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A High LO-to-RF Isolation E-band Mixer with 30 GHz Instantaneous IF Bandwidth in 90nm CMOS

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Outline

- Motivation
- Paper Survey
- Schematic
- Circuit Design
  - Bias and Transistor Size
  - Butterworth LPF
  - LC Resonators
- Simulation and Measurement
- Comparison to Reported Mixers
- Conclusion
- References

Motivation

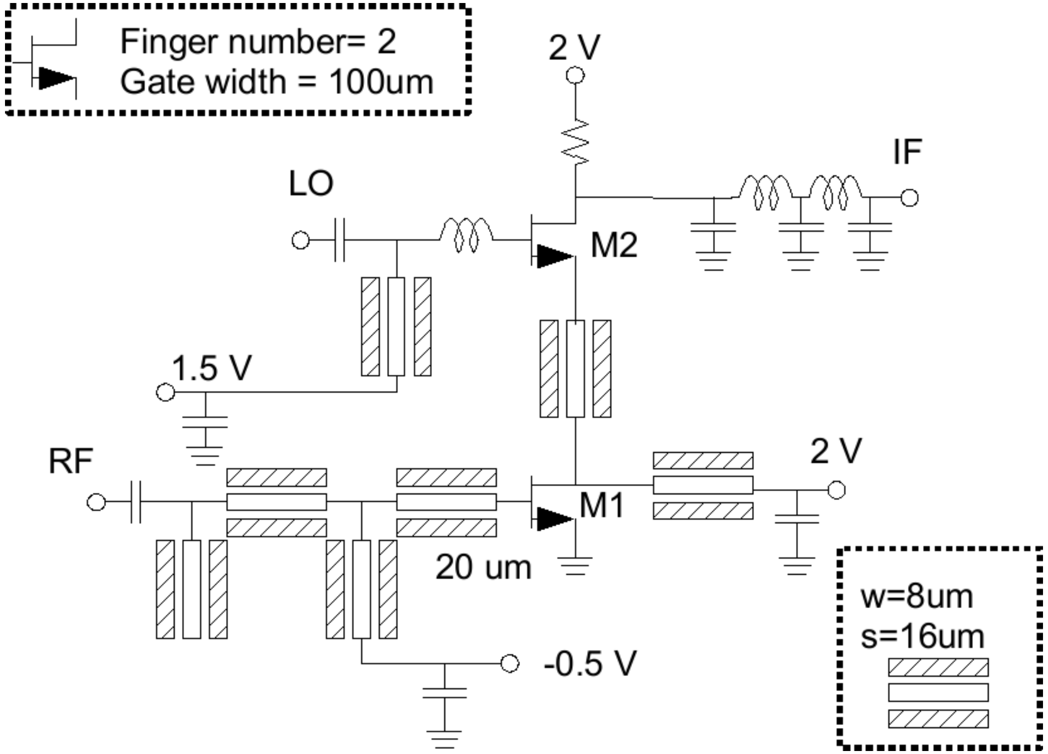
- ALMA2030 Development Roadmap
  – Goals: Explore origins of planets, galaxies, and chemical complexity
- Atacama Large Millimeter/submillimeter Array (ALMA)
  – High-sensitivity
  – High-resolution

Motivation

- ALMA receivers specification
  - Low-noise performance
    - Increase sensitivity of observation
  - Instantaneous bandwidth
    - Improve efficiency of observation

Paper Survey

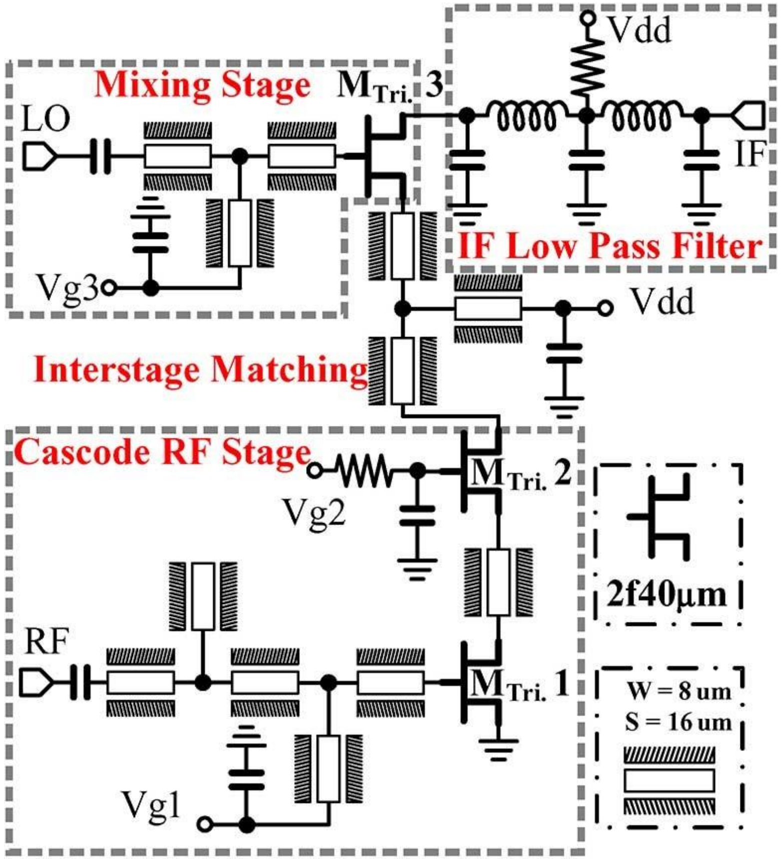
- A 24-48 GHz Cascode HEMT Mixer with DC to 15 GHz IF Bandwidth for Astronomy Radio Telescope
  - Cold-biased mixing stage
  - Common-source RF stage
  - Poor LO-to-RF isolation
  - IF frequency: DC-15 GHz



[1] Z. -M. Tsai, J. -C. Kao, K. -Y. Lin and H. Wang, "A 24–48 GHz cascode HEMT mixer with DC to 15 GHz IF bandwidth for astronomy radio telescope," 2009 European Microwave Integrated Circuits Conference (EuMIC), 2009, pp. 5-8.

Paper Survey

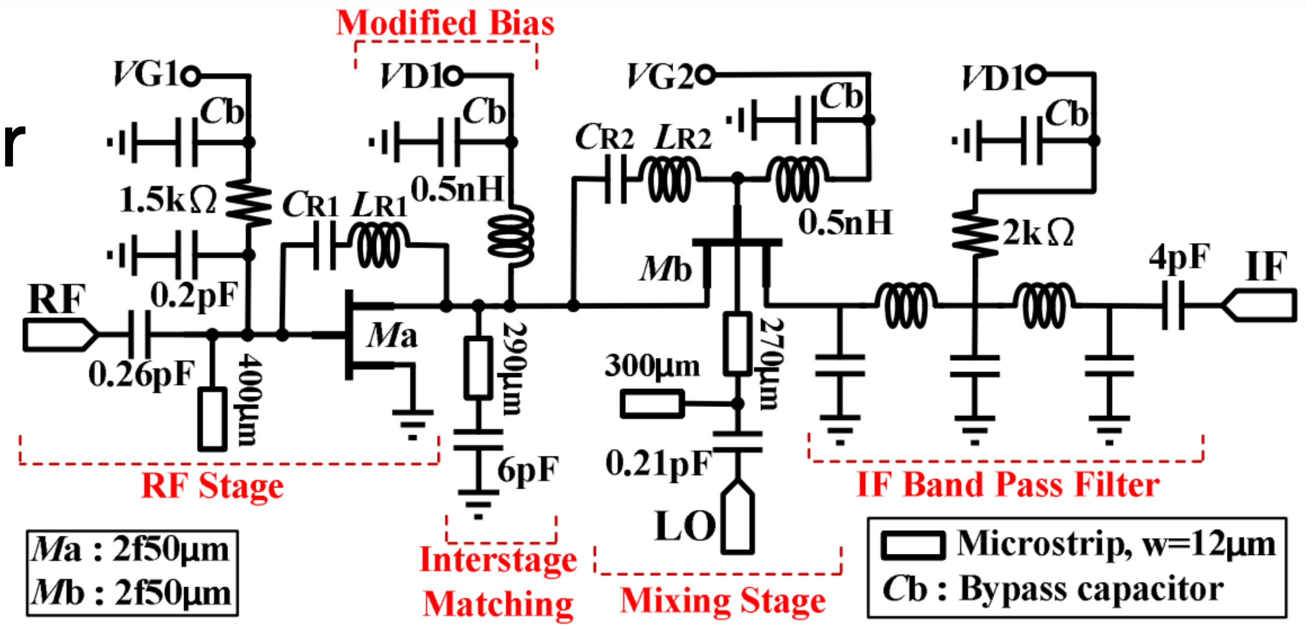
- A W-band High LO-to-RF Isolation Triple Cascode Mixer With Wide IF Bandwidth
  - Cold-biased mixing stage
  - Cascode RF stage
  - Degraded IP1dB
  - IF Frequency: DC-24 GHz



[2] J. -C. Kao, K. -Y. Lin, C. -C. Chiong, C. -Y. Peng and H. Wang, "A W-band High LO-to-RF Isolation Triple Cascode Mixer With Wide IF Bandwidth," in IEEE Transactions on Microwave Theory and Techniques, vol. 62, no. 7, pp. 1506-1514.

Paper Survey

- A High LO-to-RF Isolation 34-53 GHz Cascode Mixer for ALMA Observatory Applications
  - Cold-biased mixing transistor
  - Common-source RF stage
  - LC resonators
  - IF frequency: 3-13 GHz



[3] C. -N. Chen, Y. -H. Lin, Y. -C. Chen, C. -C. Chiong and H. Wang, "A High LO-to-RF Isolation 34–53 GHz Cascode Mixer for ALMA Observatory Applications," 2018 IEEE MTT-S International Microwave Symposium (IMS), 2018, pp. 686-689.

