An Injection Locking Scheme for Precision Quadrature Generation

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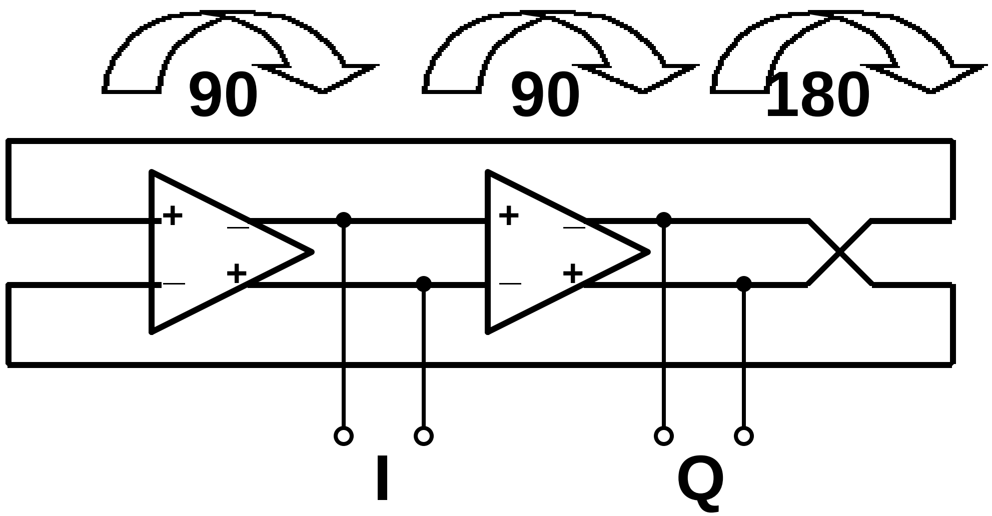
Introduction

- Goal: Generation of accurate high frequency quadrature signals from a single phase input at the same frequency i.e.:
  - 90 degrees phase difference,
  - identical amplitude.
- Applications:
  - Wireless receivers and transmitters,
  - Interleaving, multiphase signal processing.

2 Stage Ring Oscillator

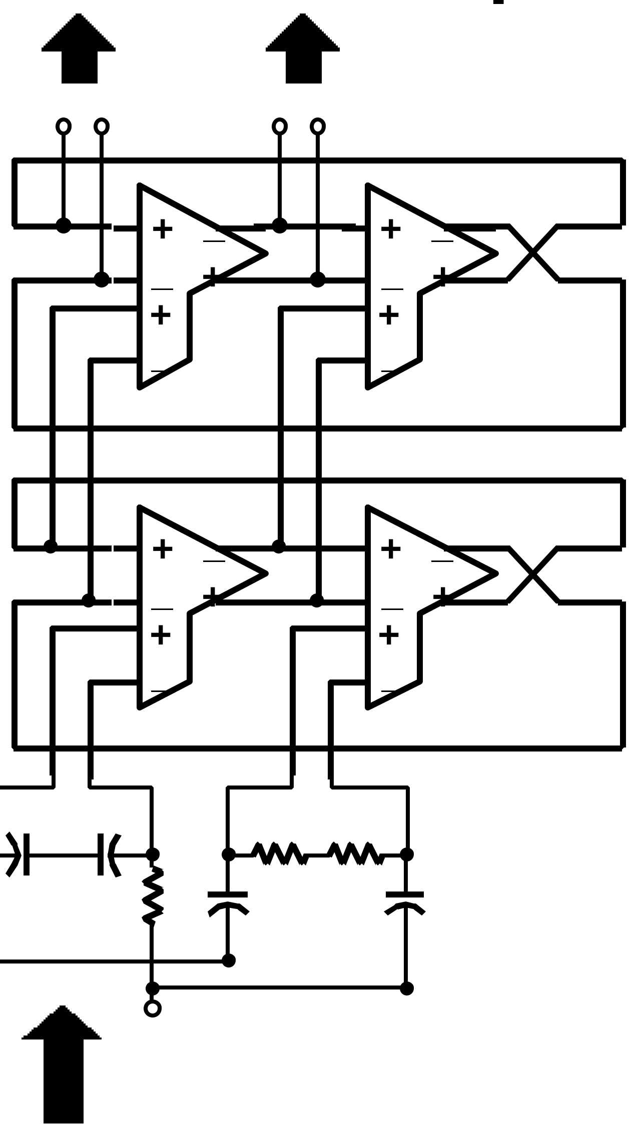


- Inherently good quadrature accuracy
  - only dependent on device matching.
- Ring oscillators are widely tunable.
- But,
  - too high phase noise ...,
  - needs to be locked to reference signal.

