CICC 2015
Session 4.3

A 3.9 mW, 35-44 / 41-59.5 GHz Distributed Injection-Locked Frequency Divider

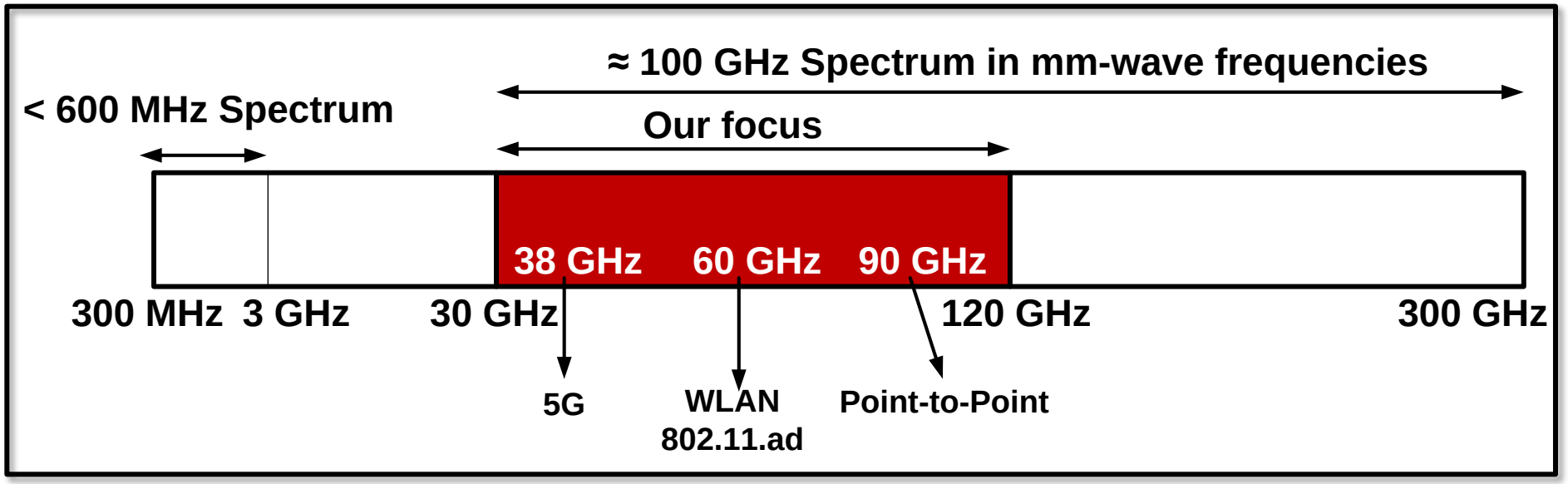
Alireza Imani and Hossein Hashemi

University of Southern California

Outline

- Motivation
- Concept
- Implementation
- Conclusion

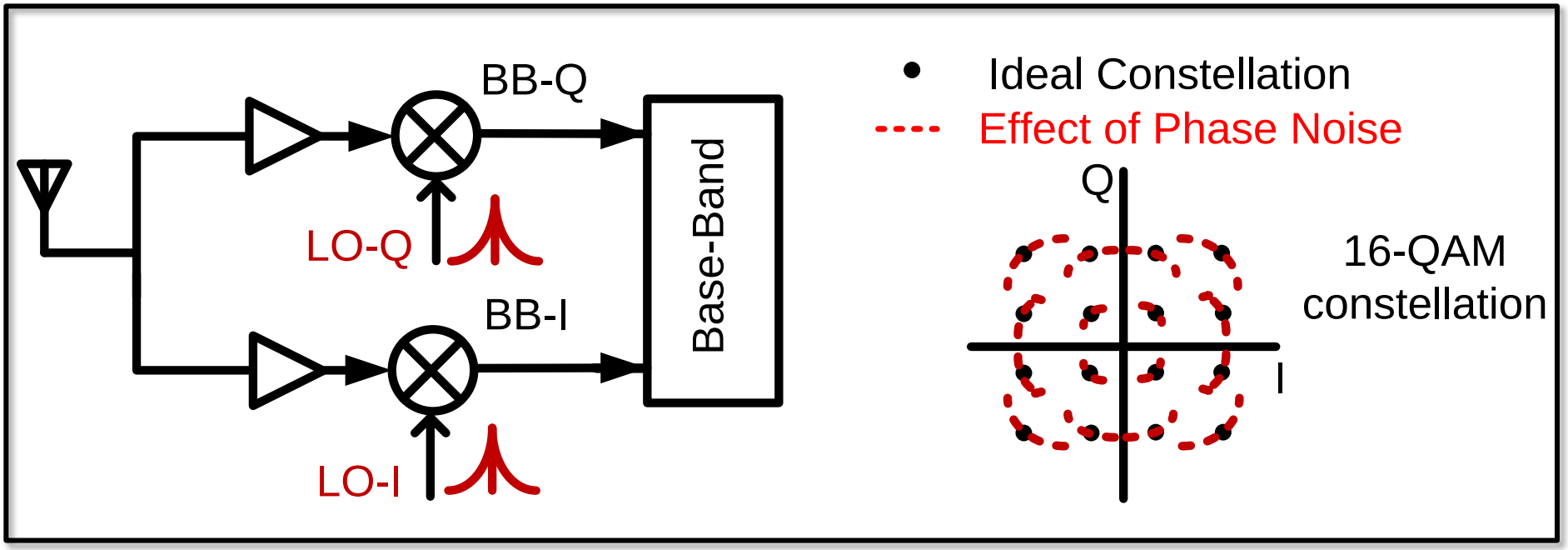
Motivation: mm-Wave SDR



- ✓ **Demand for higher data-rates**
- ✓ **Interference tolerance through beam-forming**

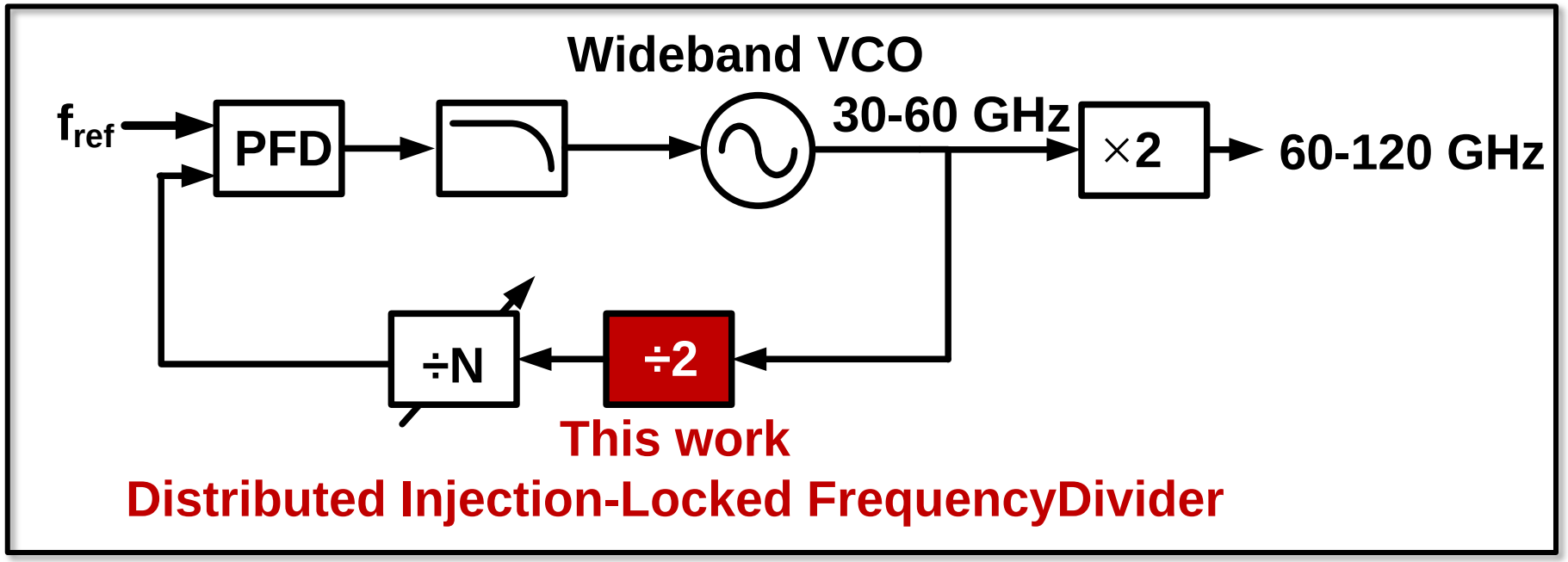
mm-wave Software Defined Radio is a meaningful proposition.