Paper Survey

- [1] Poor LO-to-RF isolation
- [2] Sacrifice IP1dB for LO-to-RF isolation
- [3] Chosen structure

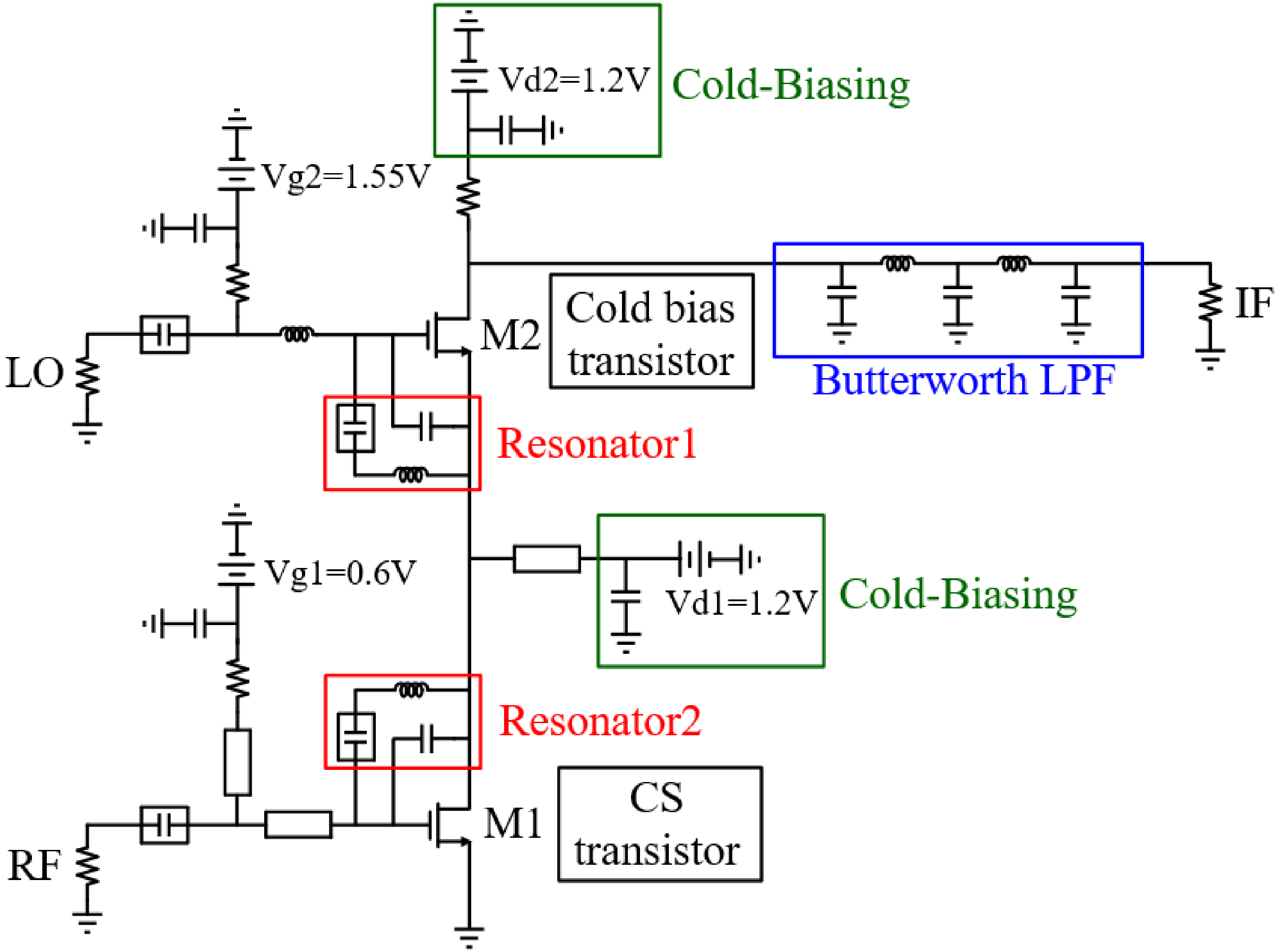
Ref.	Mixing Stage	RF Stage	Embedding	IF Bandwidth	LO-to-RF Isolation	IP1dB
[1]	Cold-biased	Common-source	N/A	☺	☹	☺
[2]	Cold-biased	Cascode	N/A	☺	☺	☹
[3]	Cold-biased	Common-source	LC resonators	☺	☺	☺

Paper Survey

- 90nm CMOS process (Compared to GaAs pHEMT)
  - Lower parasitic capacitance
    - More suitable for wide IF bandwidth design
  - Multi-layer flexibility
  - Compact layout
  - Lower cost

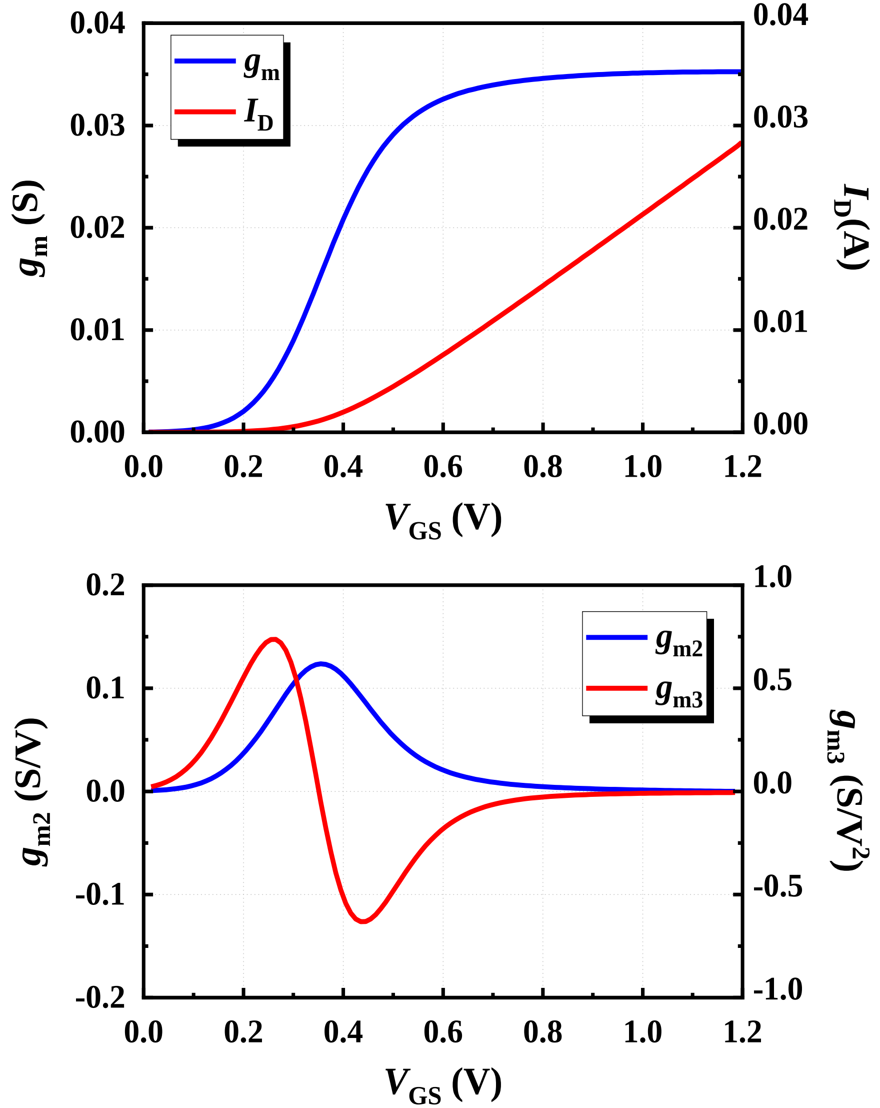
Schematic

- Cold-Biasing Technique
  - Extend IF bandwidth
- Butterworth LPF
  - Improve LO-to-IF isolation
  - Improve RF-to-IF isolation
- LC Resonators
  - Improve LO-to-RF isolation



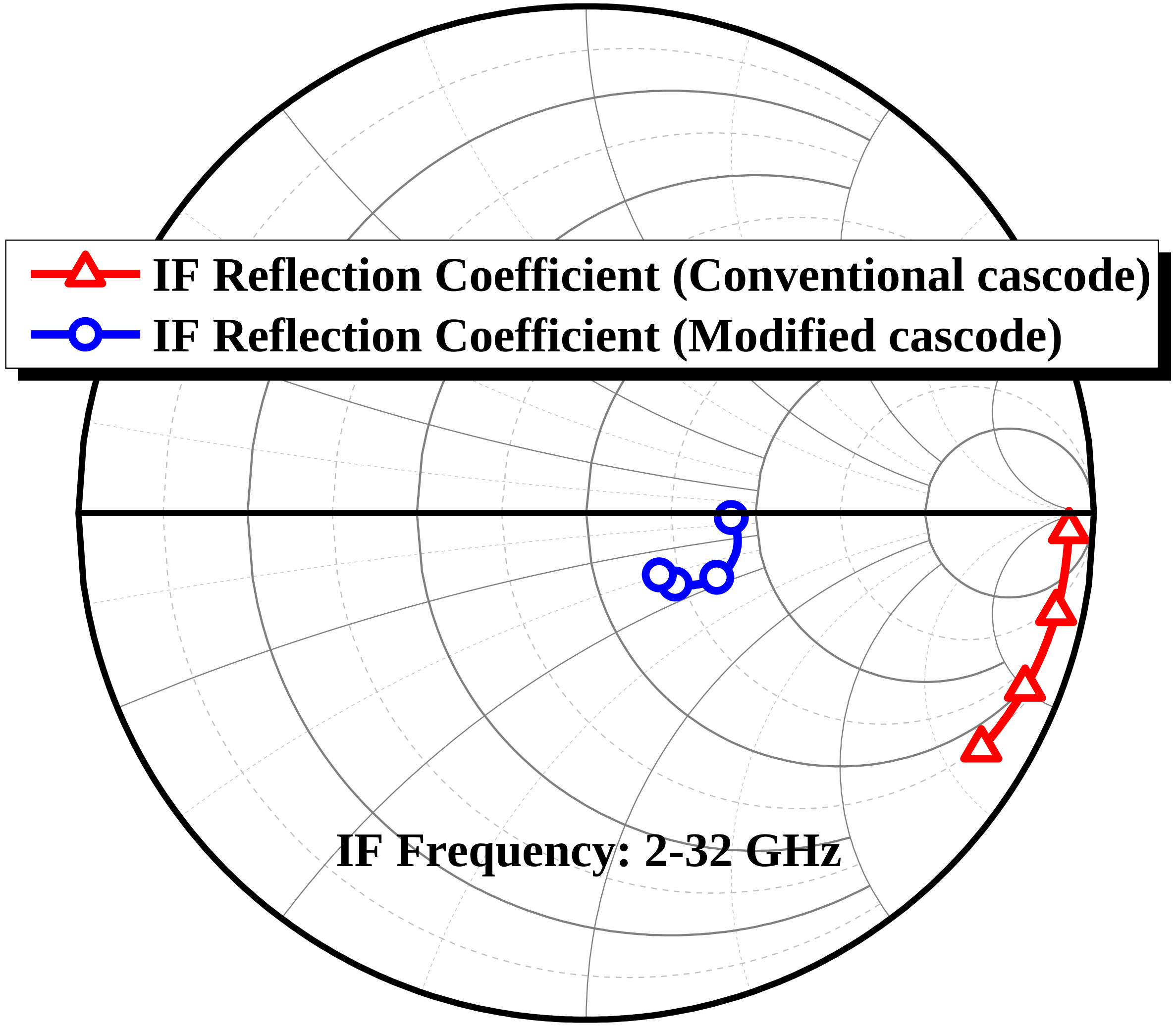
Circuit Design (Bias)

- RF Stage (V_{GS}=0.6 V)
  - Trade-Off between g_m and P_{DC}
    - $V_{GS}\nearrow$: $g_m\nearrow$, $P_{DC}\nearrow$
- Mixing Stage (V_{GS}=0.35 V)
  - Maximize second-order transconductance
    - Good conversion gain
  - Minimize third-order transconductance
    - Good linearity