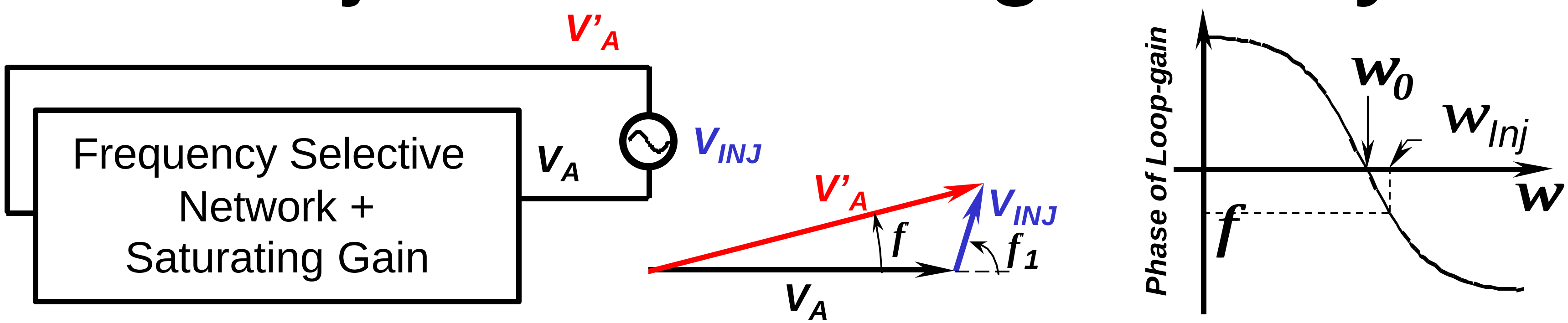
Injection locking

- Principle: injection-lock ring oscillator to incoming clean carrier signal.
  - Injection-locking is equivalent to first order PLL and is always stable.
- Effect: phase noise of ring oscillator suppressed within “the loop-bandwidth of the PLL.”
  - Benefits of a PLL without the need to build an HF PLL
- But, Injection signal disturbs symmetry in ring and thus the quadrature.
- Use ‘cascade’ :
  - RC-CR ® Ring 1 ® Ring 2
  - Gives a progressive improvement of the quadrature to within matching limitations inside the ring.

Injection locking with quadrature inputs



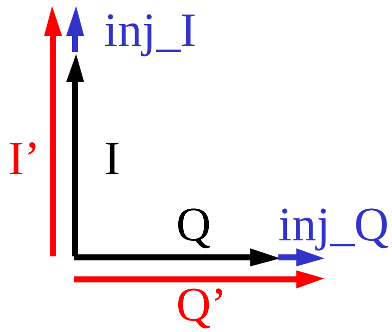
Injection Locking Theory



- After injection locking, V_{INJ} introduces a simple phase-shift in the oscillator loop.
  - The inserted phase-shift in the loop shifts the oscillation frequency from w_0 to w_{Inj}.
  - The loop adjusts f_1 , until oscillation conditions for phase are satisfied for the injected frequency w_{Inj}.
  - Fixed range of frequencies exists for which the above conditions can be satisfied $\Rightarrow$ Finite injection locking range [Adler].

Quadrature Error Transfer

<u>At the center of the lock range</u>



Amplitude imbalance between inj_I and inj_Q lead to:

- Minimum phase imbalance at the output (I' & Q')
- Maximum amplitude imbalance at the output.

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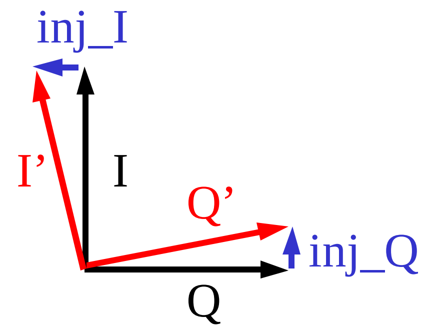
<u>At the edge of the lock range</u>



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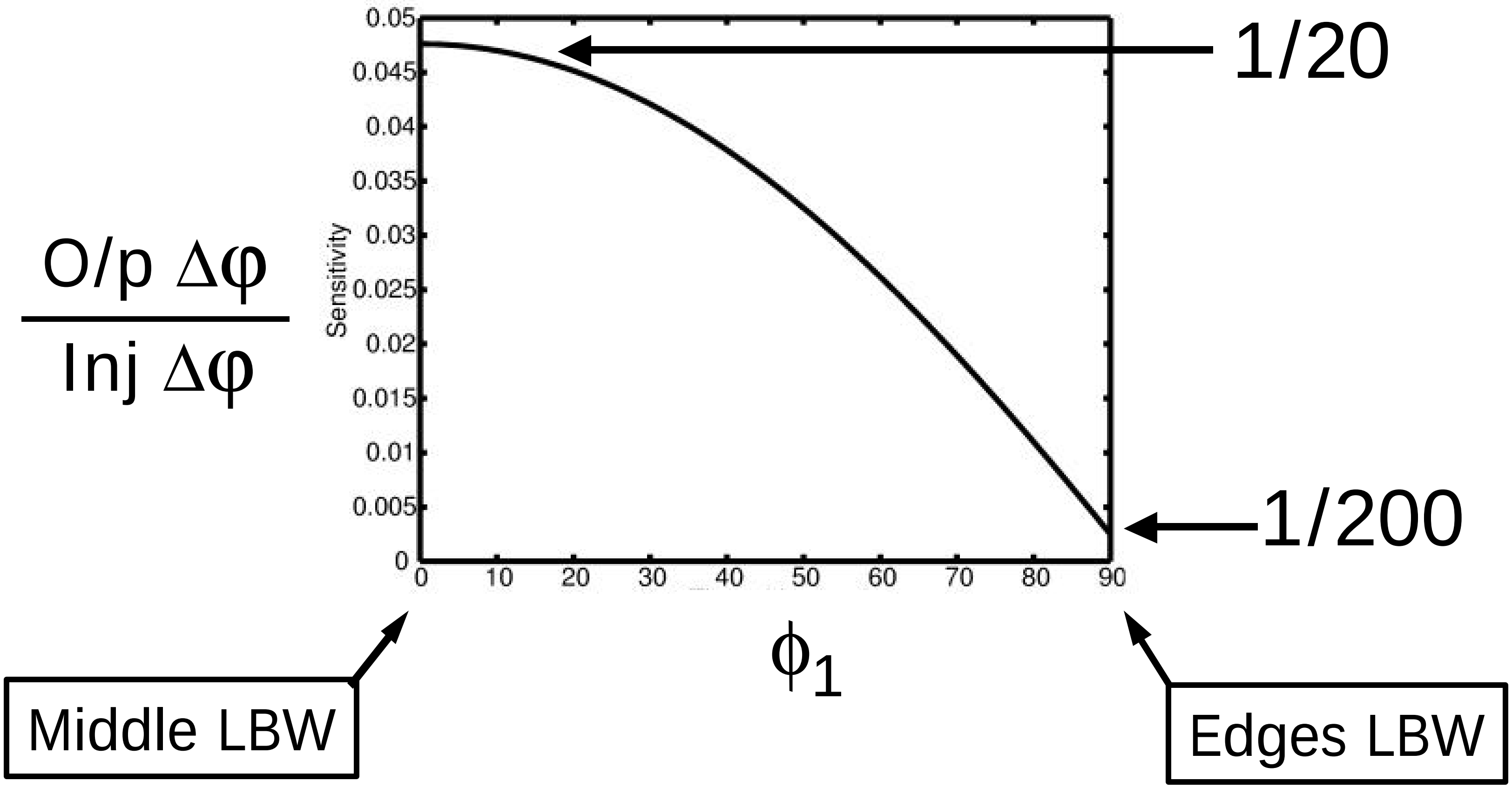
***<u>Key:</u>* Large input amp. & phase imbalances corrected after each stage of injection locking**