Frequency Synthesizer in SDR



High-data-rate spectrally-efficient mm-wave Software Defined Radio requires low phase- noise wideband frequency synthesizer.

Proposed mm-Wave Wideband Frequency Synthesizer

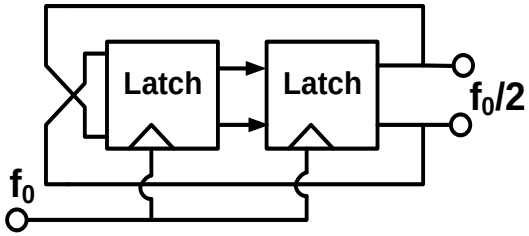
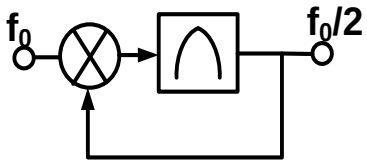
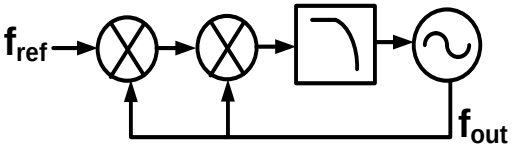
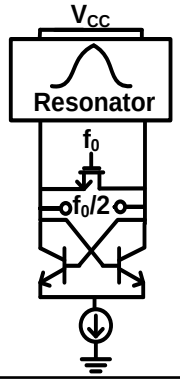


The frequency synthesizer architecture and frequency planning is chosen to minimize power consumption considering transistor f_{max}, phase noise of f_{ref}, etc.

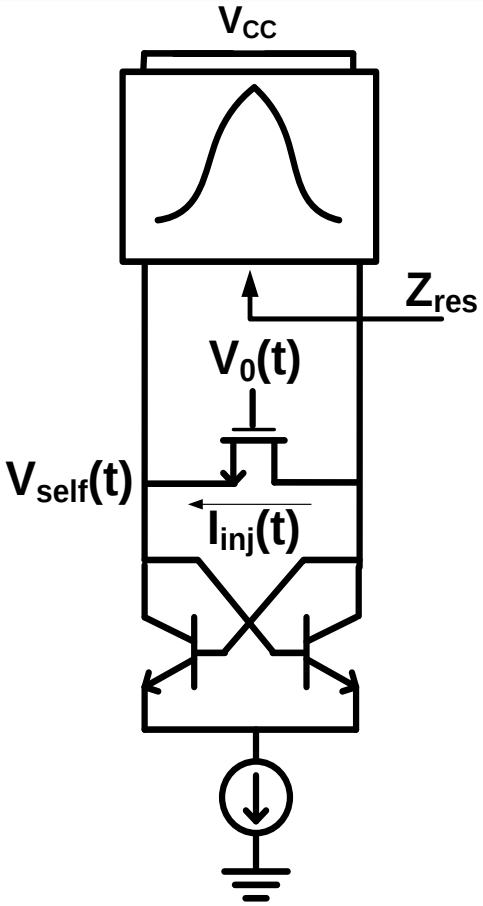
Outline

- Motivation
- Concept
- Implementation
- Conclusion

Frequency Divider Topologies

Type	Schematic	Area	Locking Range	Max Frequency	Power
Flip-Flop Based		Smallest	Widest	Low	Frequency Dependent
Miller		Medium	Narrow	High	Medium
Heterodyne PLL		Small	Medium	High	High
Injection Locked		Medium	Narrow	Highest	Low

Injection Locked Frequency Divider



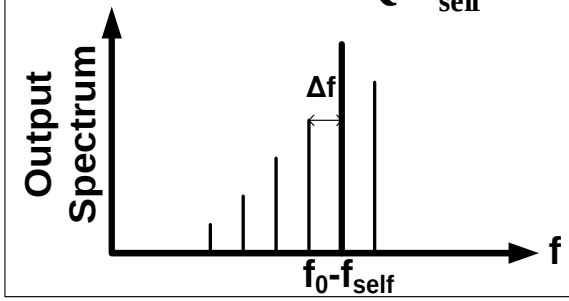
$$V_0(t) = a_0(t)\sin(\omega_0 t + \theta)$$

$$V_{self}(t) = a_{self}(t)\sin(\omega_{self} t + \theta)$$

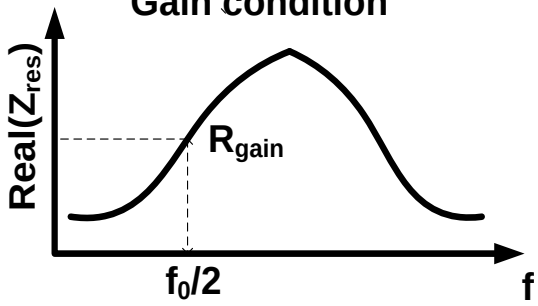
$$\omega_0 = 2\omega_{self} + \Delta\omega$$

Adler Phase Condition

$$\frac{d\theta}{dt} = \omega_{self} - \frac{\omega_0}{2} - \frac{\omega_{self}}{2Q}\frac{\alpha V_0}{V_{self}}\sin(\theta)$$



Gain condition

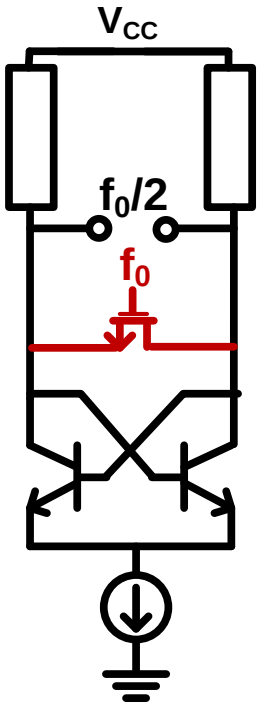


$$\mathrm{Real}\left(Z_{res}\left(\frac{f_0}{2}\right)\right) = R_{gain} < \frac{2}{g_m}$$

$$g_m = f(V_0)$$

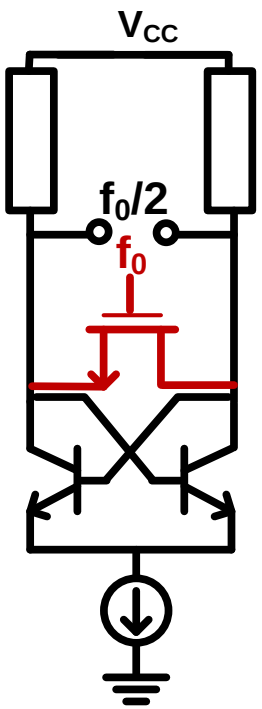
Oscillation dies!

Injection Locked Frequency Divider Locking Range



Small injection device:

✘ Limited Locking range ∝ Inj/Q (Adler phase condition)

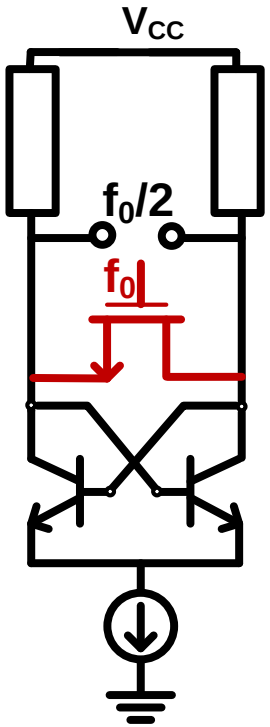


Large injection device: Small R_{on}

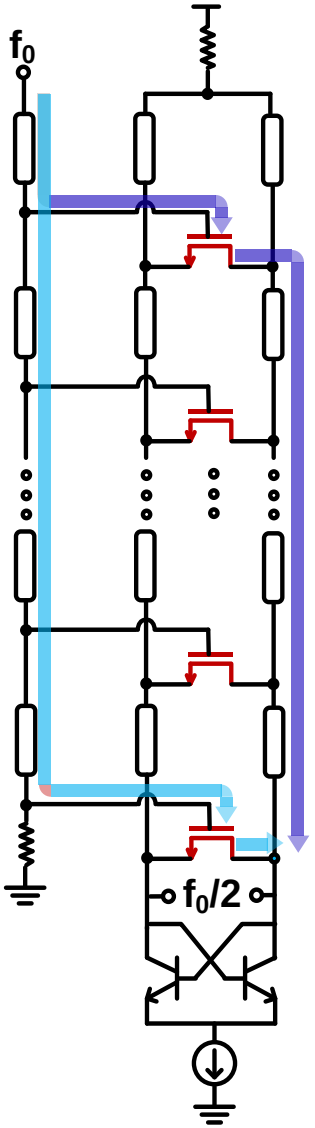
✘ Prevent oscillation start-up (Gain condition)

The trade-off limits locking range for a given power consumption.