Circuit Design (Bias)

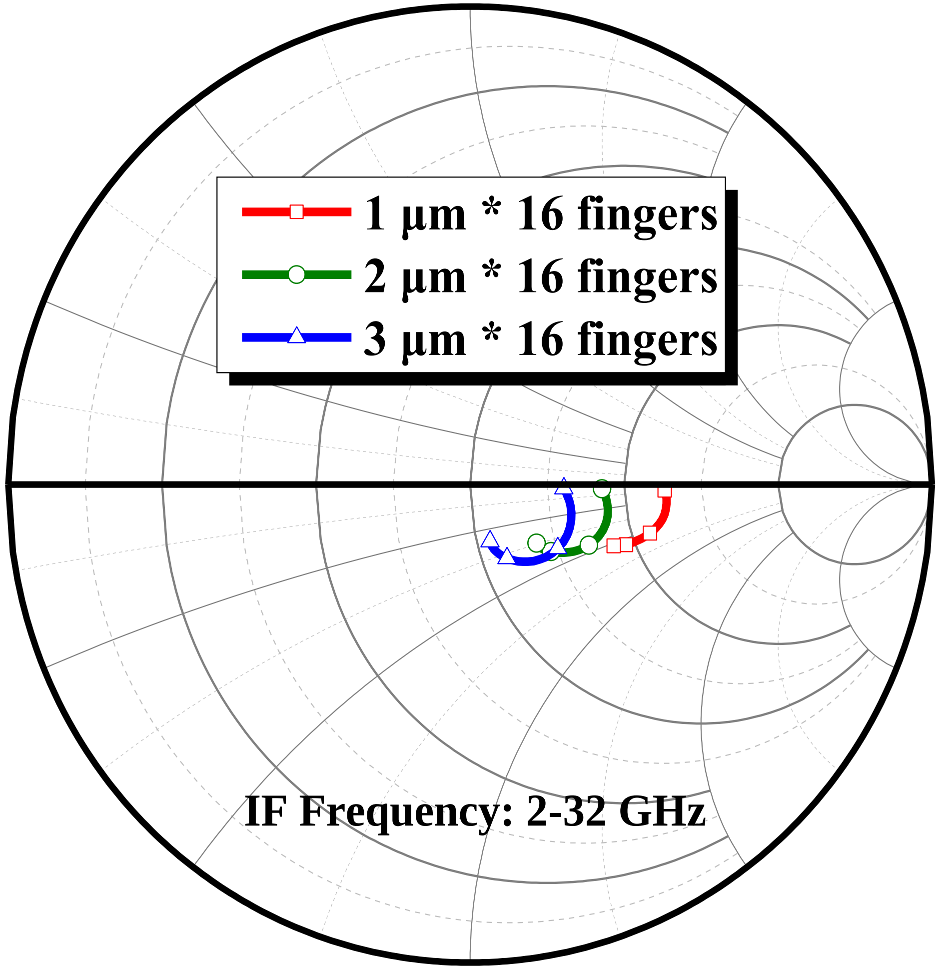
- Conventional Cascode
  - Common gate mixing stage
  - Output impedance
    - Higher
    - More frequency-dependent
- Modified Cascode
  - Cold-biased mixing stage (V_{DS}=0)
  - Output impedance
    - Lower (closer to 50 Ohm)
    - Less frequency-dependent



Circuit Design (Transistor Size)

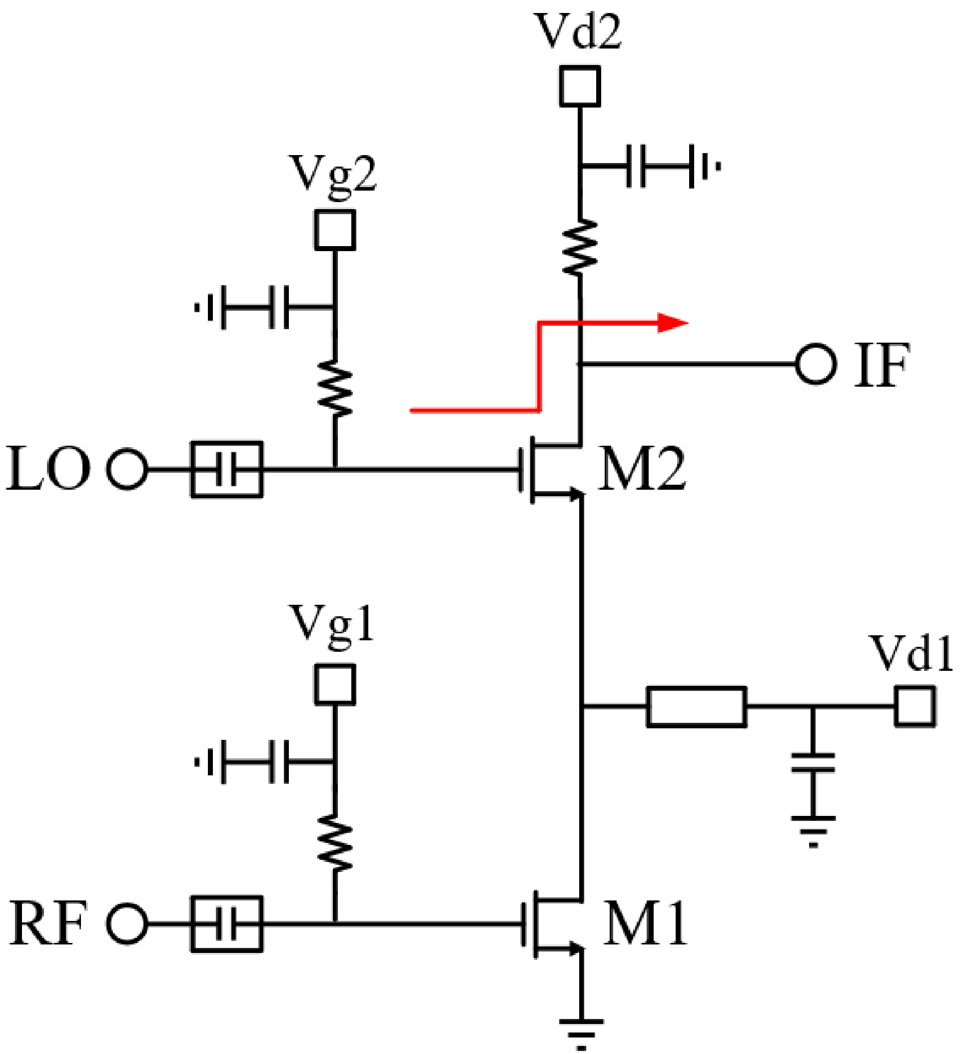
- RF Stage (2 μm*16 fingers)
  – Trade-off between g_m and P_{DC}
    - Size↗ : g_m↗, P_{DC}↗
- Mixing Stage (2 μm*16 fingers)
  – Trade-off between CG and bandwidth
    - Size↗ : CG↘, bandwidth↗

  – Output impedance close to 50 Ohm



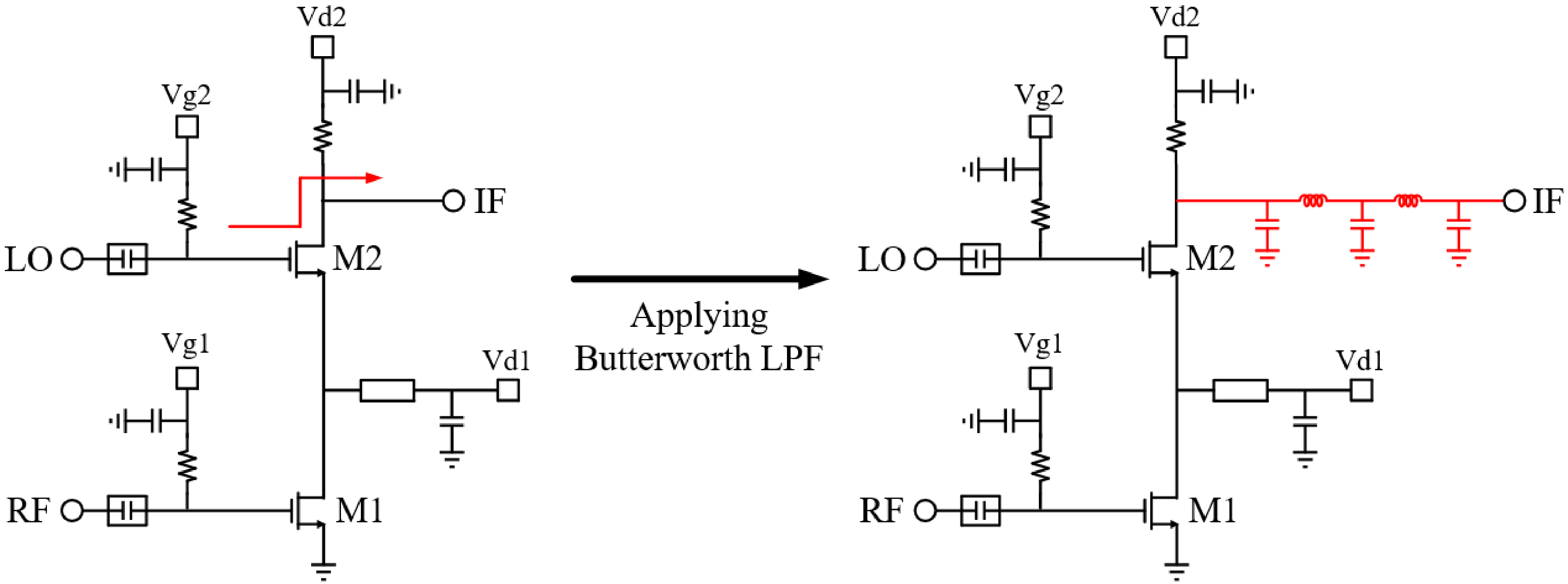
Circuit Design (Butterworth LPF)

- LO-to-IF Leakage
  - Saturate IF amplifier



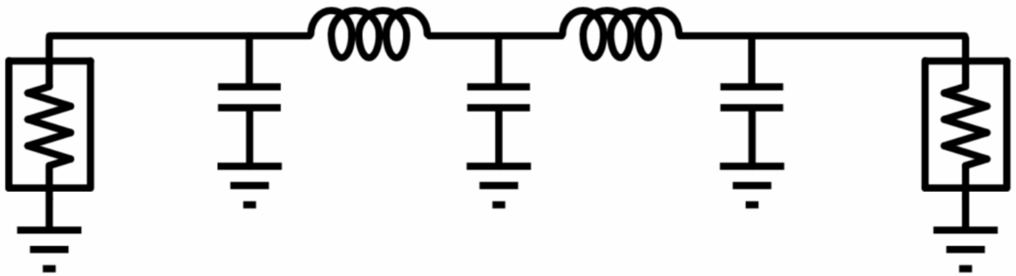
Circuit Design (Butterworth LPF)