Phase Error Transfer Function

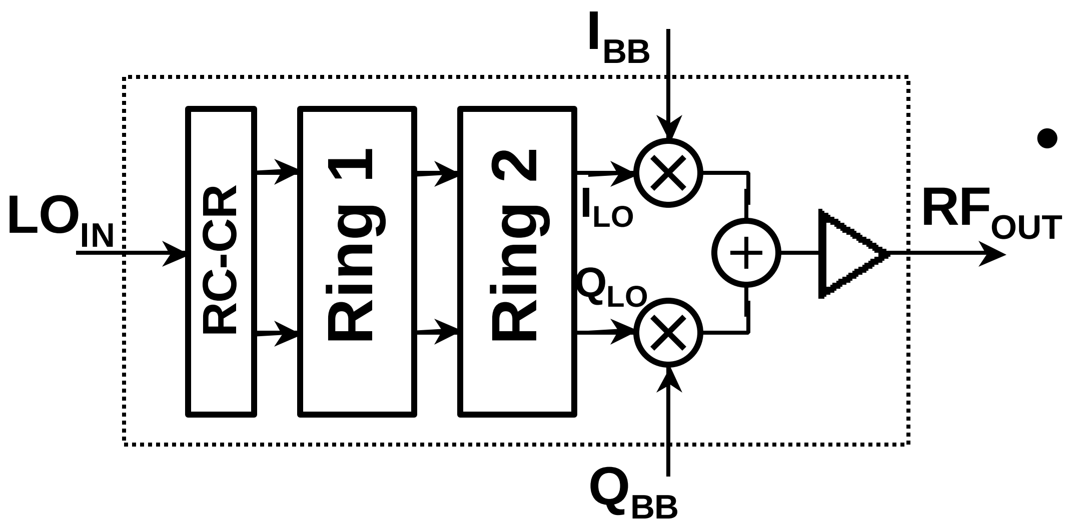
O/p to Inj Amplitude ratio: 10/1

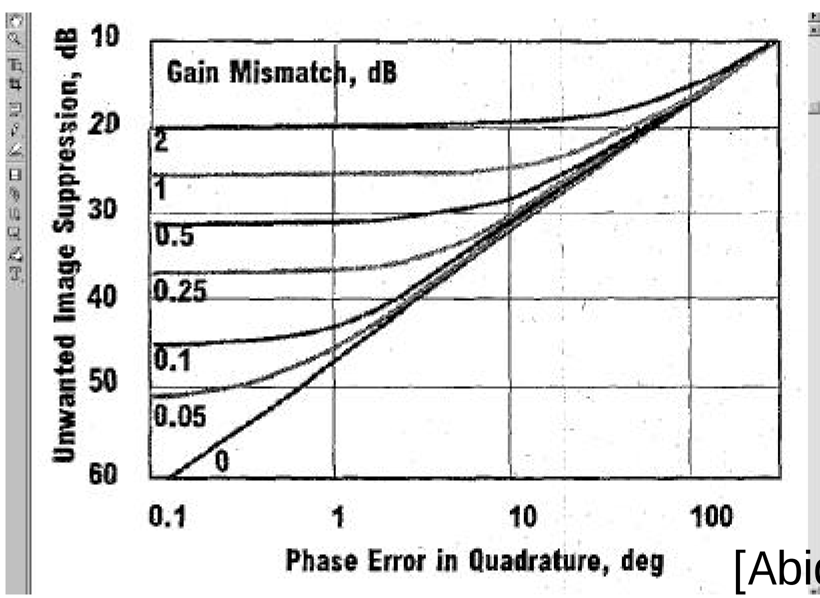


Benefits of Injection Locking over PLL

- Injection locking can be modeled as a 1st-order PLL
- Advantages:
  - No stability issues
  - Extremely wide ‘loop bandwidth’
  - Output phase noise tracks injection signal phase noise over a wide bandwidth
  - Very easy to implement
    - no phase detector, varactor, or loop filter
  - Works up to very high carrier frequencies
- Limitation:
  - Only works for small division ratios (1/1 in this application)