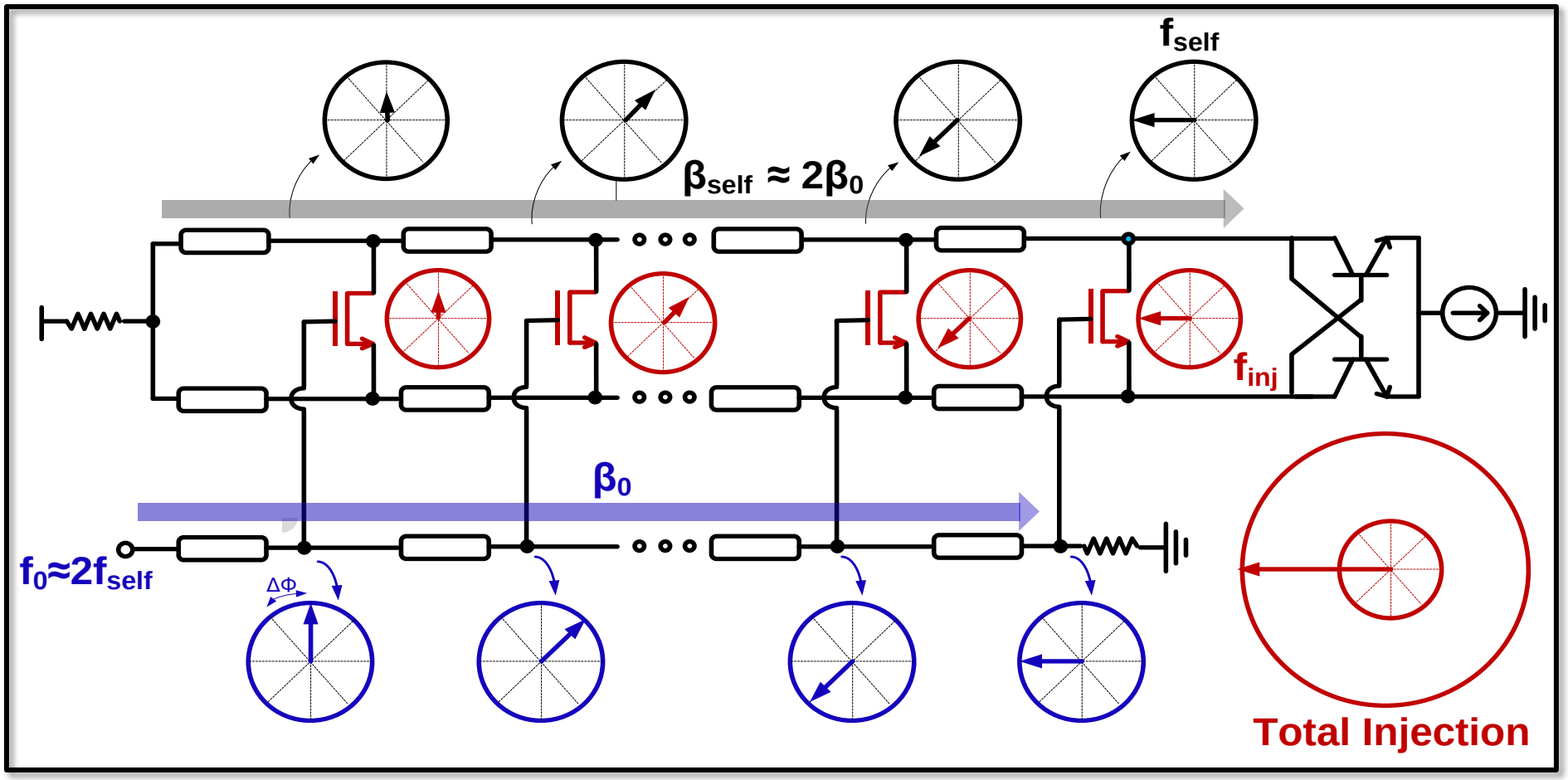
Distributed Injection Locking



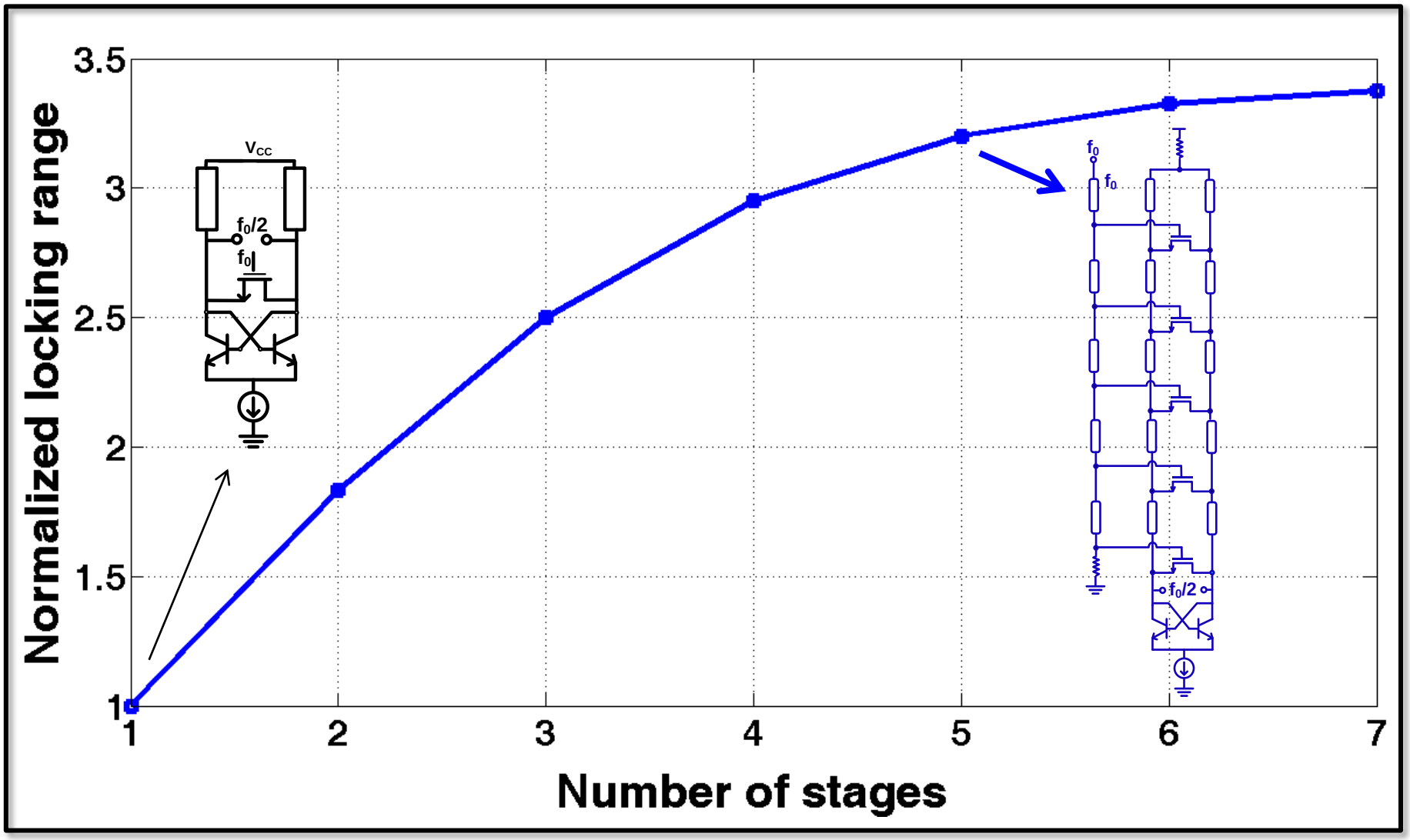
- ✓ **Smaller switches with strong injection**
- ✓ **Wide locking range.**
- ✓ **Wideband input matching.**