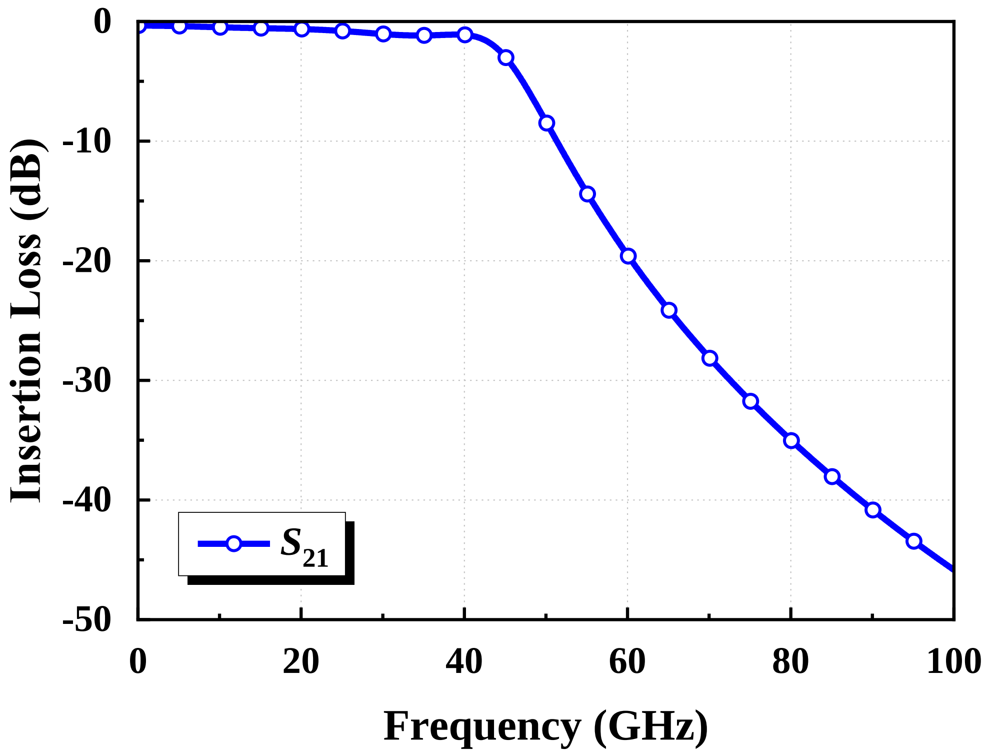
- Butterworth LPF
  - Pass IF signal (slightly matching for gain flatness)
  - Block LO and RF signal



Circuit Design (Butterworth LPF)

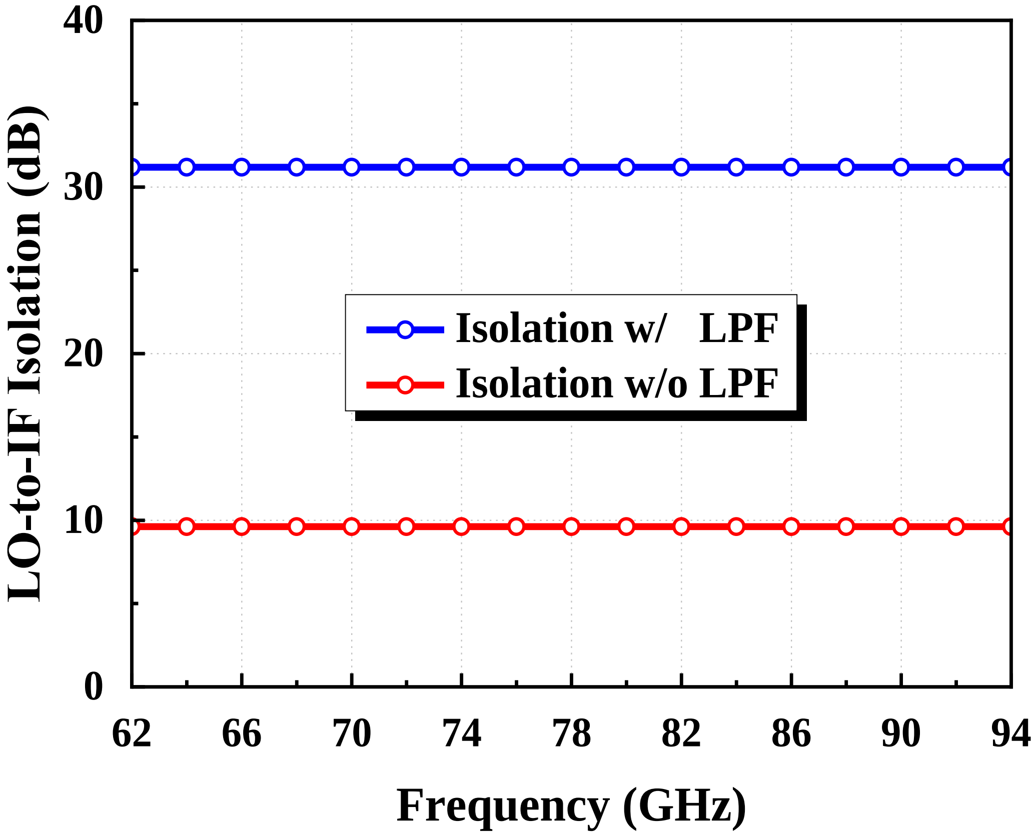
- 5^{th} order shunt-first LPF
  - Passband (DC-32 GHz)
    - Insertion loss lower than 1 dB
  - Stopband (60-92 GHz)
    - Insertion loss higher than 20 dB

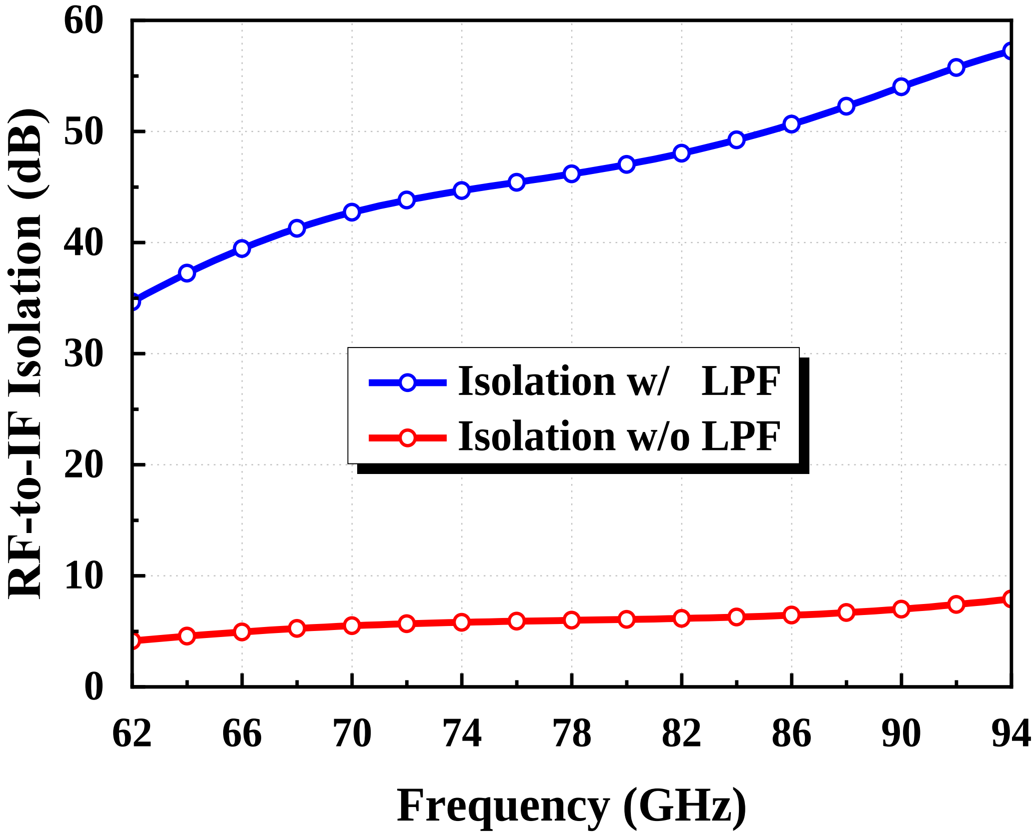




Circuit Design (Butterworth LPF)

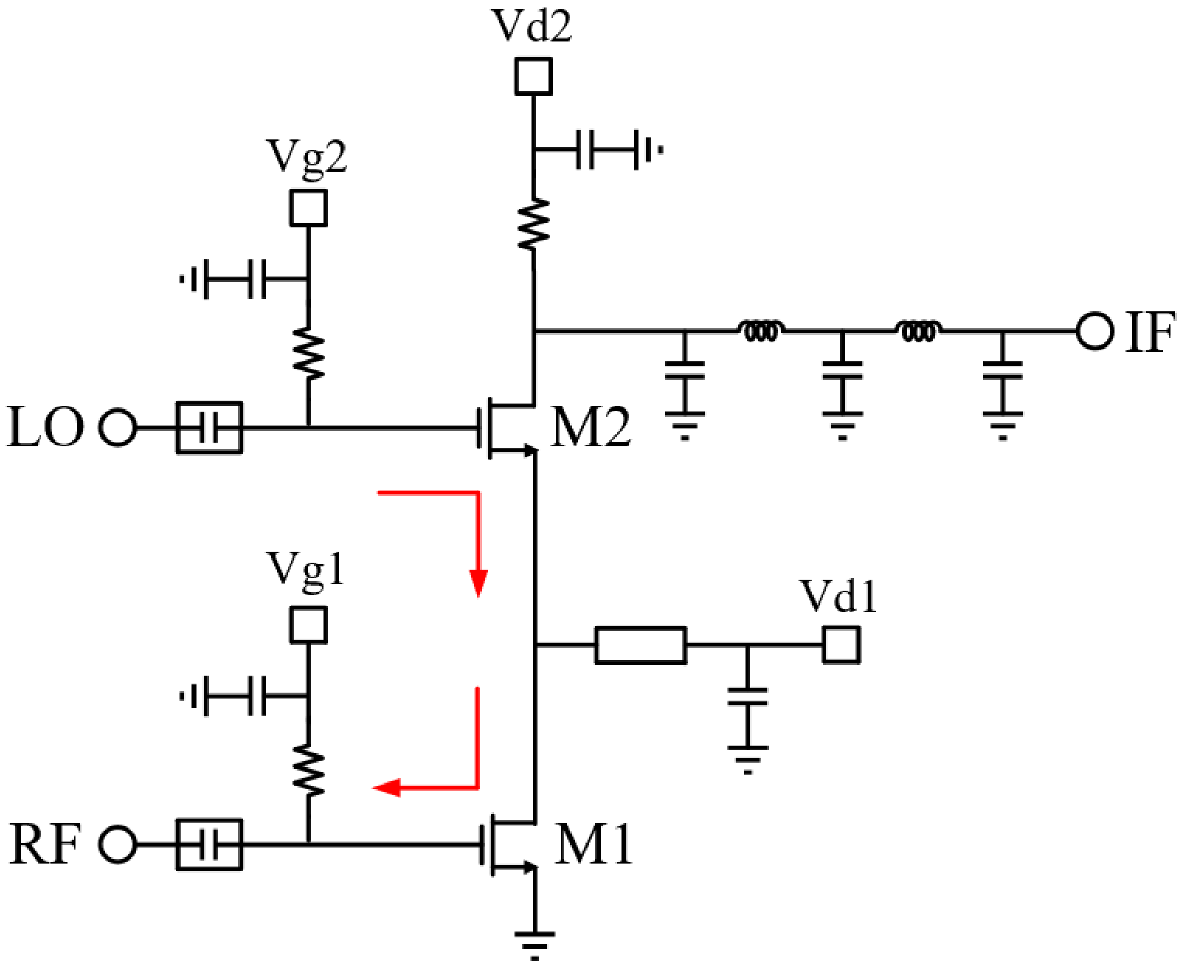
- Improvement in LO-to-IF isolation and RF-to-IF isolation