Chip Architecture

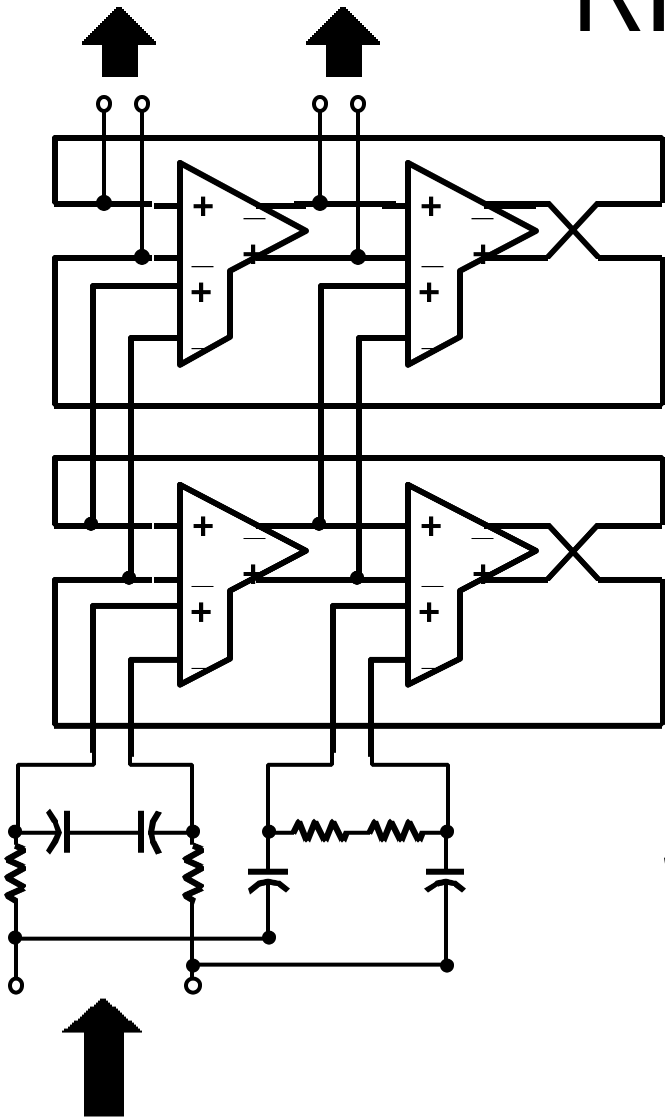




[Abidi, JSSC 12-95]

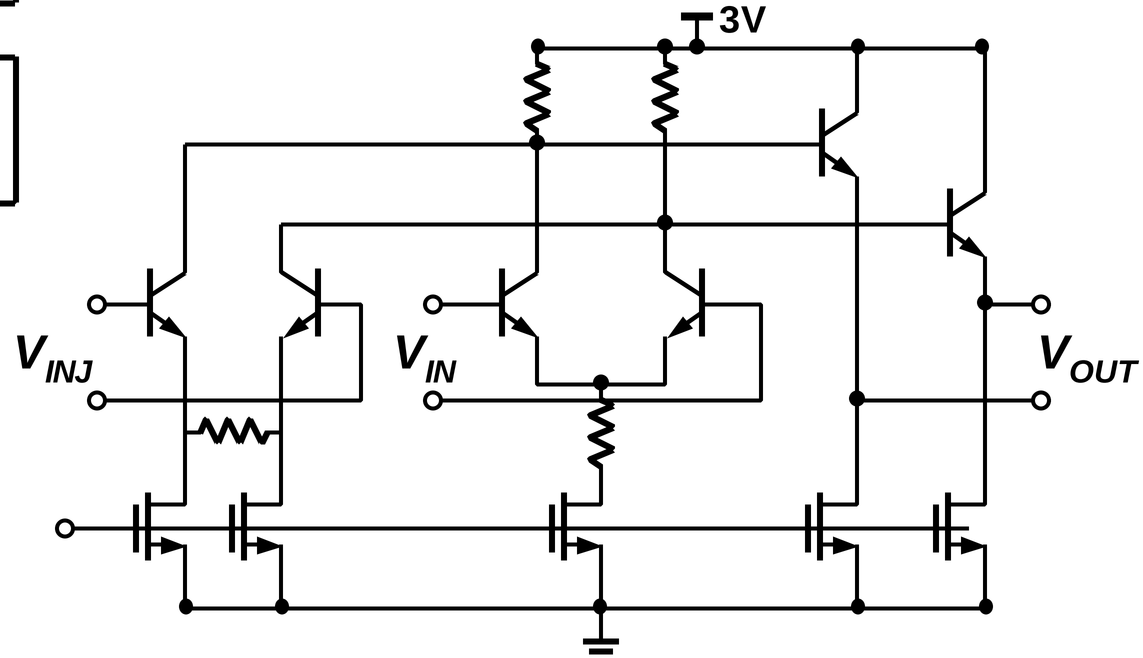
- SSB Upconvertor is on chip measurement device
  - phase & amplitude accuracy are mapped to sideband suppression
  - baseband quadrature signals are assumed to be more accurate than LO quadrature signals

