Tu1E-3

A 67 GHz High Output Power QVCO with 9.9% Efficiency and Improved Phase Noise in a 130 nm SiGe:C Technology

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Outline

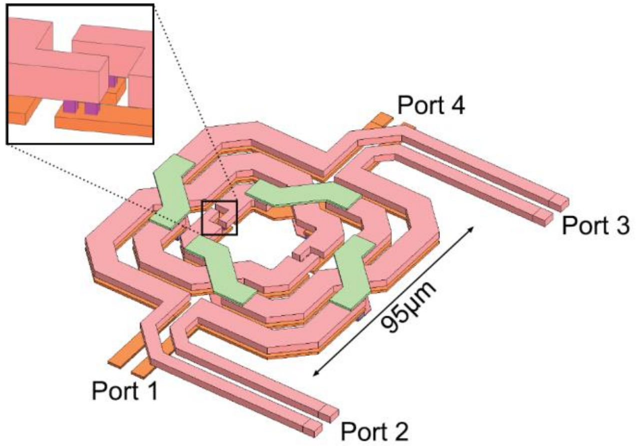
- Outline
- Motivation
- Circuit Implementation
- Output Power and Phase Noise Meas.
- Relative Phase Meas.
- Conclusion

Motivation

- Develop coupling concept for quadrature VCOs for applications >100 GHz
  - Circuits requiring IQ-signals
    - Phase modulators
    - IQ-down-conversion mixers
  - Differential signal sources using push-push frequency doublers
    - Loss of one signal phase
      - Input: Differential
      - Output: Single-ended

Circuit Implementation

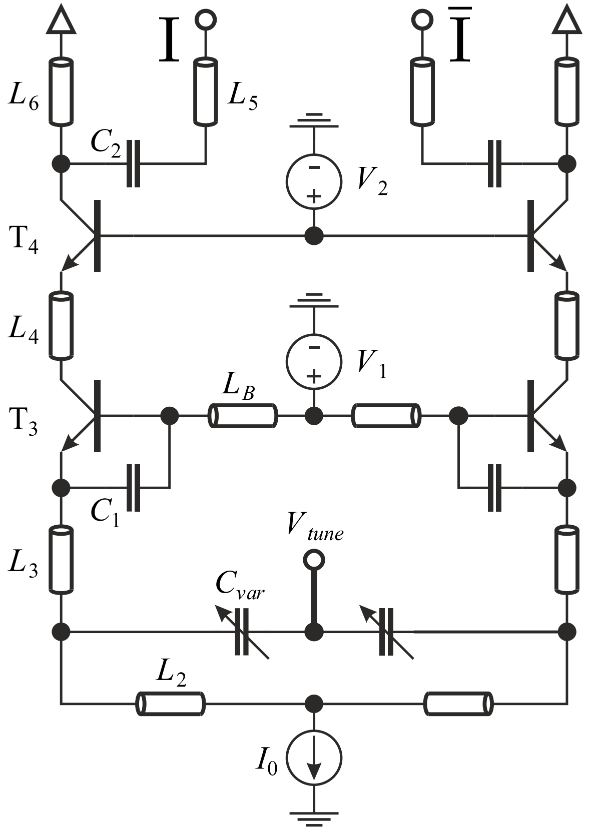
- Traditional approach to generate IQ signals
  – Quadrature couplers: branchline coupler, hybrid coupler
    - Phase and amplitude errors for high bandwidths
- Quadrature oscillator
  – Improved phase noise performance because of coupling
  – Superharmonic coupled oscillators
  – Fundamentally coupled oscillators



J. Schoepfel et al., "A Fully Differential Hybrid Coupler for Automotive Radar Applications“ *2022 17th European Microwave Integrated Circuits Conference (EuMIC)*

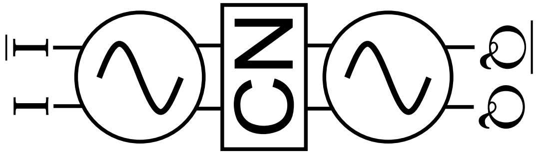
Circuit Implementation

- Fundamentally coupled oscillator
  - Two coupled differential Colpitts VCOs
  - Coupling Network (CN) to couple the oscillators
- 67 GHz integrated Colpitts oscillator
  - High output power and efficiency
  - Very high tuning range
  - Good phase noise performance
  - Designed and manufactured in B11HFC by Infineon Technologies AG



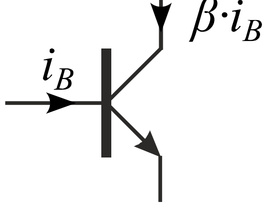
Circuit Implementation

- Coupling Network (CN)
  - Couple the cores of the oscillators:
  - Low power consumption