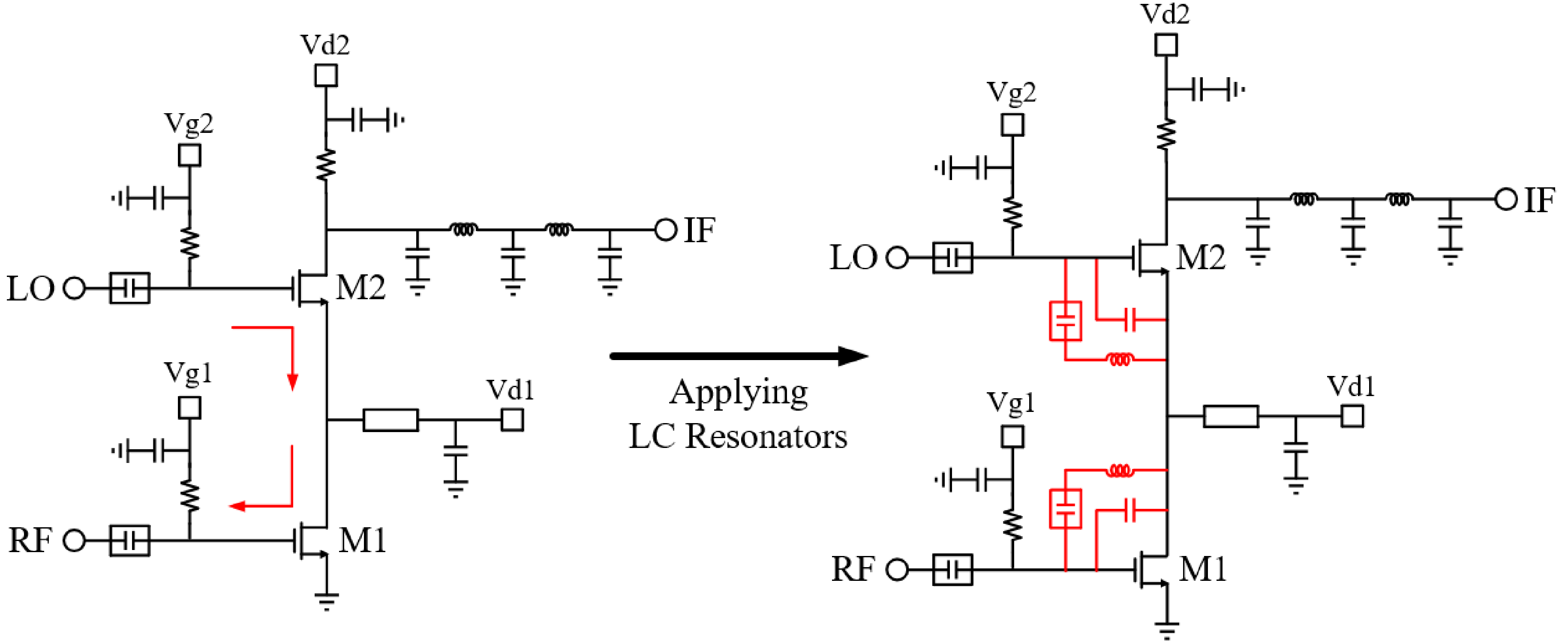
Circuit Design (LC resonators)

- LO-to-RF Leakage
  - Interfere RF circuit
  - Self-Mixing causing DC-offset



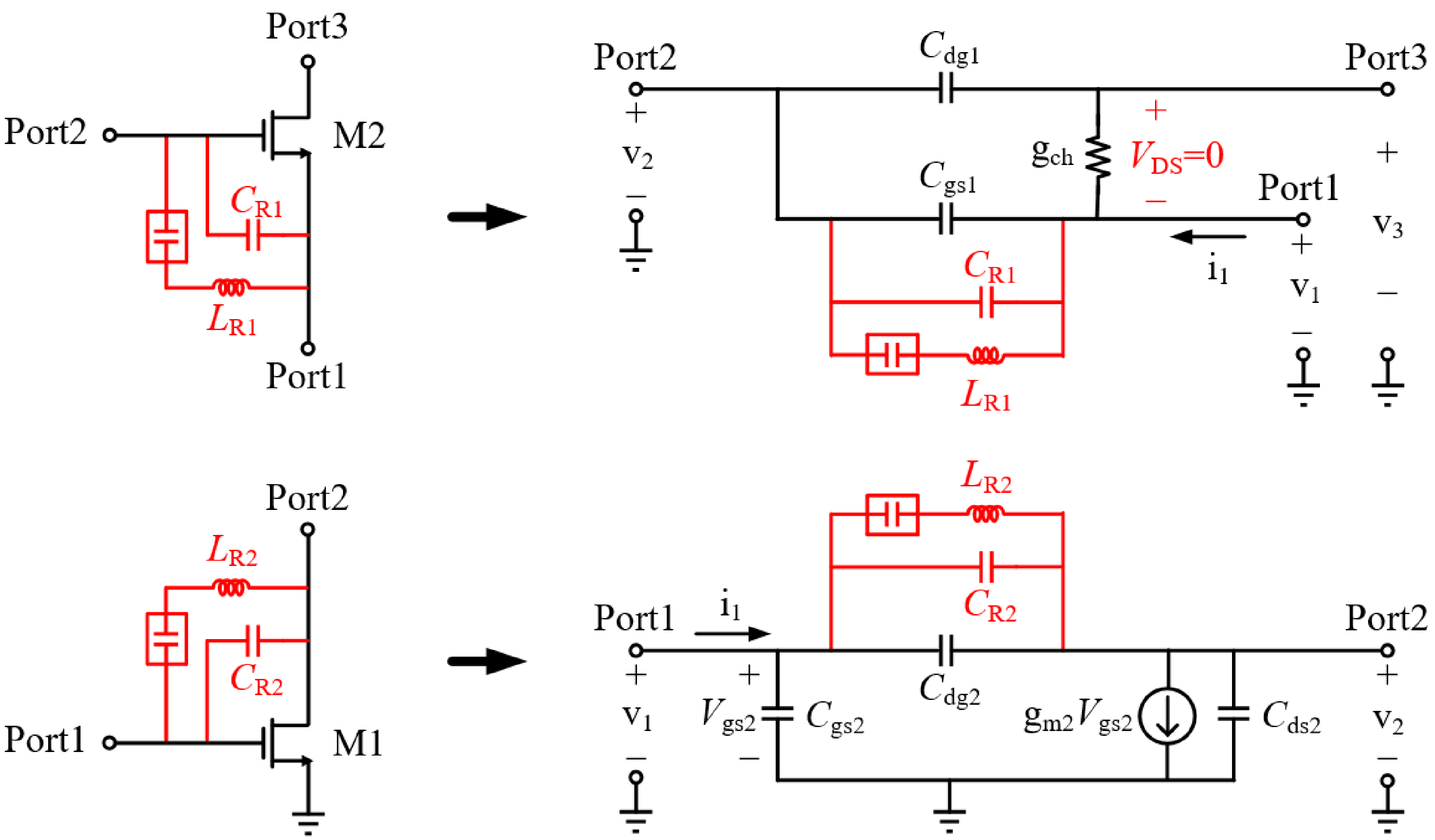
Circuit Design (LC resonators)

- LC resonators
  - Parallelled LC pairs resonating at LO frequency (60 GHz)
  - Parasitic capacitor included (C_{gs} of mixing stage and C_{dg} of RF stage)



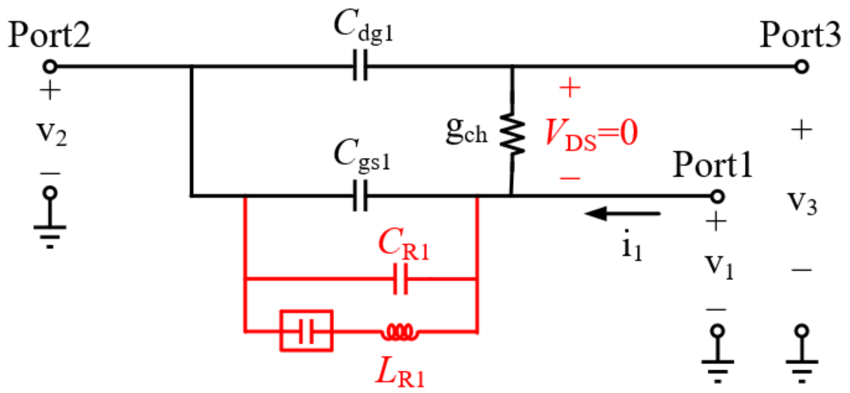
Circuit Design (LC resonators)

- Small signal equivalent circuit

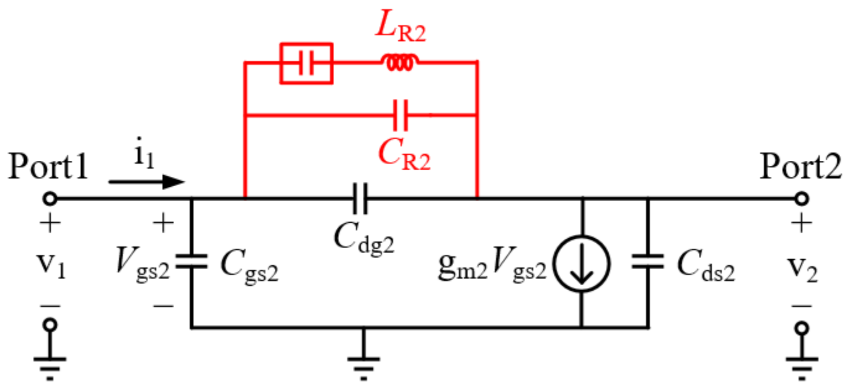


Circuit Design (LC resonators)

- Admittances between ports of LO-to-RF leakage path
  - Both need to be minimized!