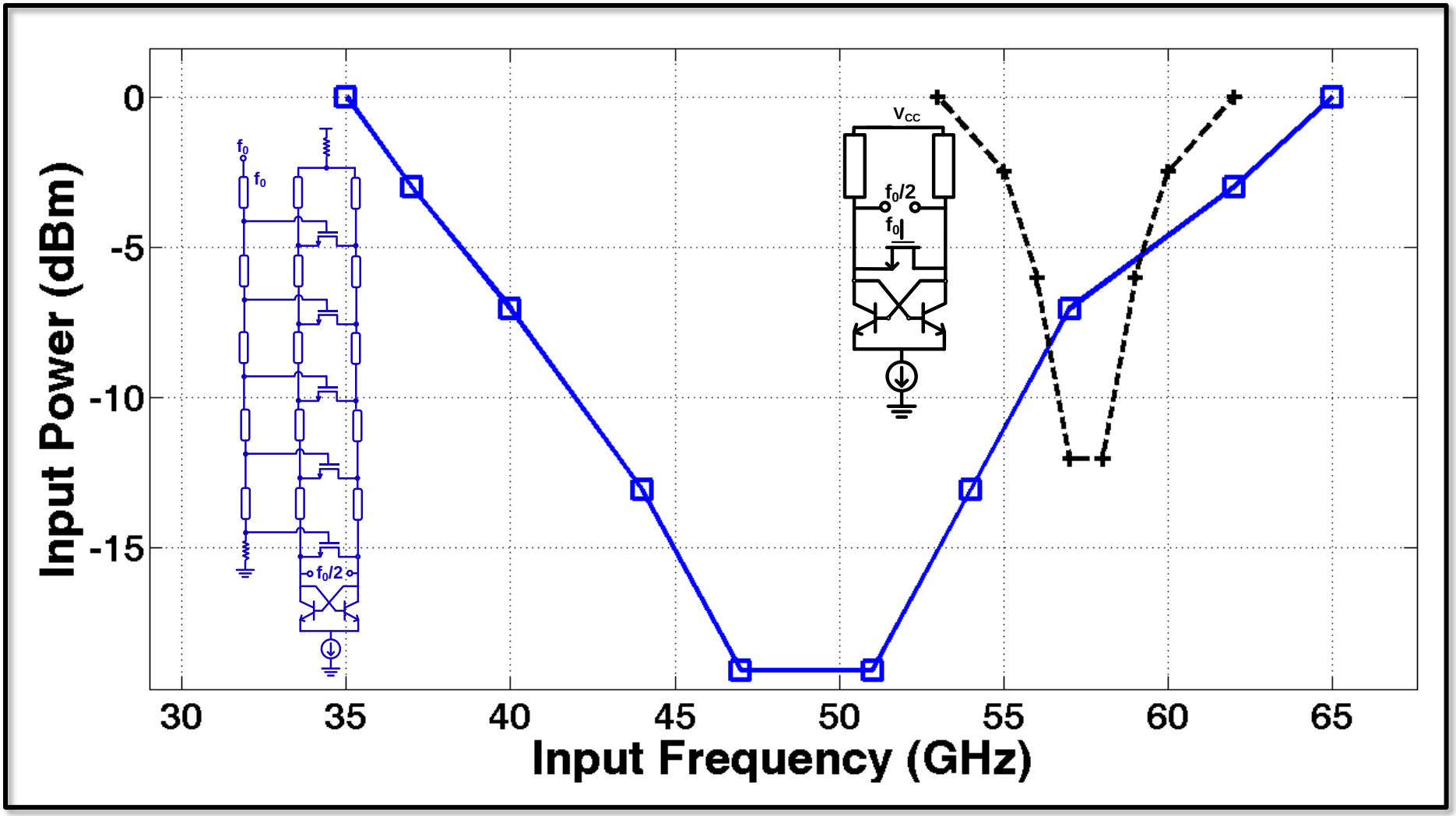
Operation Principle



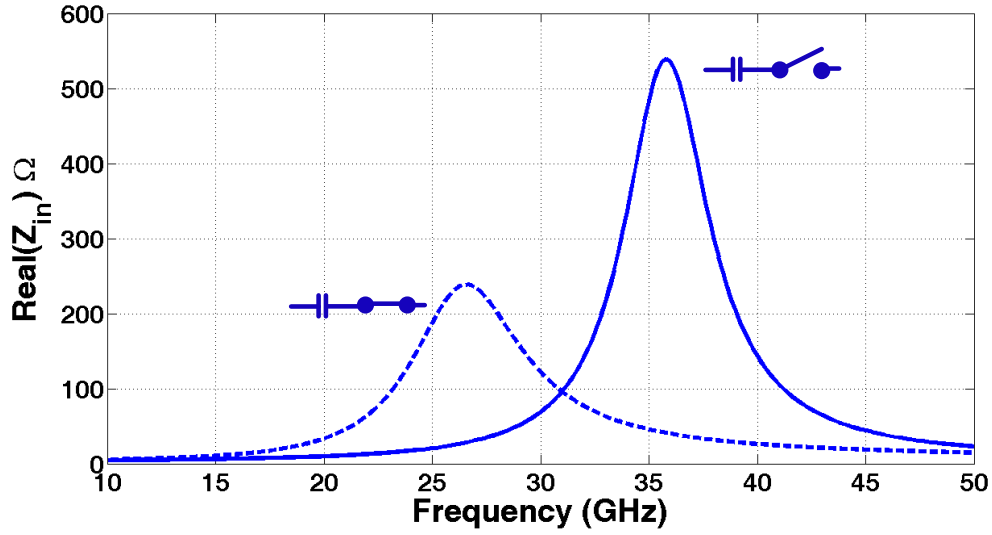
Optimum Number of Stages

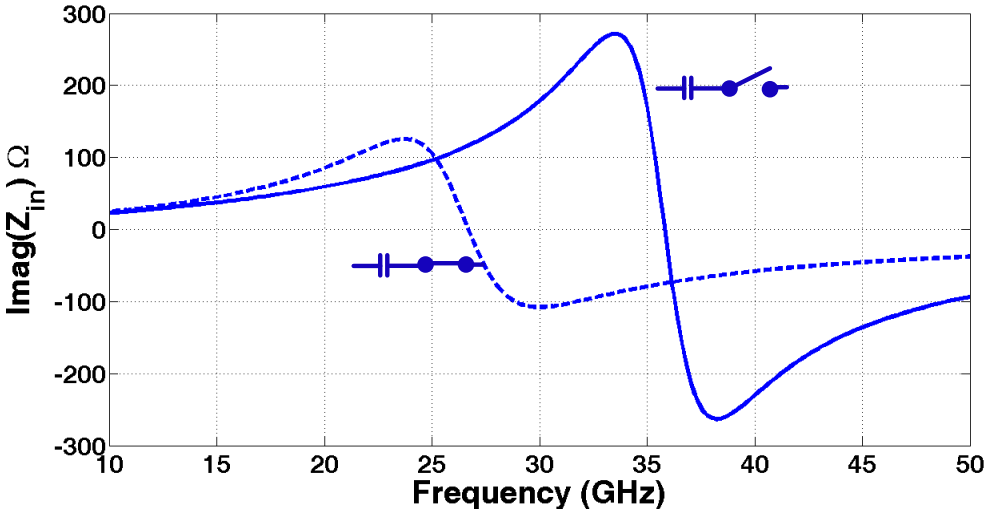


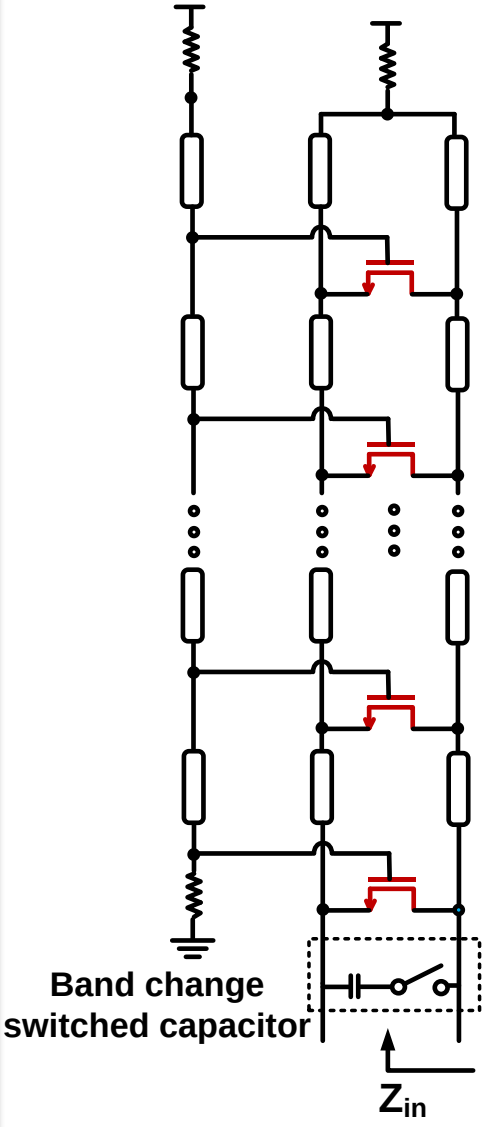
Comparison (Simulations)



