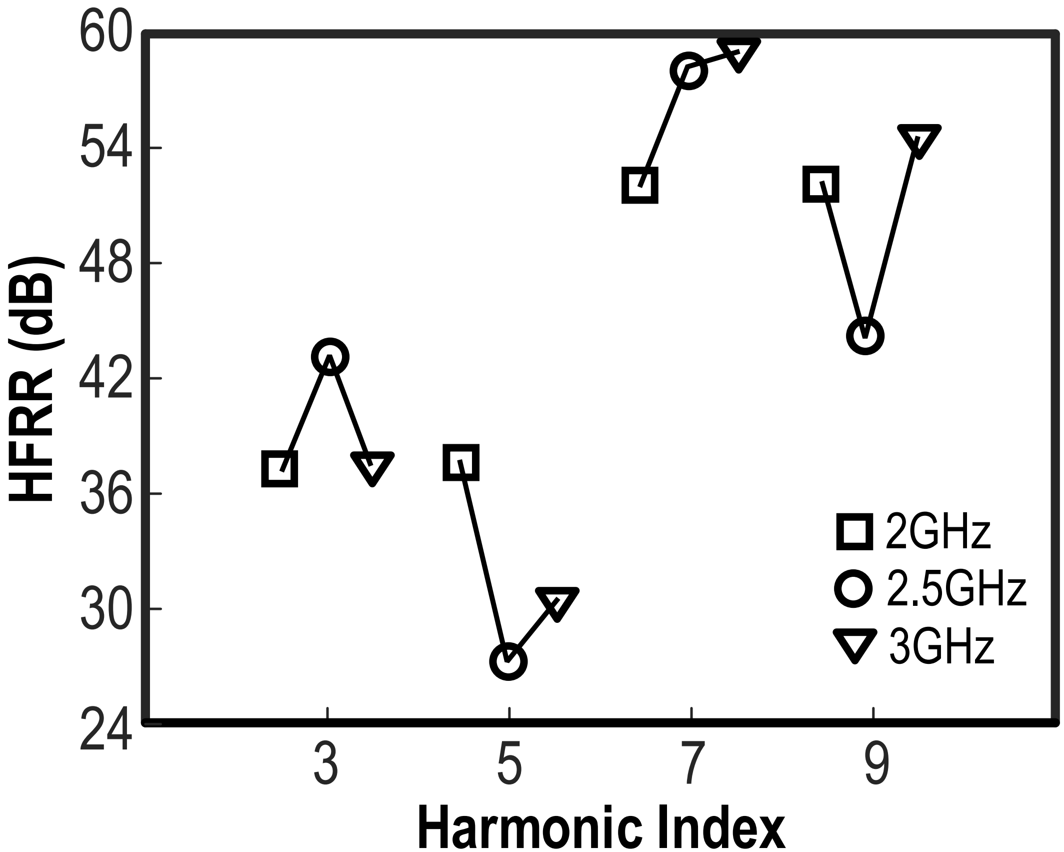




- **OB-IIP2: 64dBm**
- **OB-IIP3: 23.5dBm**

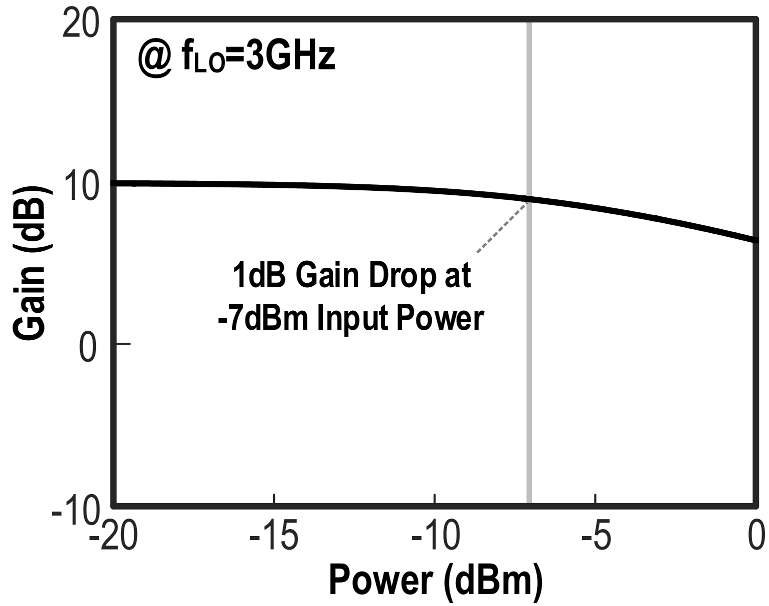
- **B_{1dB}: 1.7dBm**
- **24.9dB better than the Inverter Amplifier**
- **14.1dB better than the N-path active-LNA**