Ring Cascade

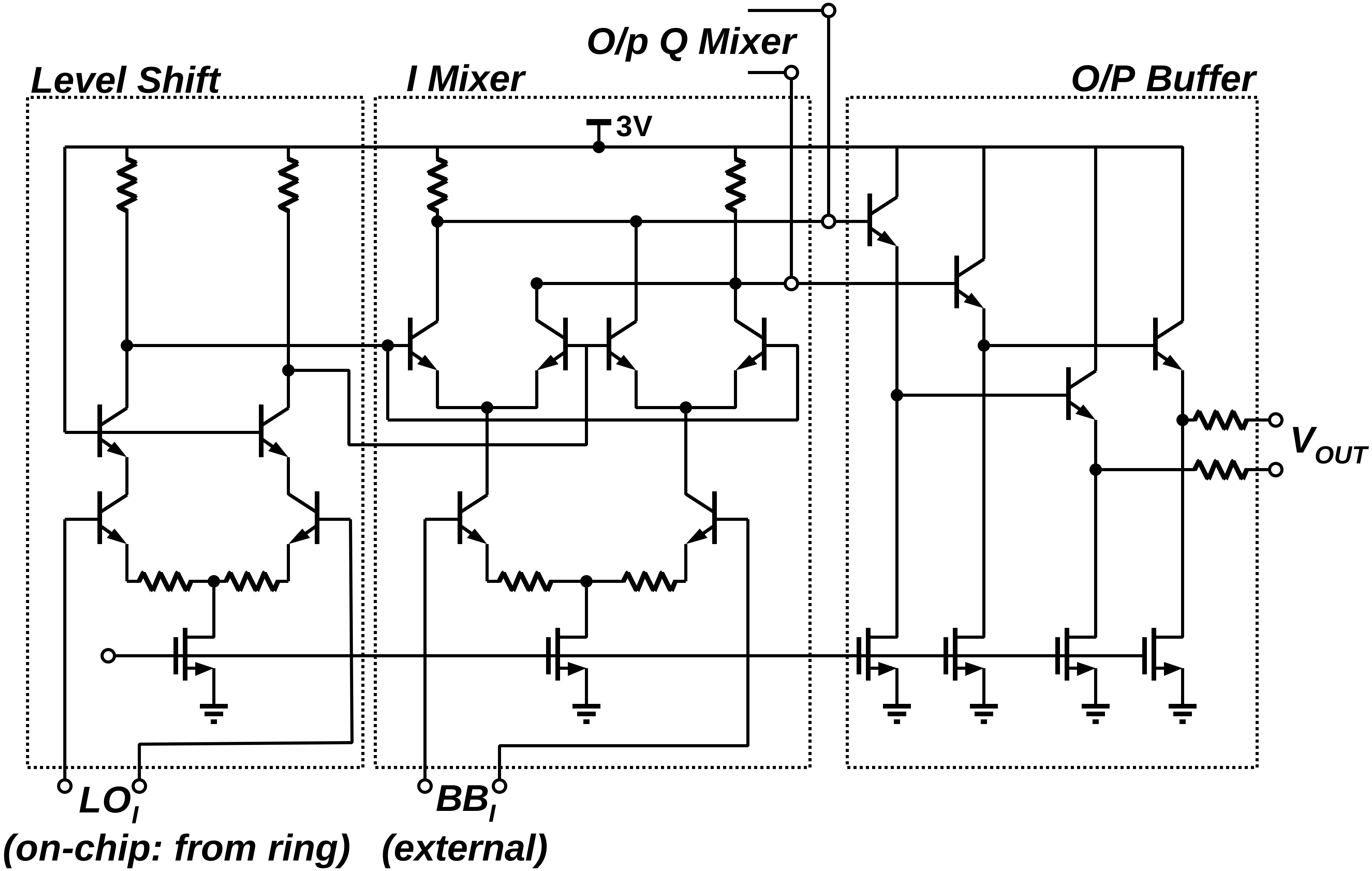


- 0.25um BiCMOS technology
- 2.7 GHz center frequency

Ring stage w/ injection port



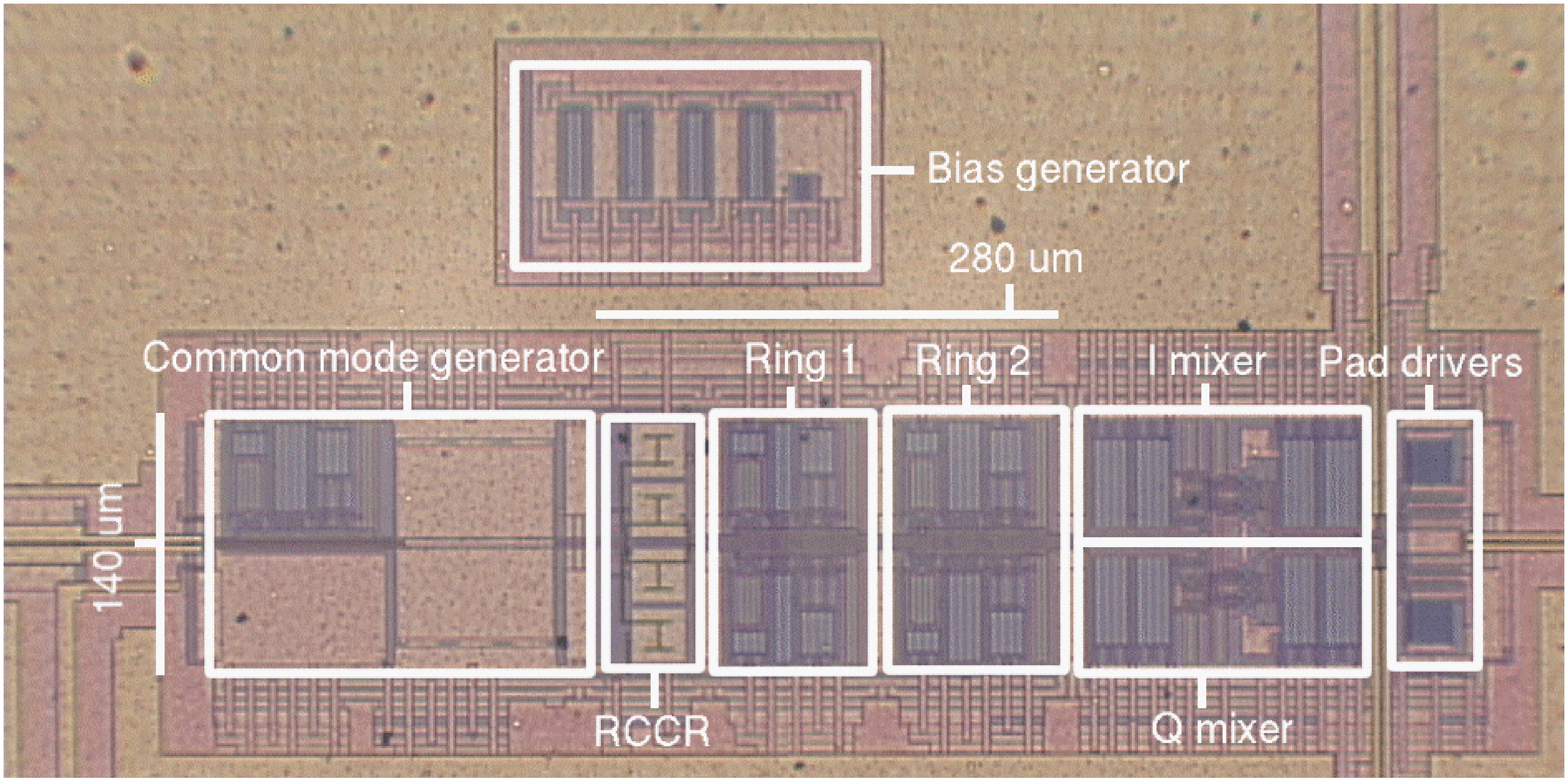
Mixers & O/P Buffer



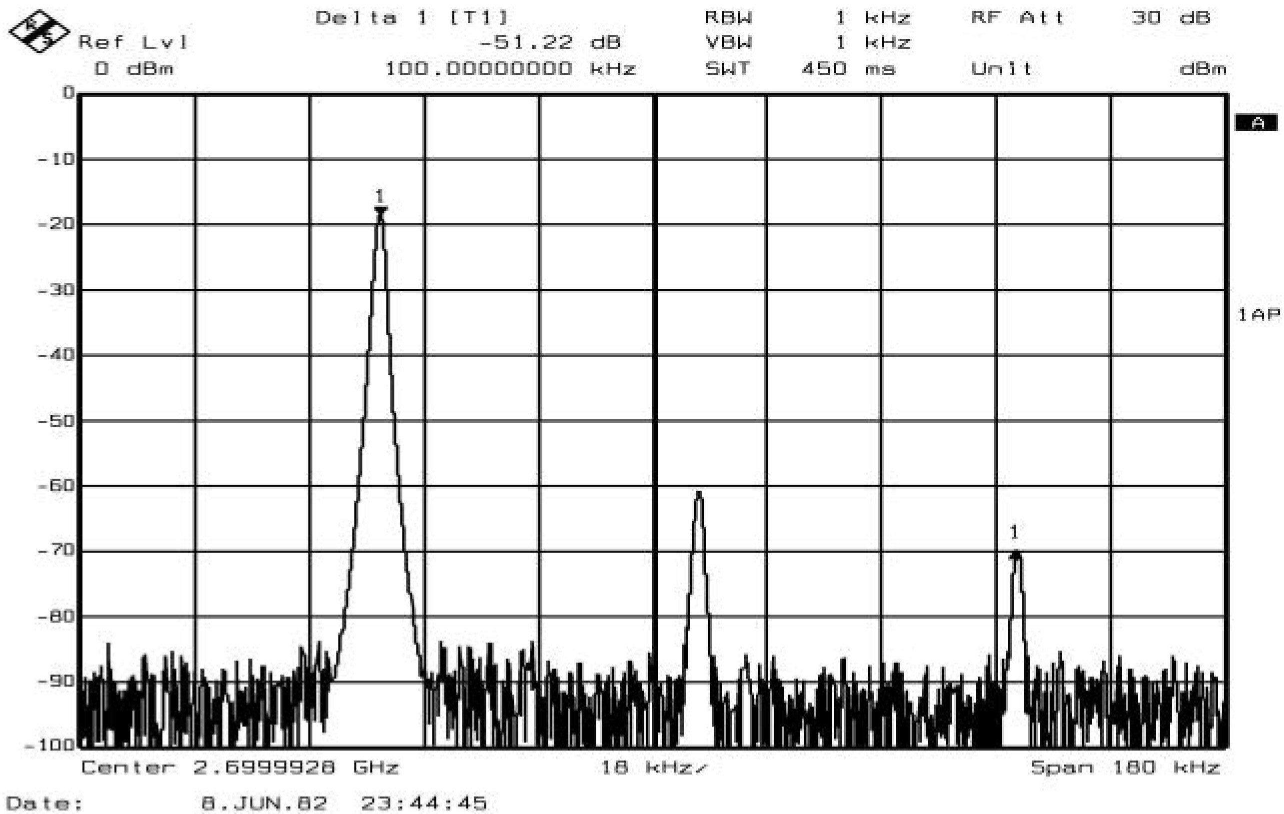
Simulation Techniques

- Harmonic balance offers several benefits:
  - 1. Accurate determination of phase between signals
  - 2. *Exact computation of locking range*
  - 3. Large-signal sensitivity analysis of mismatch effects
- These are possible with transient analysis in Spice, but more difficult and time-consuming
- Difficulties with harmonic balance:
  - 1. Getting a good starting guess - low Q oscillator, so use short transient
  - 2. Can find unstable solutions - also solved by initial transient analysis