Load Frequency Shifting



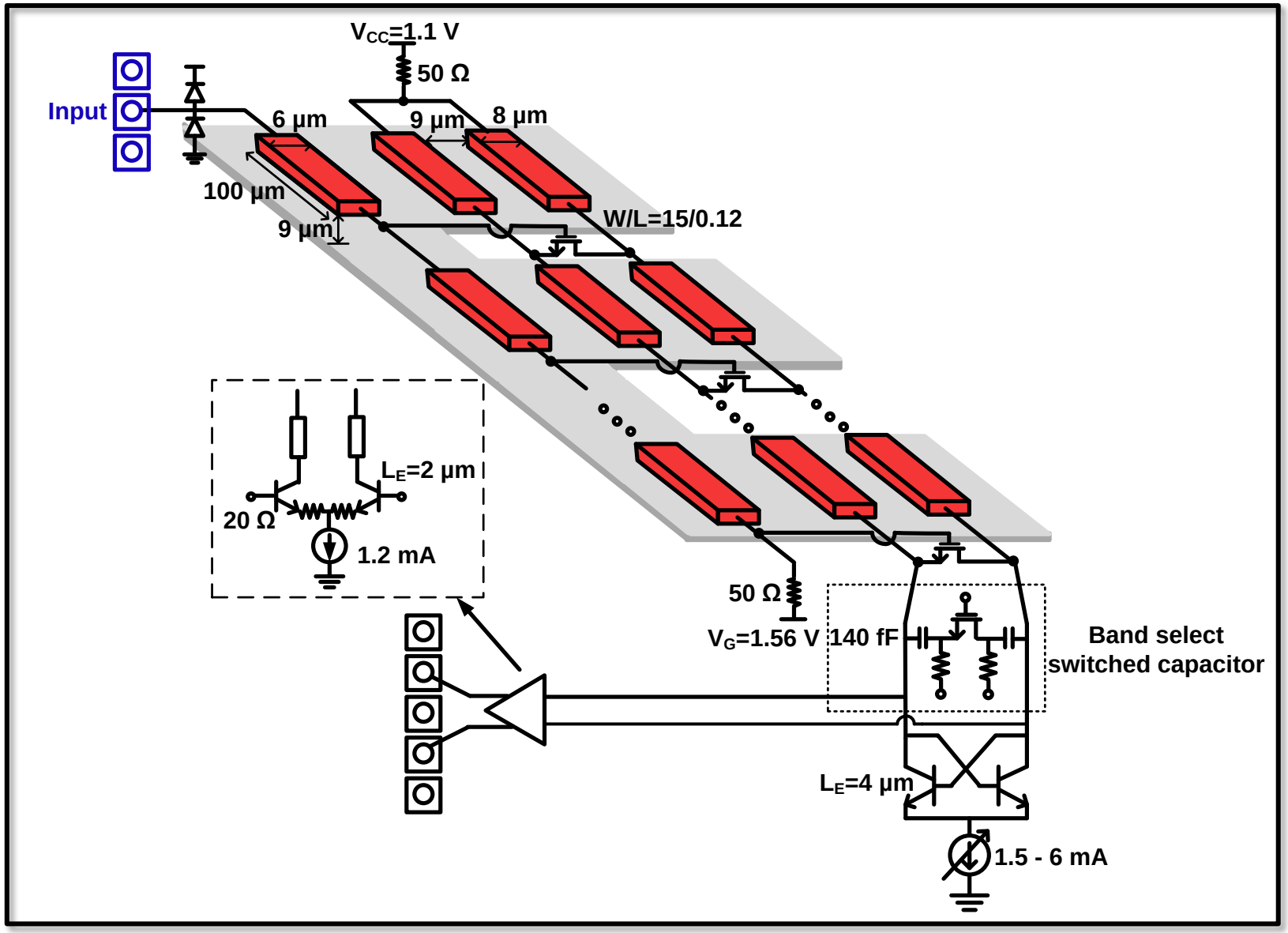




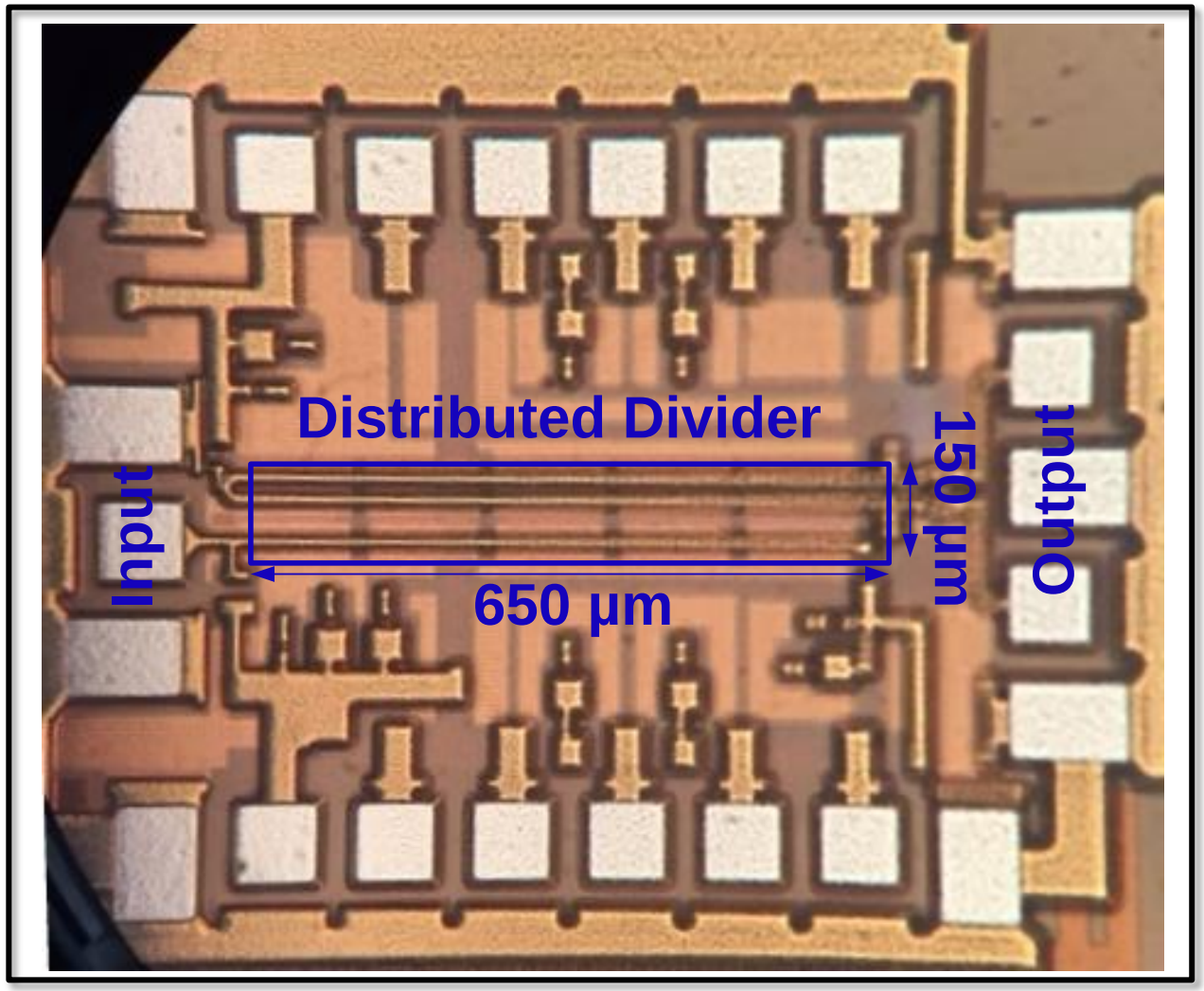
Outline

- Motivation
- Concept
- Implementation
- Conclusion

Schematics

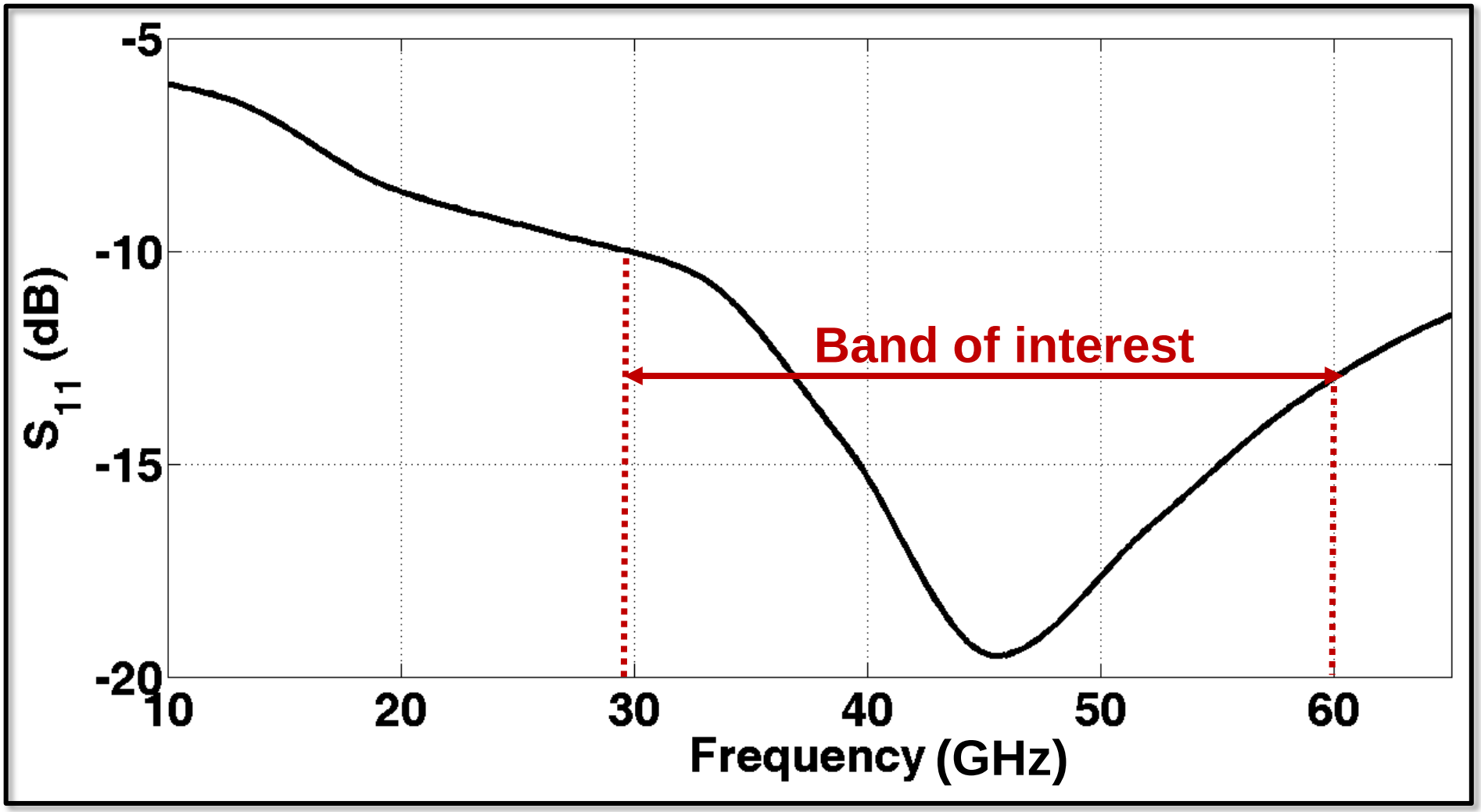

V_{CC}=1.1 V