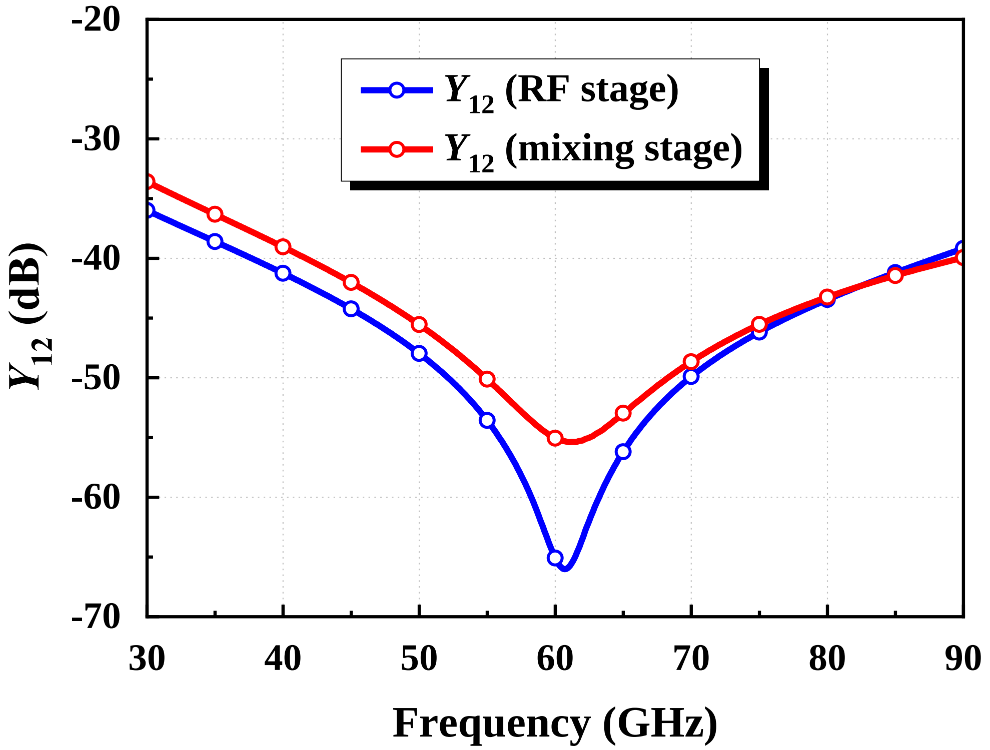
$$Y_{12}=\frac{i_1}{v_2}\Big|_{\substack{v1=0\\ v3=0}}=-j2\pi f\left(C_{R1}+C_{gs1}-\frac{1}{4\pi^2 f^2 L_{R1}}\right)$$

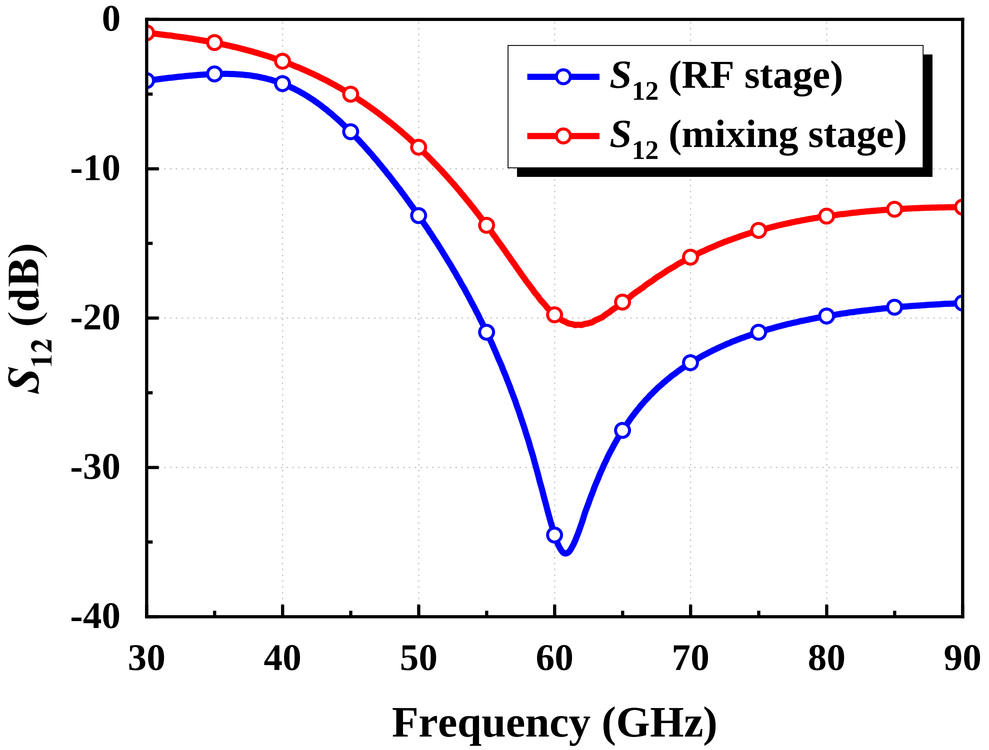


$$Y_{12}=\frac{i_1}{v_2}\Big|_{v_1=0}=-j2\pi f\left(C_{R2}+C_{dg2}-\frac{1}{4\pi^2 f^2 L_{R2}}\right)$$

Circuit Design (LC resonators)

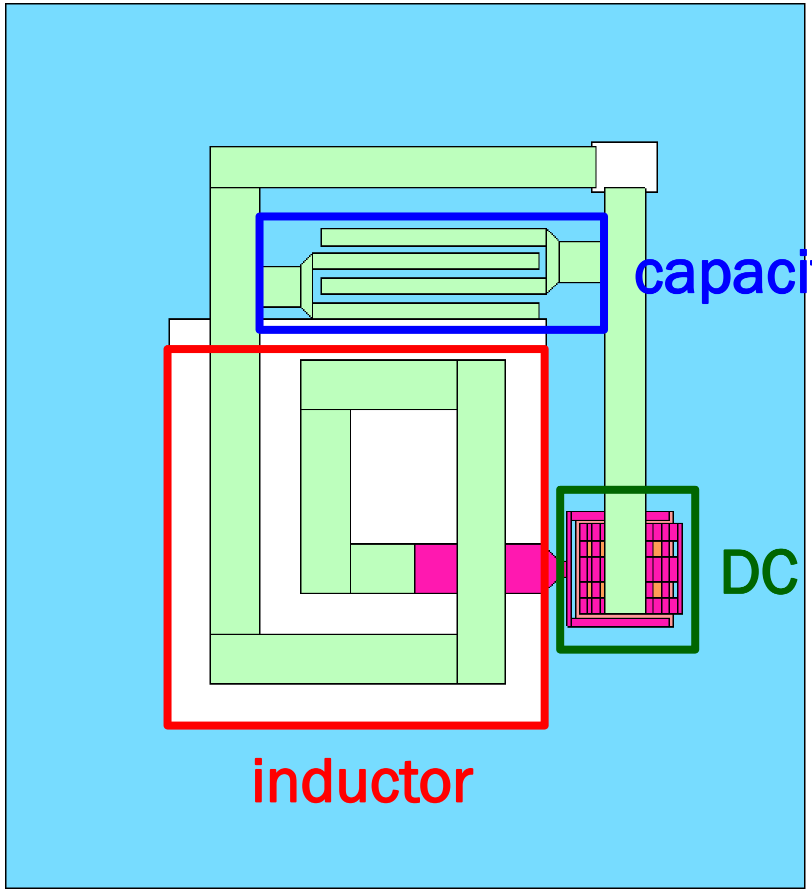
- Inductance and Capacitance
  - Minimize Y_{12} at 60 GHz
    - LC Resonance frequency: 60 GHz





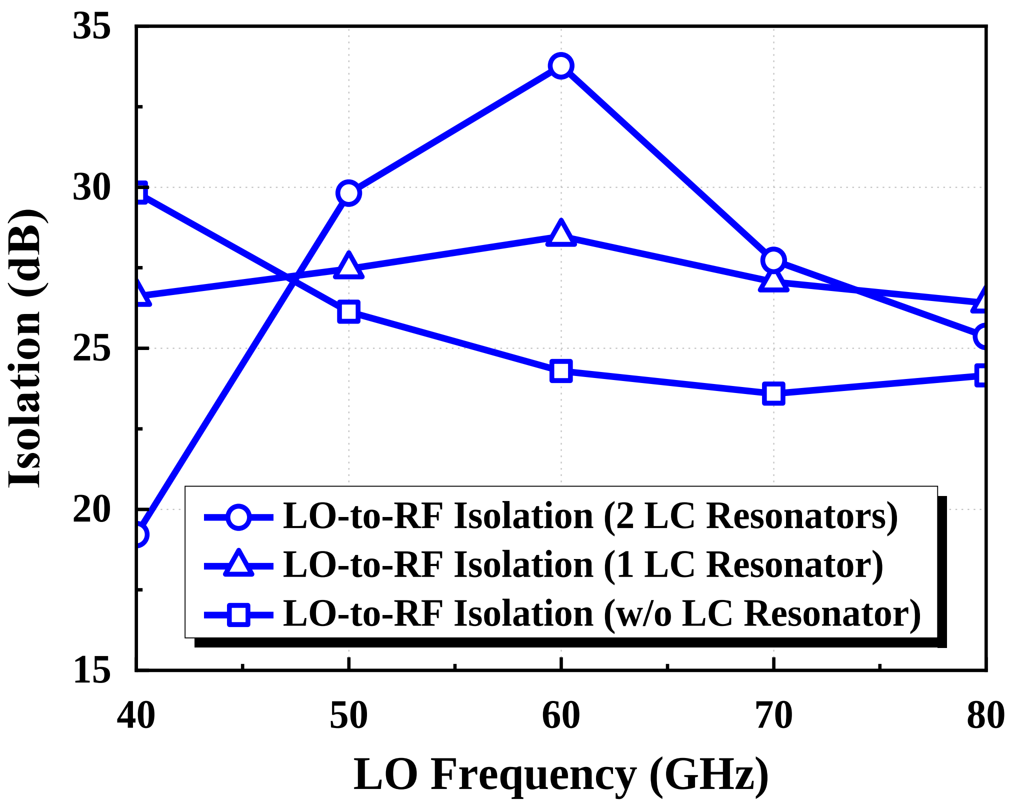
Circuit Design (LC resonators)

- Layout consideration
  - Spiral inductor
  - Edge-coupled MOM capacitor
    - Reduce impact of process variation
  - DC block
    - Large capacitor with negligible reactance

