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
After injection locking, $V_{\text{INJ}}$ introduces a simple phase-shift in the oscillator loop.

- The inserted phase-shift in the loop shifts the oscillation frequency from $\omega_0$ to $\omega_{\text{Inj}}$.
- The loop adjusts $\phi_1$, until oscillation conditions for phase are satisfied for the injected frequency $\omega_{\text{Inj}}$.
- Fixed range of frequencies exists for which the above conditions can be satisfied $\Rightarrow$ Finite injection locking range [Adler].
Quadrature Error Transfer

At the center of the lock range

Amplitude imbalance between inj_I and inj_Q lead to:
- Minimum phase imbalance at the output (I' & Q')
- Maximum amplitude imbalance at the output.

Phase imbalance between inj_I and inj_Q lead to:
- Maximum phase imbalance at the output (I' & Q')
- Minimum amplitude imbalance at the output.

Key: Large input amp. & phase imbalances corrected after each stage of injection locking

At the edge of the lock range

Amplitude imbalance between inj_I and inj_Q lead to:
- Maximum phase imbalance at the output (I' & Q')
- Minimum amplitude imbalance at the output.

Phase imbalance between inj_I and inj_Q lead to:
- Minimum phase imbalance at the output (I' & Q')
- Maximum amplitude imbalance at the output.
Phase Error Transfer Function

\[ \frac{O/p \Delta \phi}{Inj \Delta \phi} \]

O/p to Inj Amplitude ratio: $10/1$

Middle LBW

Edges LBW

\[ 1/20 \]

\[ 1/200 \]
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

- 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

[Abidi, JSSC 12-95]
Ring Cascade

- 0.25um BiCMOS technology
- 2.7 GHz center frequency

Ring stage w/ injection port
Mixers & O/P Buffer

Level Shift | I Mixer | O/p Q Mixer | O/P Buffer

\( \text{LO}_i \) | \( \text{BB}_i \) | \( V_{\text{OUT}} \)

(on-chip: from ring) | (external)
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
- **Setup:** HP4352B phase noise meter
  - -10dBm Reference is from high Q cavity oscillator
Inj. Power > -20dBm guarantees more than 100MHz lock range

Locking Range Measurement

Inj. Power (dBm)

Locking Range (MHz)
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
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