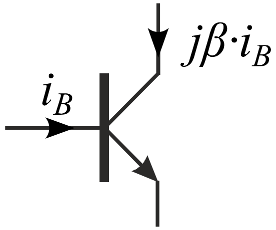
- Active coupling network
  - Common-emitter amplifier

$$\beta(j\omega) = \frac{\beta_0}{1+j\frac{\omega}{\omega_\beta}} \approx \beta_0$$

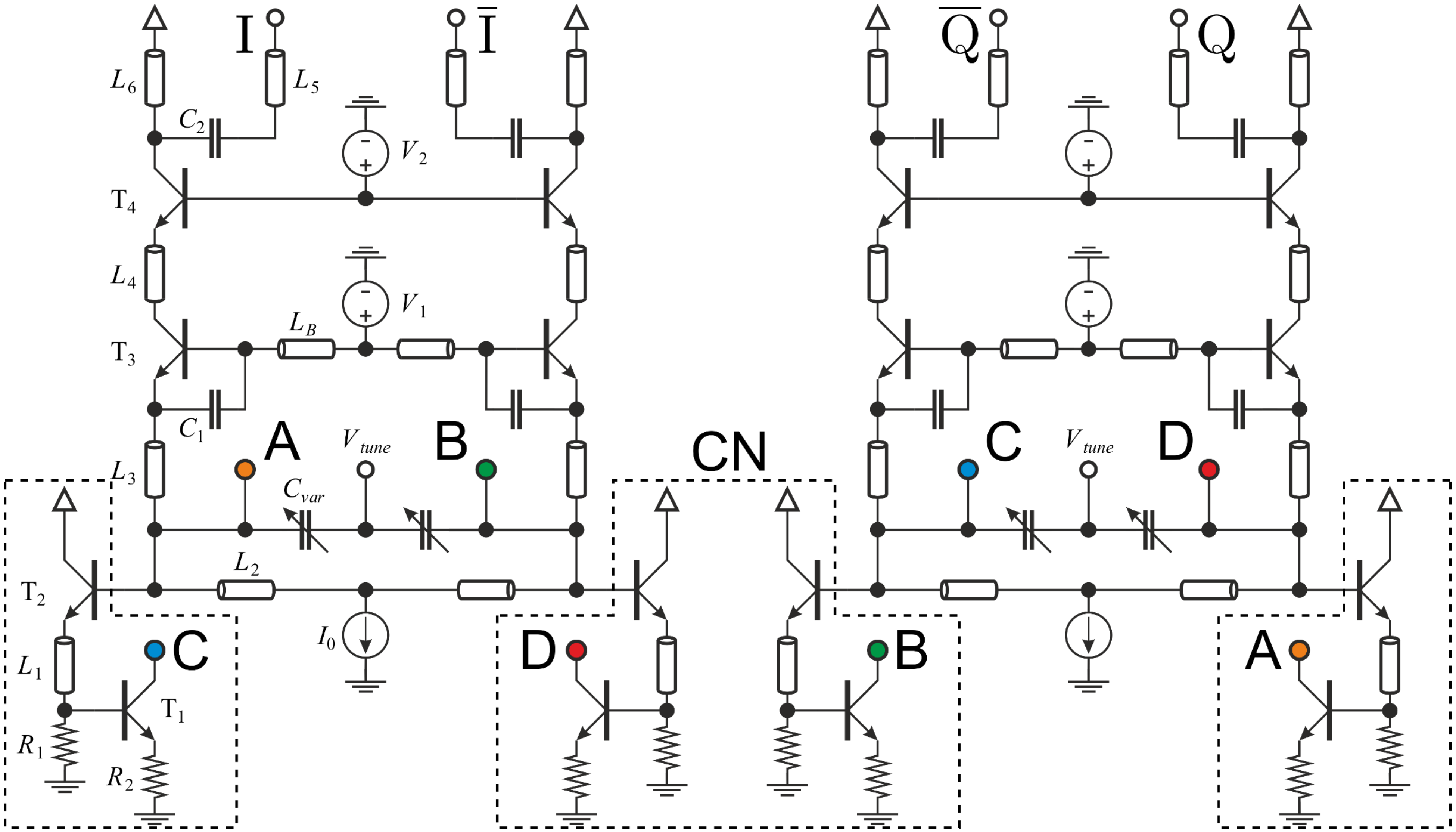


  - 90° phase shift in current gain for high frequencies