50 Ω
Input
6 µm
9 µm
8 µm
100 µm
9 µm
W/L=15/0.12
L_E=2 µm
20 Ω
1.2 mA
50 Ω
V_G=1.56 V
140 fF
Band select
switched capacitor
L_E=4 µm
1.5 - 6 mA

Chip Micrograph



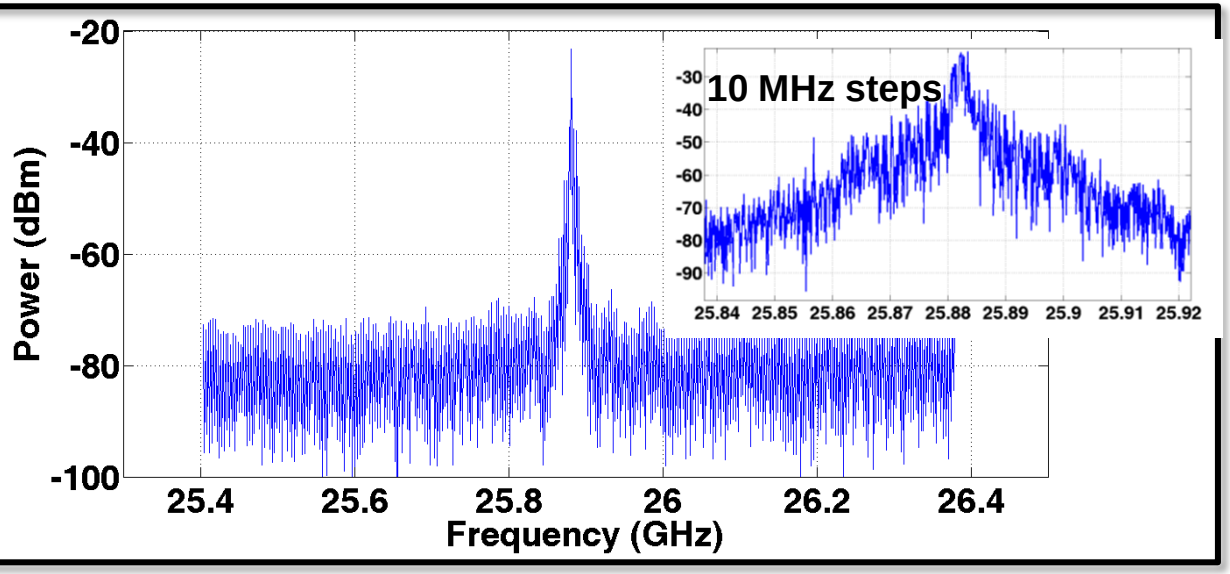
0.13 µm SiGe BiCMOS (IBM 8HP)