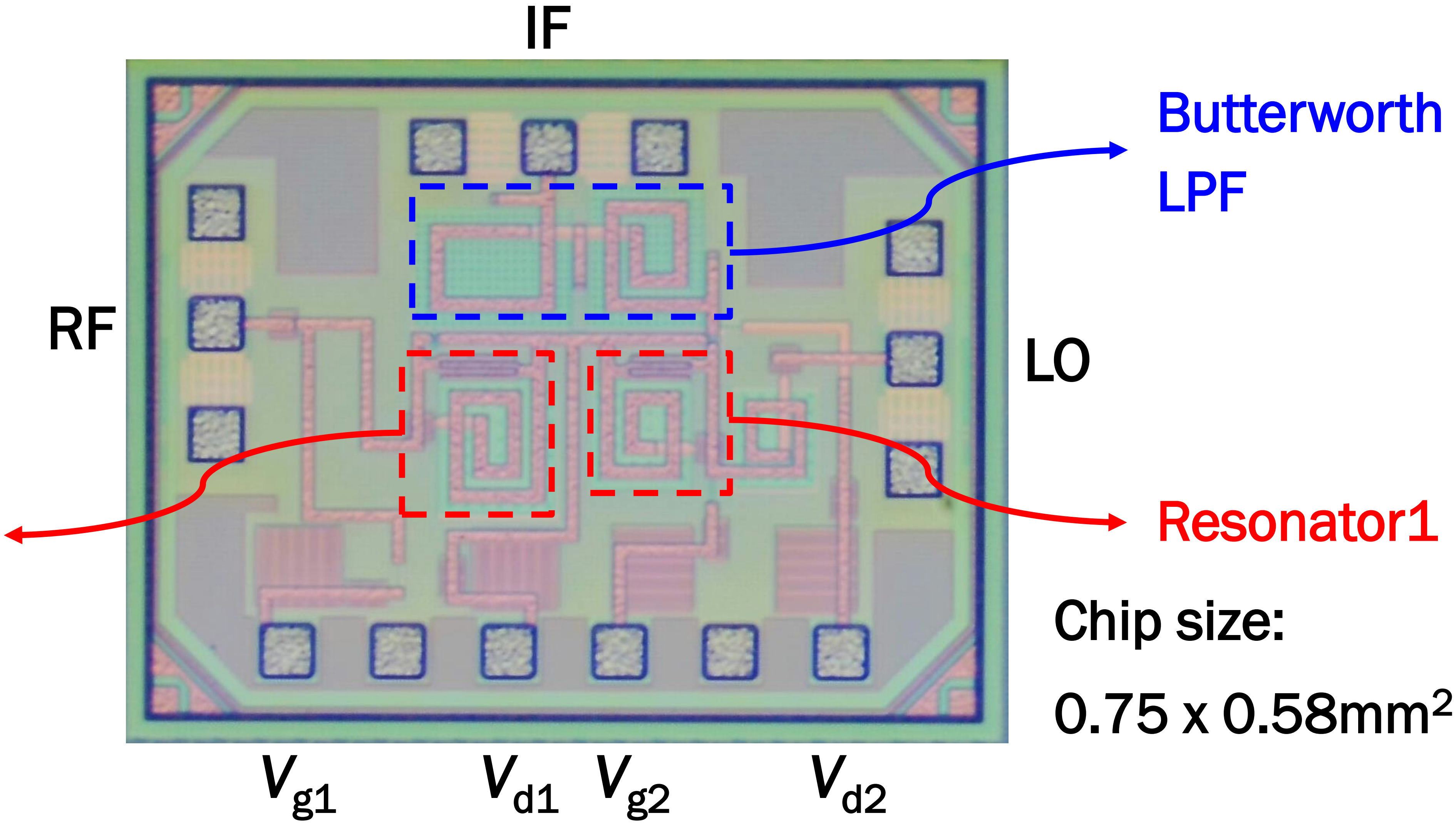


Circuit Design (LC resonators)

- Without LC Resonator
  - 24 dB LO-to-RF Isolation
    - Signal interference and DC offset
- With 2 LC Resonators
  - 34 dB LO-to-RF Isolation
    - Meeting system requirement



Simulation and Measurement



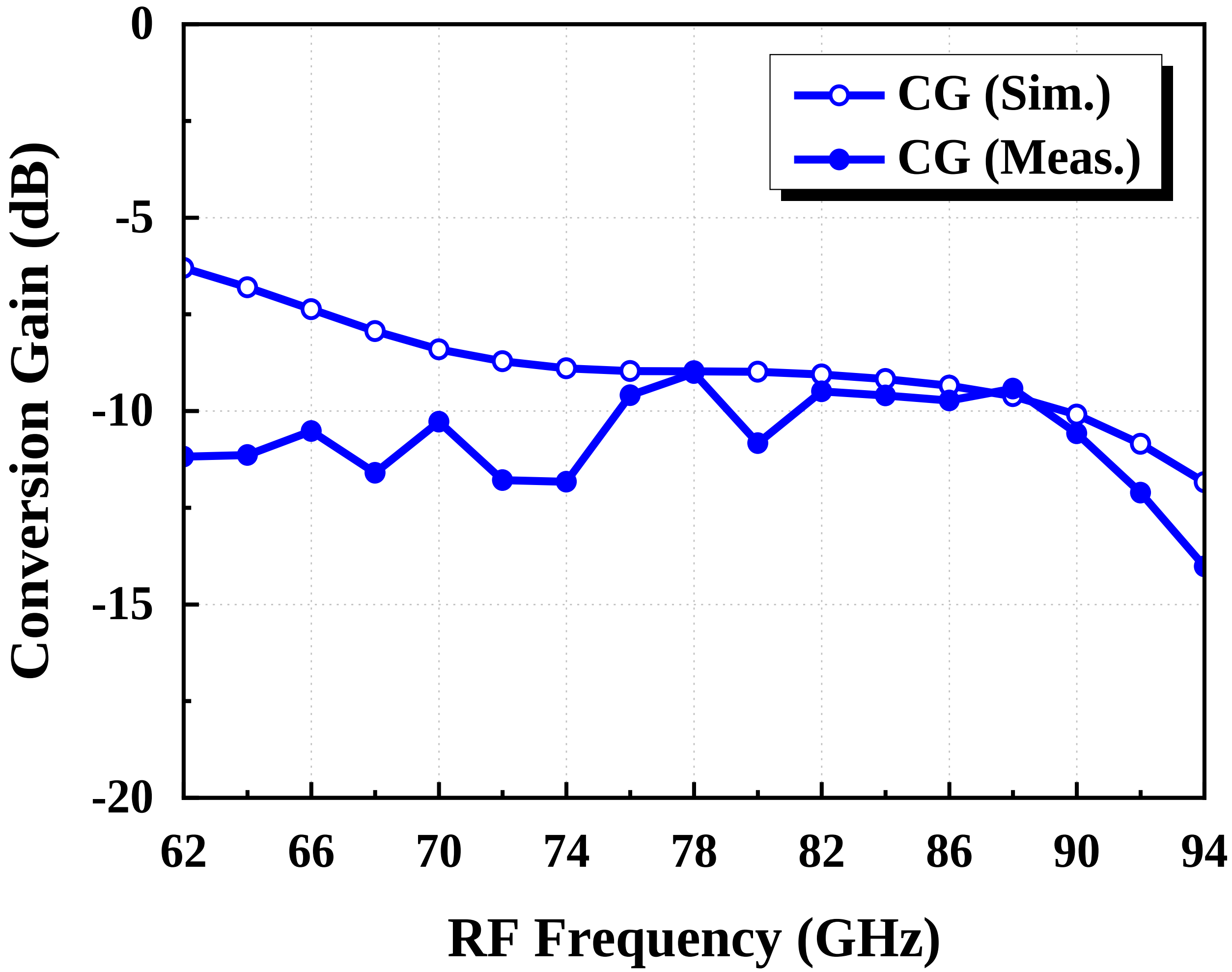
Chip size:

$0.75 \times 0.58 mm^2$

Simulation and Measurement

- Conversion Gain
  - -9 to -12 dB
- 3 dB IF Frequency
  - 2 to 32 GHz

(With 8-dBm 60-GHz LO signal)