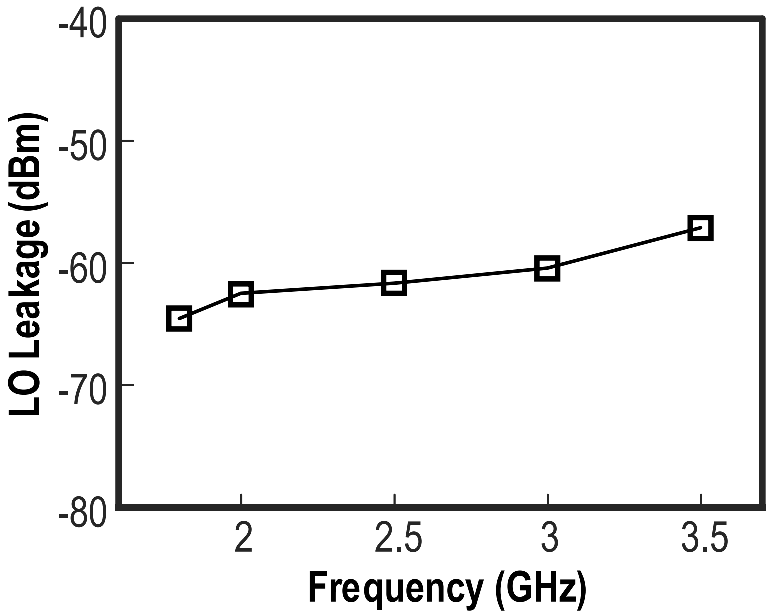
Measured $HFRR_3$ and $HFRR_5$

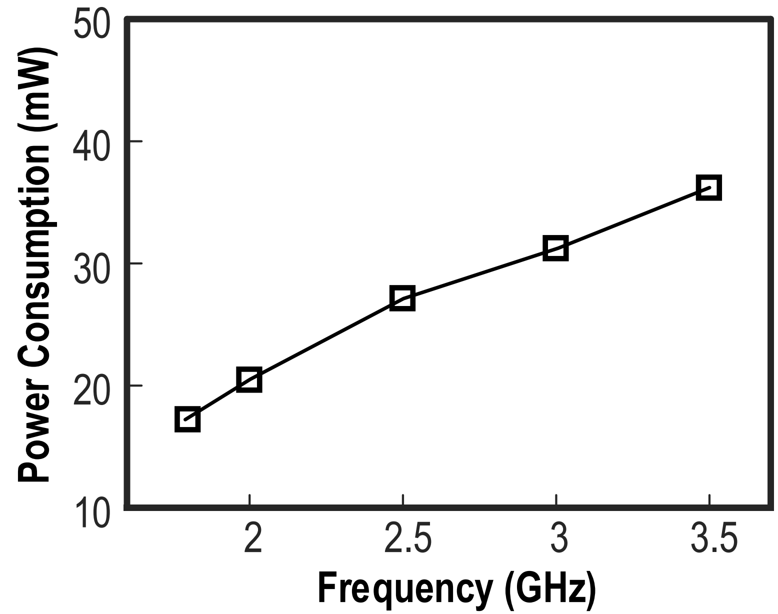


- **$HFRR_3$: 37 to 42dB**
- **$HFRR_5$: 28 to 36dB**

Measured 1dB Gain Drop, LO Leakage and Power







Comparison with the State-of-the-Art

	This Work	JSSC'20 [4]	JSSC'19 [3]	JSSC'18 [5]	JSSC'18 [2]	JSSC'11 [1]
Topology	**N-Path pLNA with SCT Network**	Mixer-First RX w/ BW-Extended BB-TIA	High-Order Passive N-Path Filter	Harmonic-Rejection N-Path LNA	Gain-Boosted N-path LNA w/ Shunt LC	Passive N-Path Band-Pass Filter
RF Input Style	Differential	Single-Ended	Differential	Differential	Single-Ended	Differential
N-Path Type	N=4	N=4	N=4	N=8	N=4	N=4
RF Range (GHz)	**1.7 to 3.6**	0.2 to 2	0.8 to 1.1	0.2 to 1	0.7 to 1	0.1 to 1
RF BW (MHz)	20	18	30 to 50	2	8*	35
Voltage Gain (dB)	9.8	13	-4.6 to -3.8	36	4.8 to 5.5	-2
DSB NF (dB)	**3.4 to 4.8**	4.3 to 7.6	8.6 @ 1.1GHz	5.4 to 6	8.7 to 9.2[&]	3 to 5
0dBm Blocker NF (dB) @ Offset (MHz)	**4.7 @ 80**	6.4 @ 90	No Data	No Data	9.2 @ 40	No Data
B_{-1dB} (dBm) @ Offset (MHz)	**1.7 @ 80**	6* @ 80	9 @ 50	-2.4* @ 20	8	No Data
IB-IIP3 (dBm)	**12.5**	8*	25	No Data	7.6	14
OB-IIP_3 (dBm) @ Offset (MHz)	**23.5 @ 80**	24* @ 80	24 @ 50	9	32.3	No Data
$HFRR_3$ (dB)	**37 to 42**	No data	No data	No data	No data	12
$HFRR_5$ (dB)	**28 to 36**	No data	No data	No data	No data	17
Power (mW)	**17.8 to 38.2**	147 to 179	80 to 97	26 to 32	62.5	2 to 16
Supply (V)	1	1.2	2, -1	1.2, 2.5	1.5	1.2
Die Size (mm^2)	0.84	0.48	1.9	0.29	2.2	0.07
Technology	28nm CMOS	28nm CMOS	65nm CMOS	65nm CMOS	180nm SOI	65nm CMOS

Conclusions

RF-Channel-Selection Passive-LNA (pLNA):

- Only **switches**, **capacitors** and a **step-up transformer**
- Inductive and lowpass features of the transformer allows passband centering and harmonic-folding reduction.
- Only LO dynamic power of **17.8 to 38.2mW** between **1.7 to 3.6 GHz.**
- Key metrics: **9.8dB voltage gain, 3.4-to-4.8dB NF, 20MHz channel BW, 23.5dBm OB-IIP3, 0.84mm^2 @ 28nm**

Acknowledgments

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Details:

Haijun Shao, Gengzhen Qi, Pui-In Mak and Rui P. Martins, “A 1.7-3.6-GHz 20-MHz-Bandwidth Channel-Selection N-Path Passive-LNA Achieving 23.5dBm OB-IIP3 and 3.4-4.8dB NF,” **IEEE Journal of Solid-State Circuits**, vol. 57, pp. 413–422, Feb. 2022.