Input Reflection Coefficient

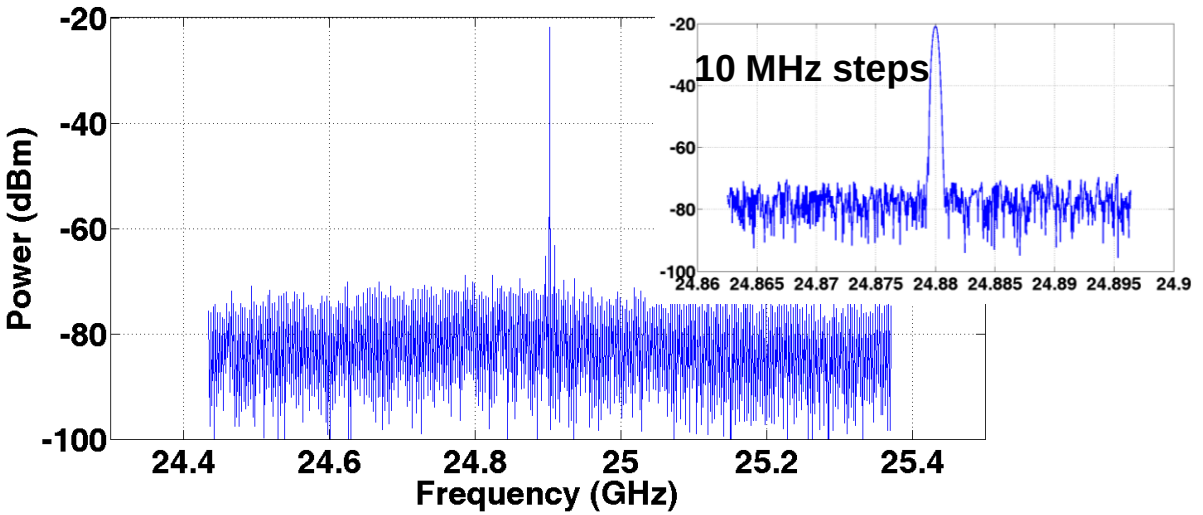


Output Spectrum

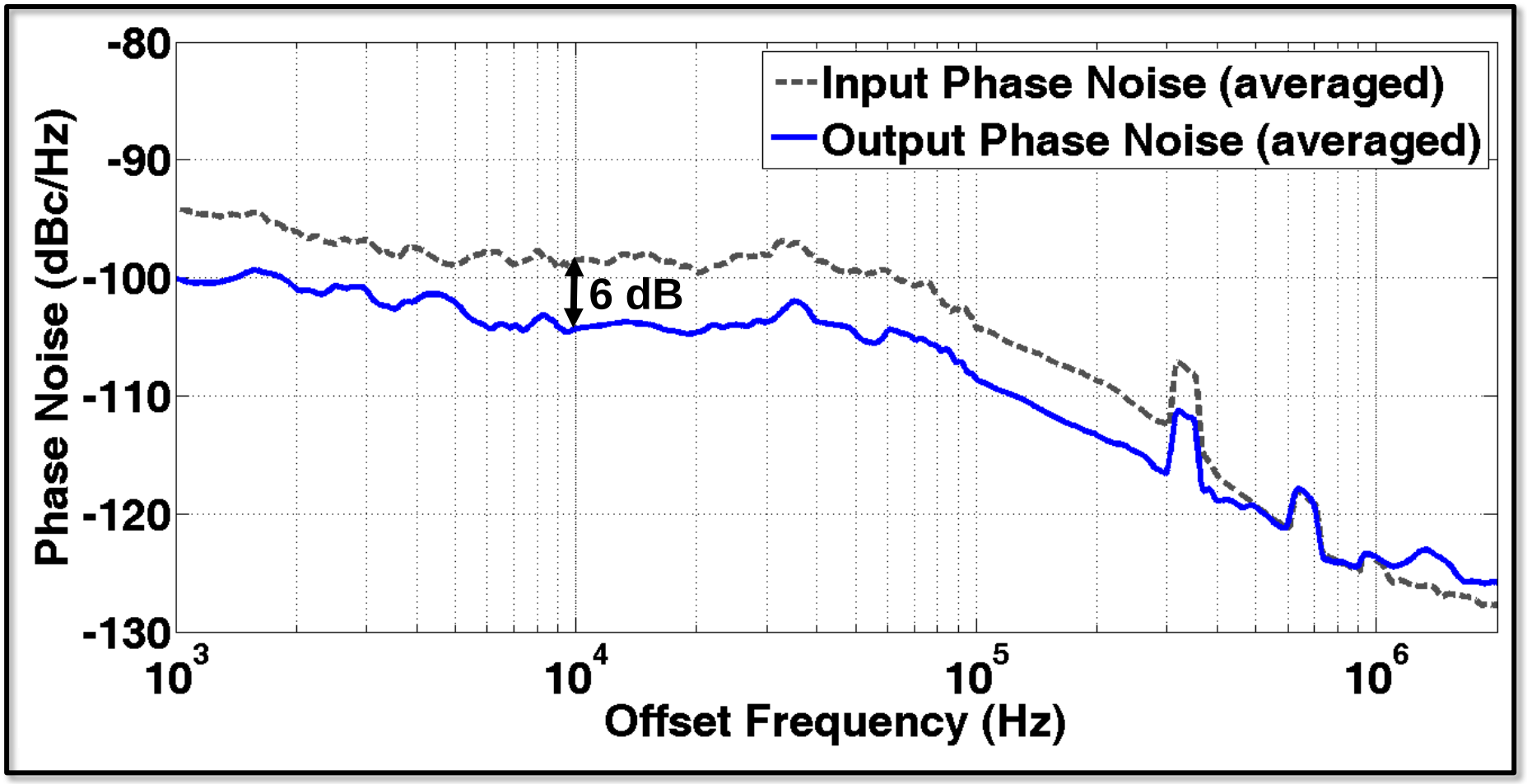
Self-Oscillation



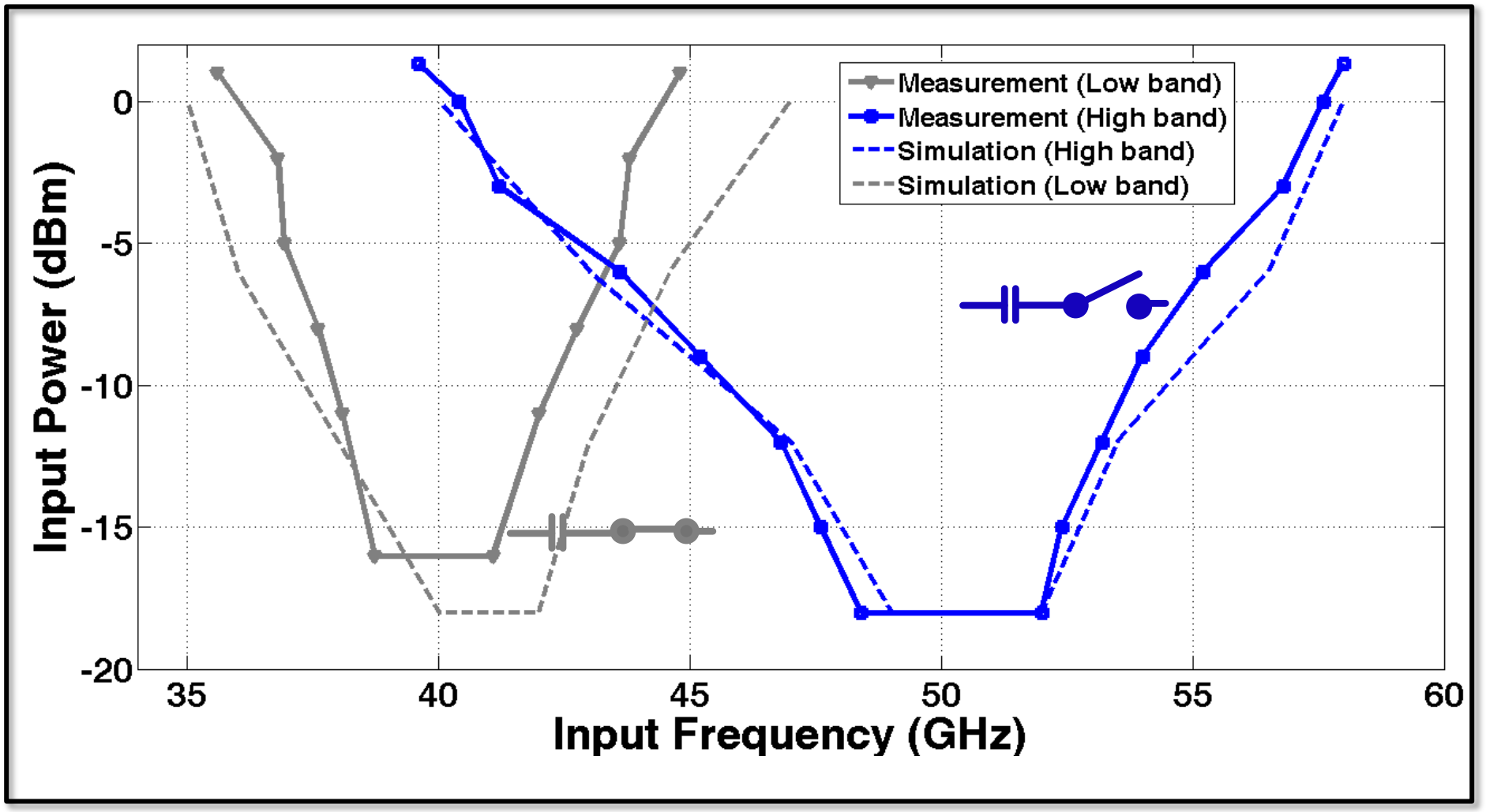
Injection-Locked



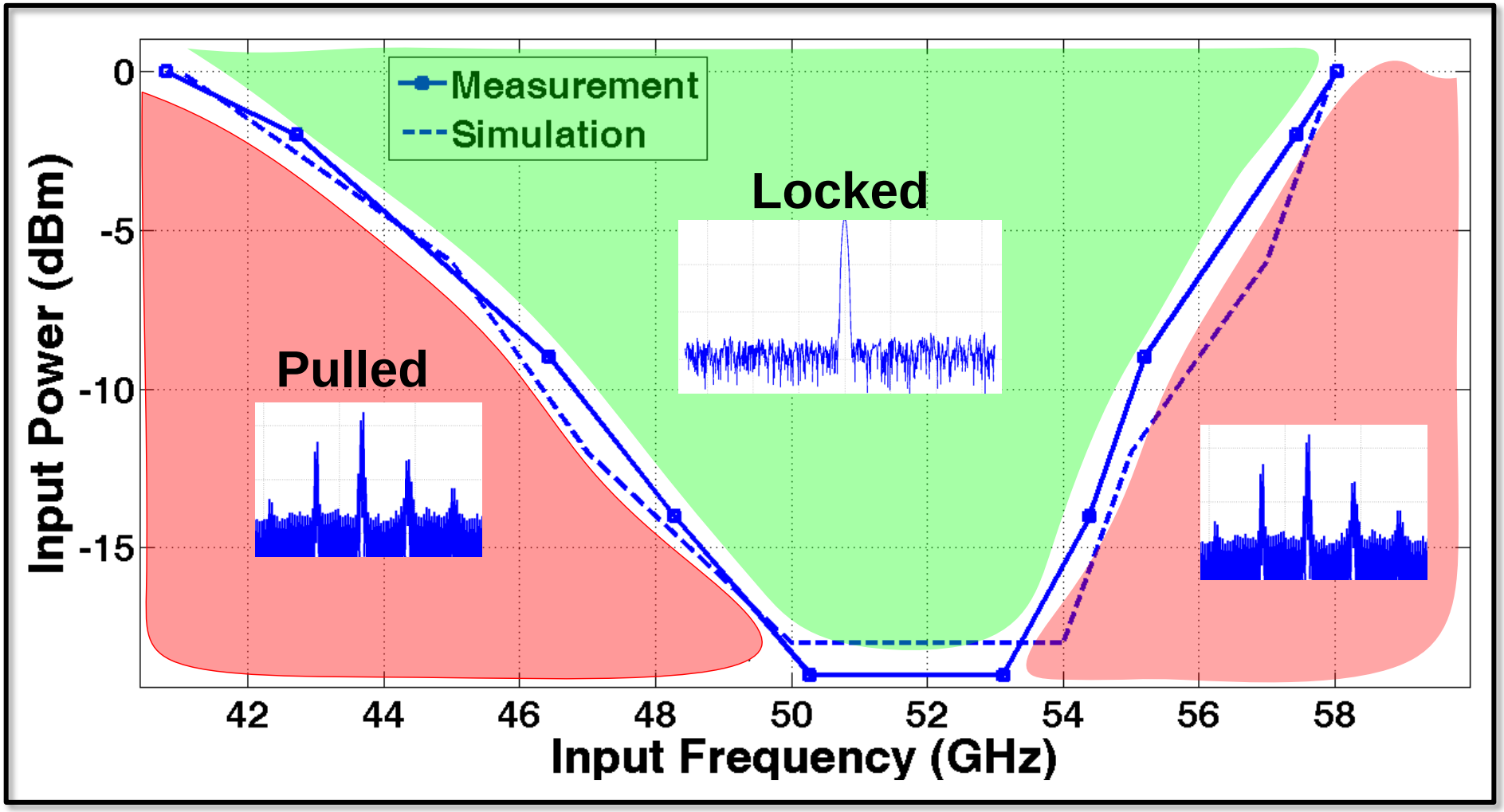
Measured Locked Phase Noise



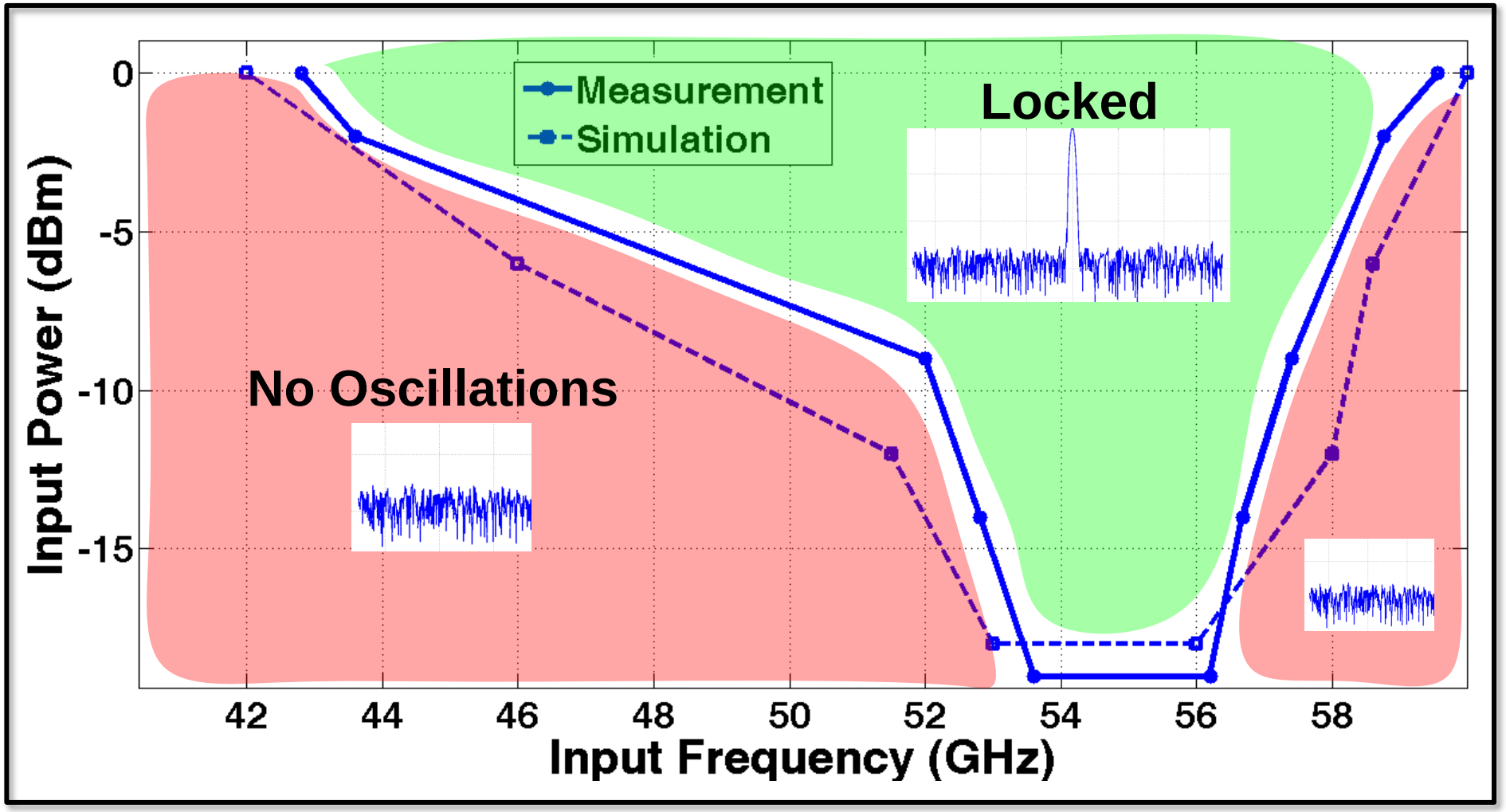
Sensitivity Curve
(I_{core}=4 mA, I_{buf}=1 mA)



Sensitivity Curve
(I_{core}=5 mA I_{buf}=0.6 mA)



Sensitivity Curve
(I_{core}=2.5 mA, I_{buf}=0.6 mA)



Performance Summary

	This Work	ISSCC 2007	ISSCC 2009	JSSC May 2013	RFIC 2012	JSSC October 2013
Technology	0.13 µm BiCMOS	0.18 µm CMOS	0.13 µm CMOS	32nm CMOS	65 nm CMOS	65 nm CMOS
Operation Frequency (GHz)	35 - 44 41 - 60	37.5 - 49	59.6 - 67	40 - 70	53.7 - 72	53.4 - 79
Locking Range	Low band: 22% High band: 37% Total: 53%	26.6%	11.6%	54%	29%	39%
Power Consumption (mW)	3.8	6	1.6	4.8	1.9	2.9
Core Area (mm^2)	0.07	0.428	0.017	0.001	0.02l	0.126
Topology	Distributed IL	Regenerative	Class-B injection	Latch with load modulation	Frequency Tracking	Frequency Tracking

Conclusion

- Low power wideband low phase noise frequency synthesizer enables mm-wave software defined radio.

- Concept of distributed injection locking is introduced to increase locking range of frequency dividers for a given power consumption.

- Prototype with measured 35-60 GHz locking range was implemented in a 130 nm BiCMOS SiGe HBT technology.

Acknowledgement

This work was partially supported by

- ONR

Our Thanks to

- Our group members, USC