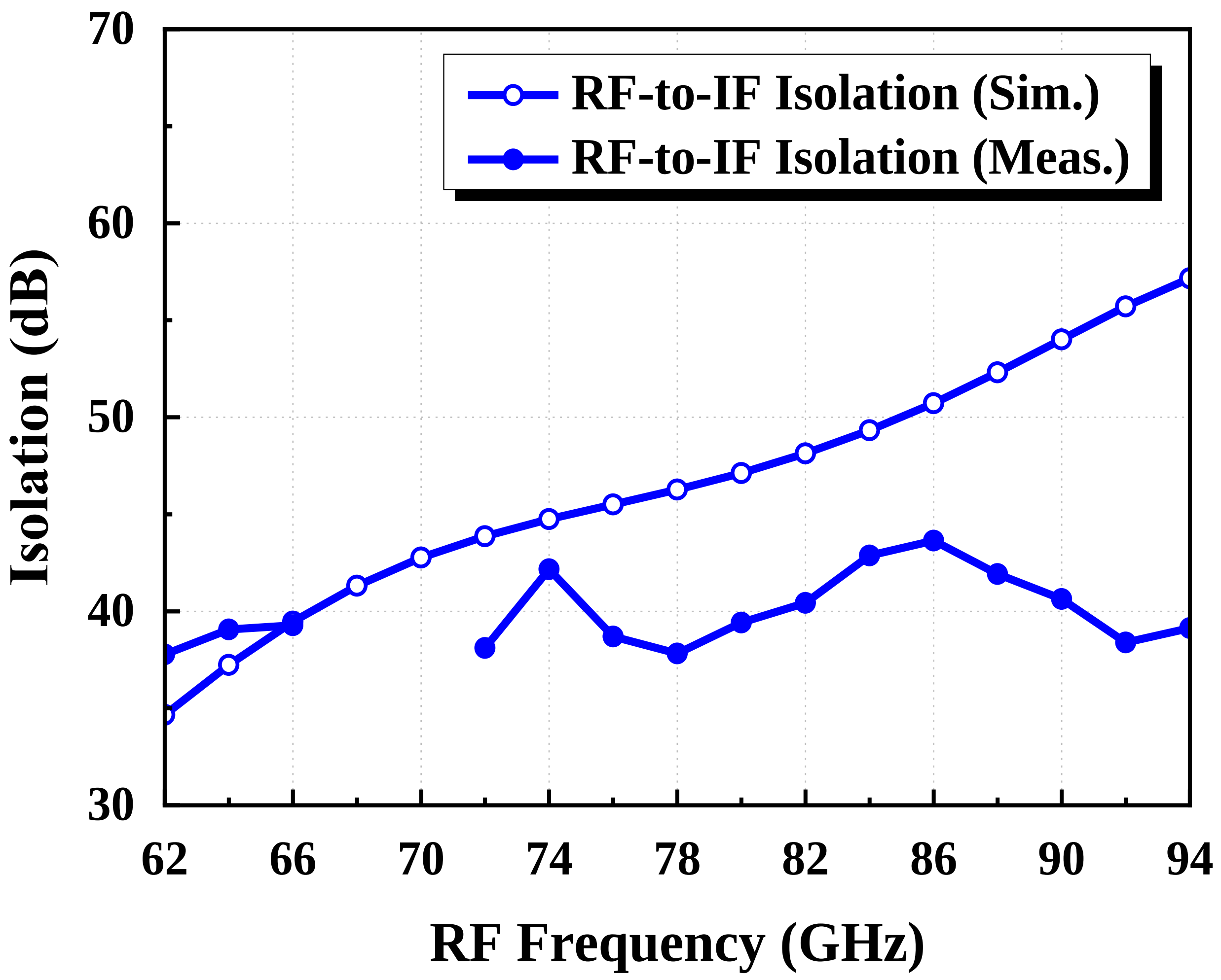


Simulation and Measurement

- LO-to-RF Isolation
  - 40 dB
- LO-to-IF Isolation
  - 31 dB

  (Single LO frequency: 60 GHz)
- RF-to-IF Isolation
  - > 38 dB

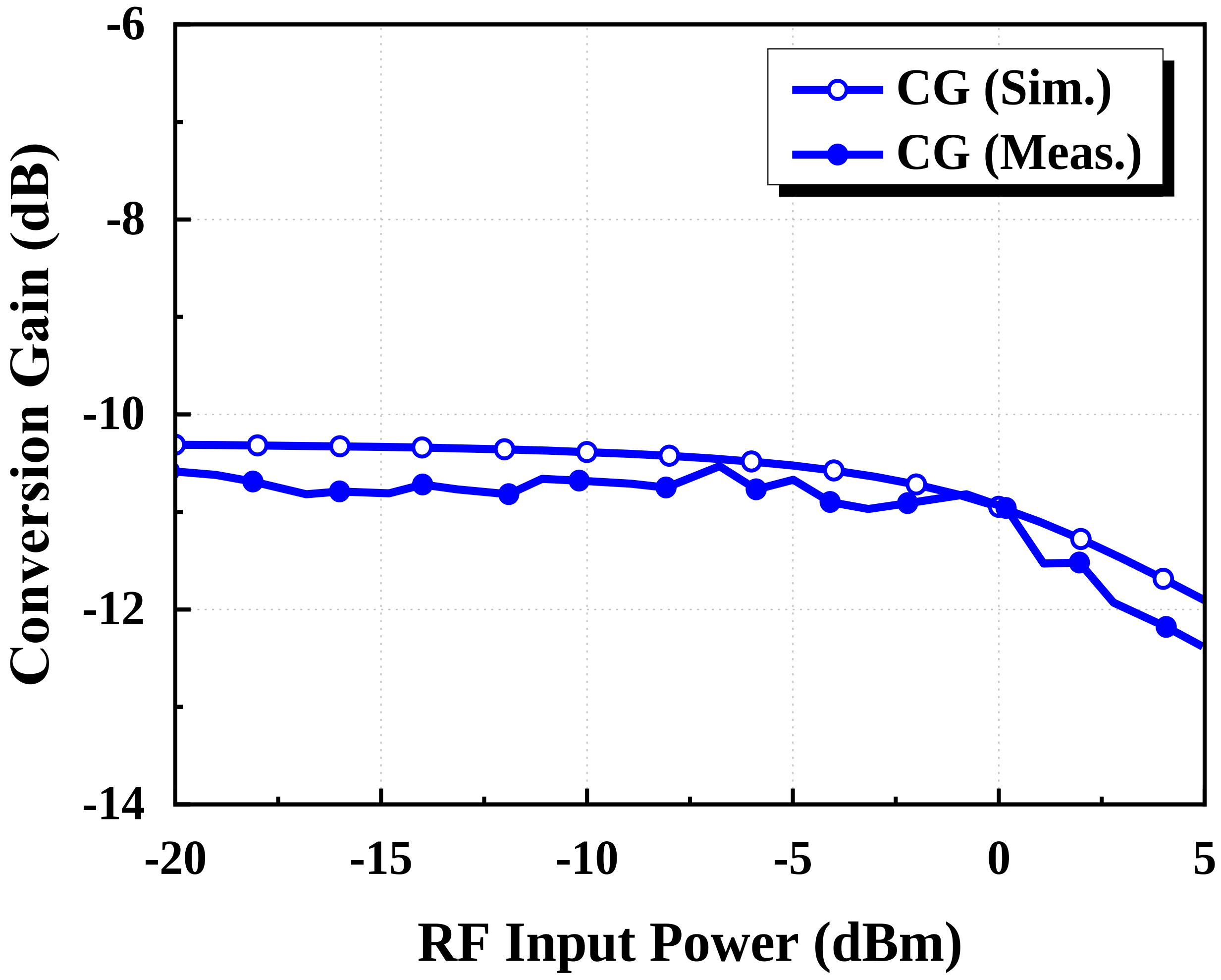
  (RF frequency: 62-94 GHz)



Simulation and Measurement

- IP1dB at 90 GHz
  - – 2 dBm

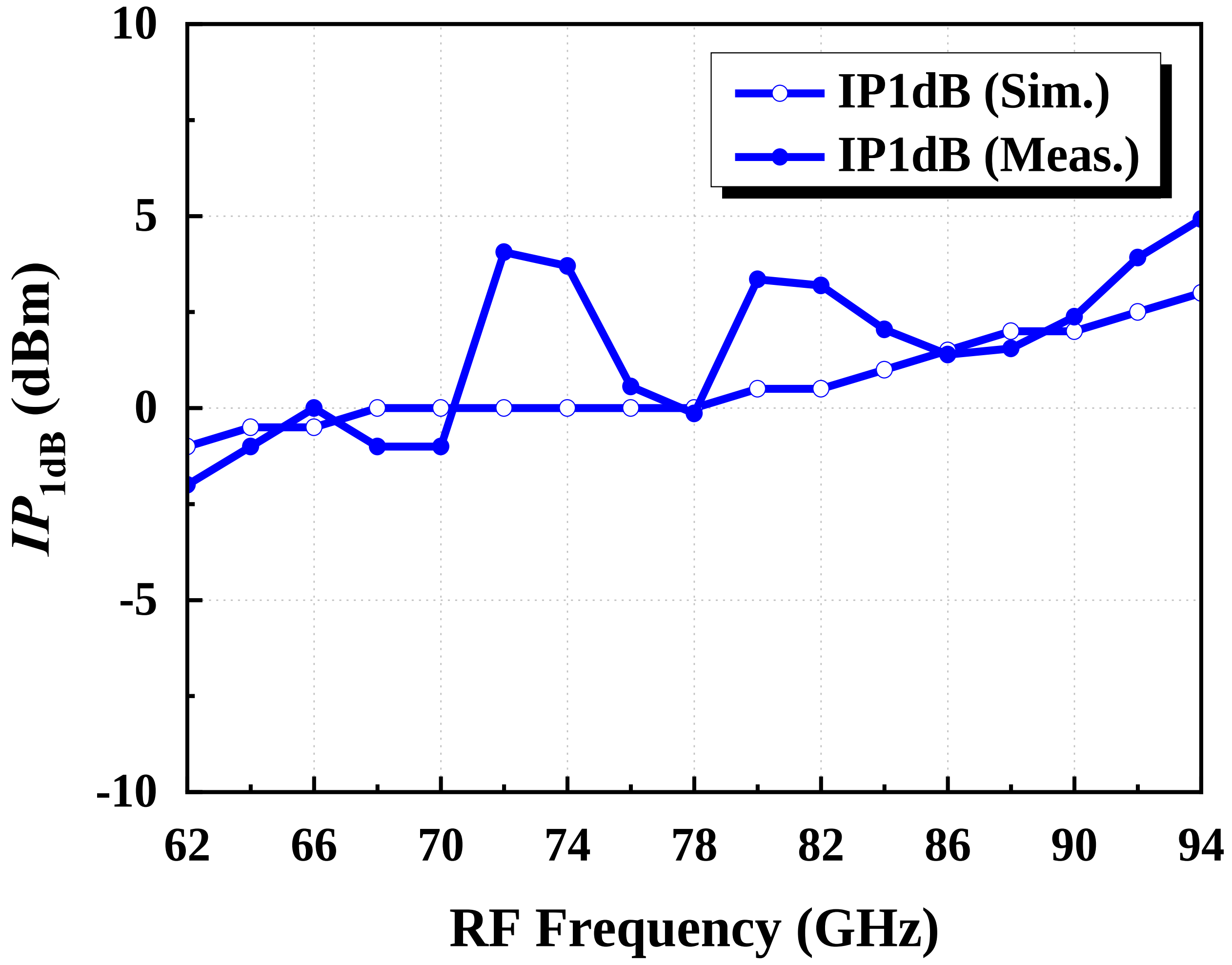
(With 8-dBm 60-GHz LO signal)



Simulation and Measurement

- IP1dB in Full E-band
  - -2 to 4 dBm

(With 8-dBm 60-GHz LO signal)



Comparison to reported mixers

Ref.	Process	Topology	RF freq (GHz)	IF freq (GHz)	CG* (dB)	IP_{1dB} (dBm)	LO-to-RF ISO# (dB)	P_{dc} (mW)	LO power (dBm)	Area (mm^2)
[1]	0.15-μm GaAs pHEMT	Modified cascode	27-47	DC-15	0	N/A	N/A	N/A	4	1.5
[2]	0.15-μm GaAs pHEMT	Modified triple cascode	75-120	DC-24	-10 - -17	N/A	41.5	24	7	1
[3]	0.1-μm GaAs pHEMT	Modified cascode	34-53	3-13	-2--4	-2--4	37	36	0	2.3
[4]	0.25-μm GaAs pHEMT	Star mixer	17-34	0.1-13	-6.6--15.2	N/A	22.6	0	14	0.8
[5]	0.15-μm GaAs pHEMT	Ring mixer	40-50	DC-10	-9.2--11.9	N/A	20	0	15	1.2
[6]	0.15-μm GaAs pHEMT	Subharmonically pumped diode	75-105	DC-21	-4.7	N/A	15	0	11	2
[7]	GaAs	Double balanced	18-50	DC-21	-8.7	9	39	0	12-22	16
[8]	90nm CMOS	Fundamental drain/gate pumped	30-90	DC-16	-7.2--13.7	2	30.2	0.6	4.2	0.4
This work	**90nm CMOS**	**Modified cascode**	**62-92**	**2-32**	**-9--12**	**-2-4**	**40.8**	**8.1**	**8**	**0.4**

*Conversion gain, # LO-to-RF isolation

Conclusion

- Cold-Biasing Technique
  - Extend Instantaneous IF Bandwidth
    - 2-32 GHz 3-dB IF frequency
- LC Resonators
  - Improve LO-to-RF Isolation
    - 40 dB LO-to-RF Isolation
- Acceleration in Astronomical Observation
  - The observation is two to three times faster than before

References

[1] Z. -M. Tsai, J. -C. Kao, K. -Y. Lin and H. Wang, "A 24–48 GHz cascode HEMT mixer with DC to 15 GHz IF bandwidth for astronomy radio telescope," 2009 European Microwave Integrated Circuits Conference (EuMIC), 2009, pp. 5-8.

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Thank you for listening!