Chip Photograph



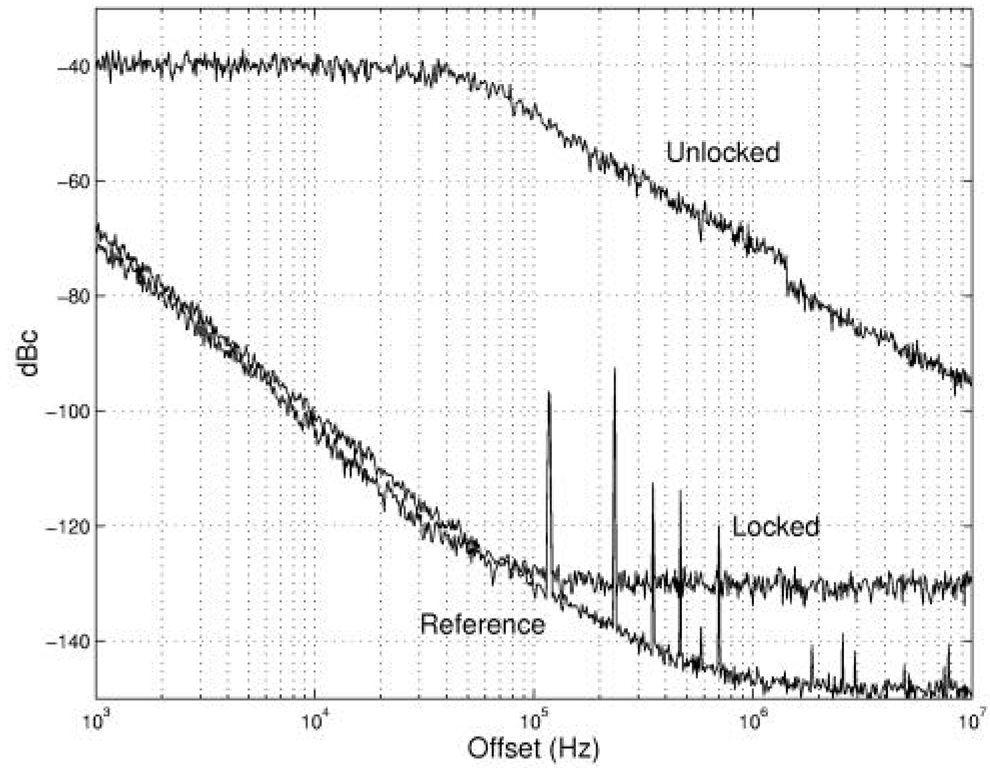
SSB O/P spectrum



Carrier: 2.7GHz / -10dBm
Baseband: 30kHz

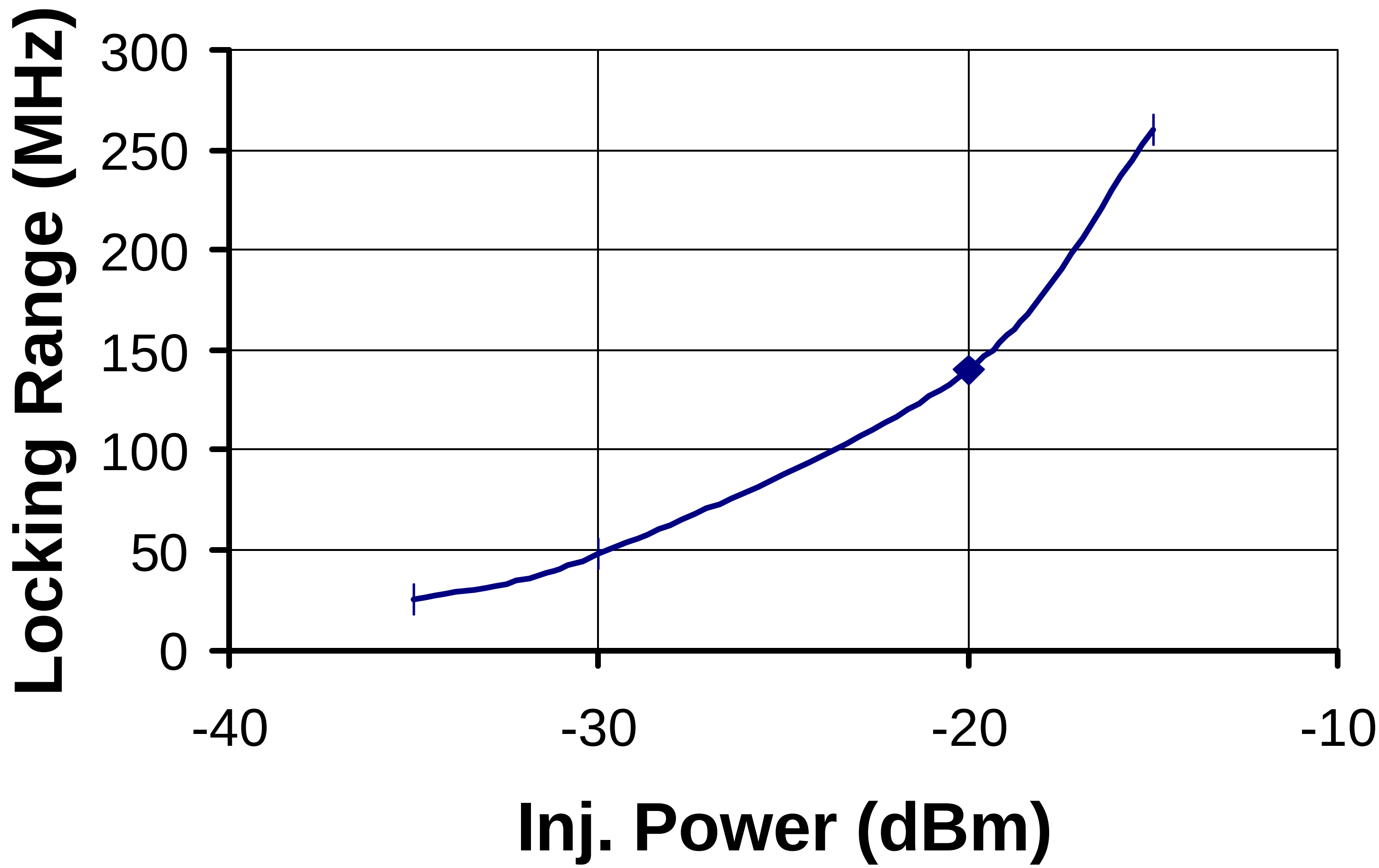
Sideband Suppression = 51.22dB
(sample#1)

O/P Phase Noise Measurement



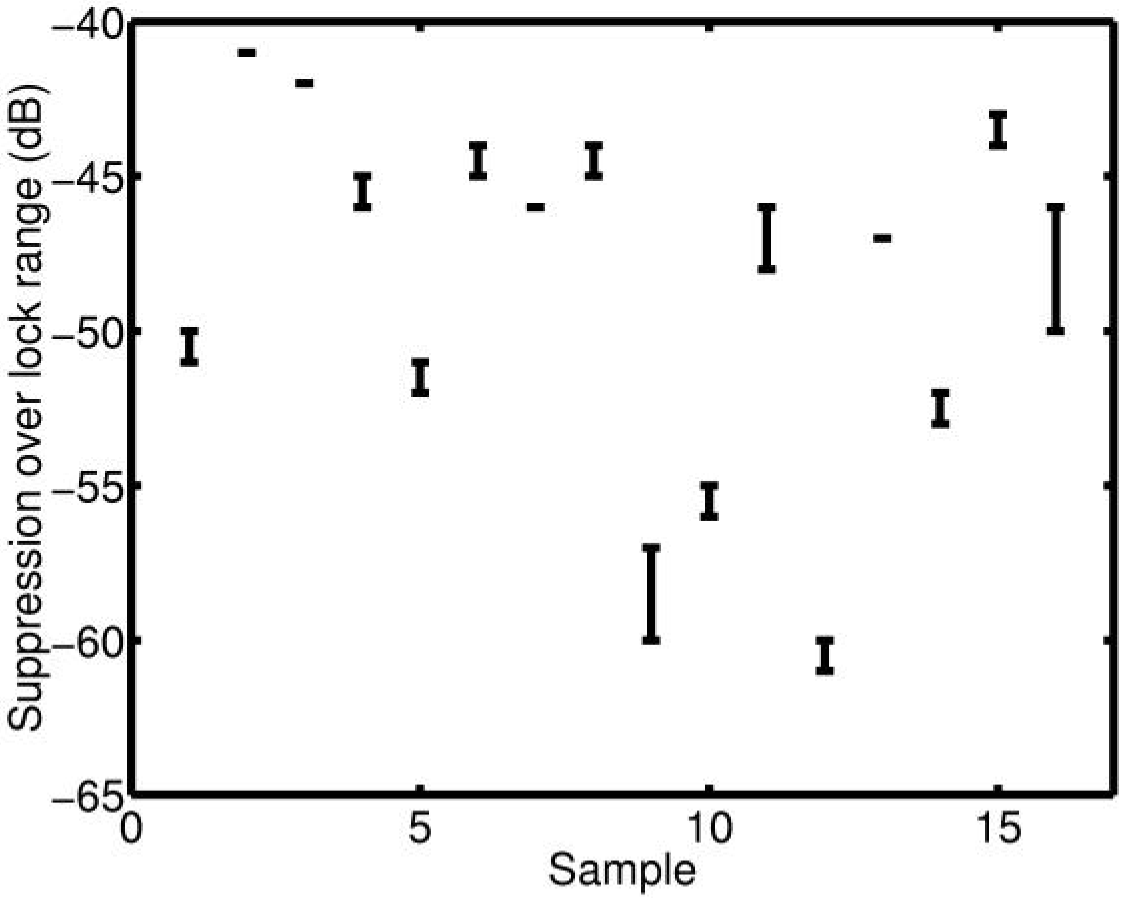
- Significant Phase noise improvement out to 10MHz
- <u>Setup:</u> HP4352B phase noise meter
  -10dBm Reference is from high Q cavity oscillator

Locking Range Measurement



Inj. Power > -20dBm guarantees more than 100MHz lock range

SSB suppression for 16 chips



- All *identical* bias, input signal, output load etc.
- -10dBm inj. power
- Measured over 100MHz range around 2.7GHz

Conclusions

- Demonstrated a wideband scheme for generation of accurate quadrature signals from a single phase input signal of the same frequency
- Inherently a high frequency scheme for quadrature generation
  - Compact
  - No need for elaborate calibration loops
  - No need for complicated signal processing
- Can be expanded for other multiphase systems by using higher number of stages

Acknowledgements

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