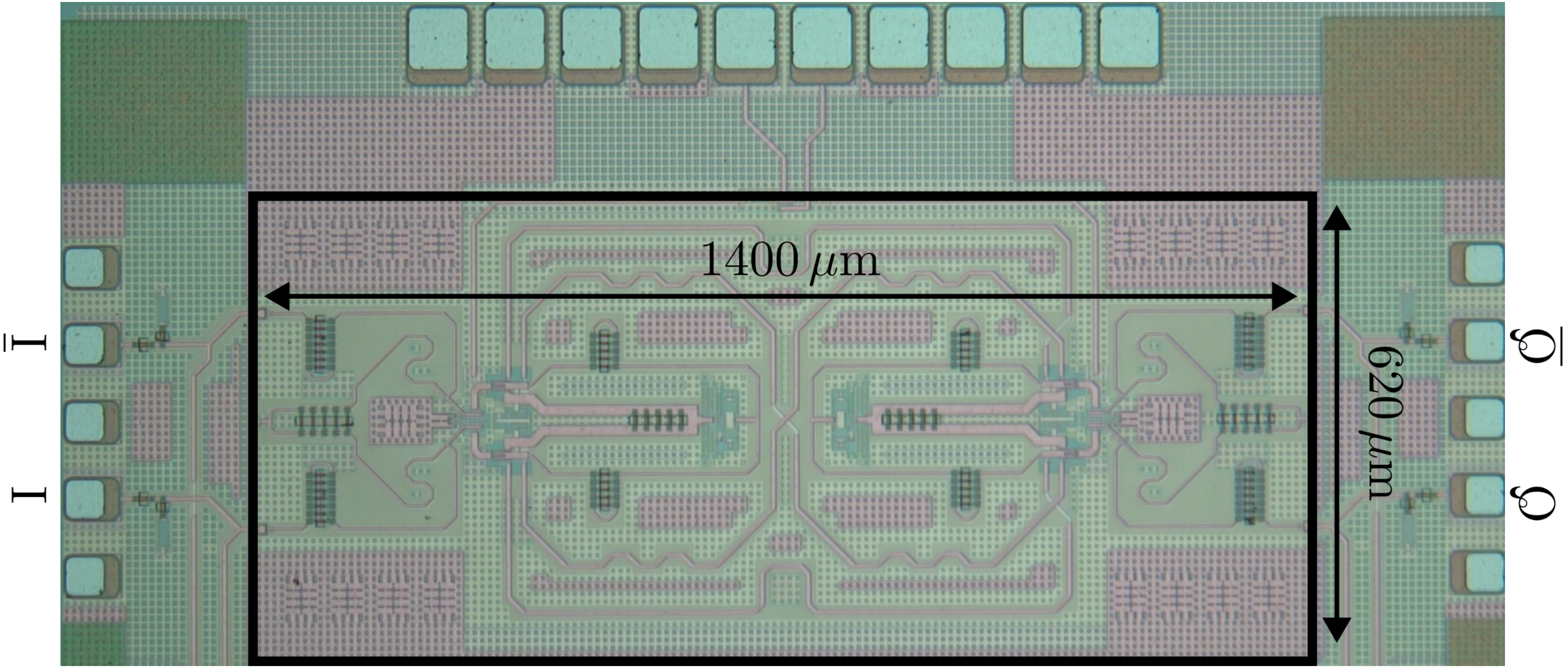
$$\beta(j\omega) = \frac{\beta_0 \omega_\beta}{j\omega} = \frac{\omega_T}{j\omega}$$



Circuit Implementation

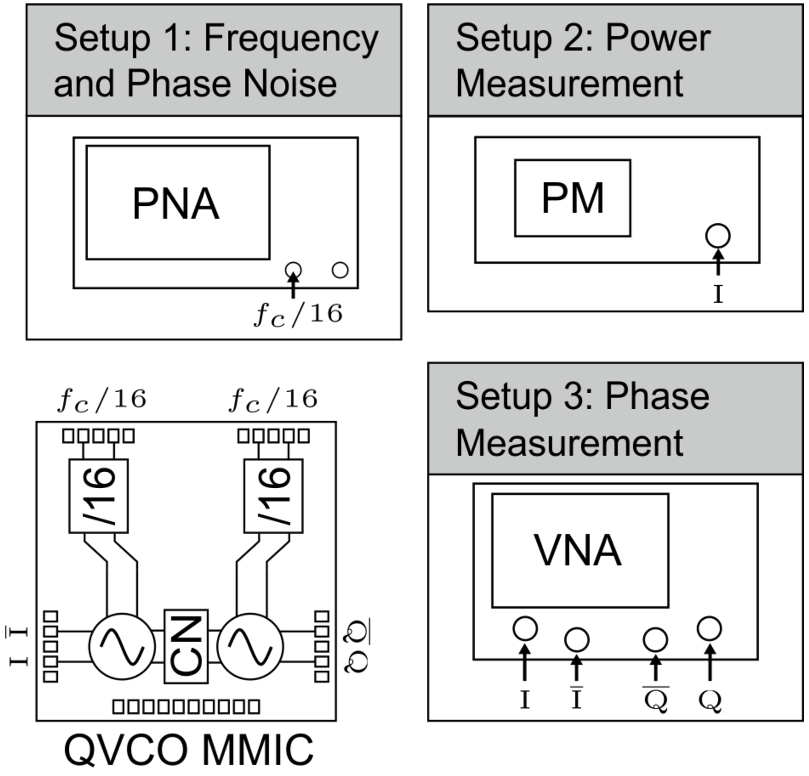


Circuit Implementation



Power and Phase Noise Meas.

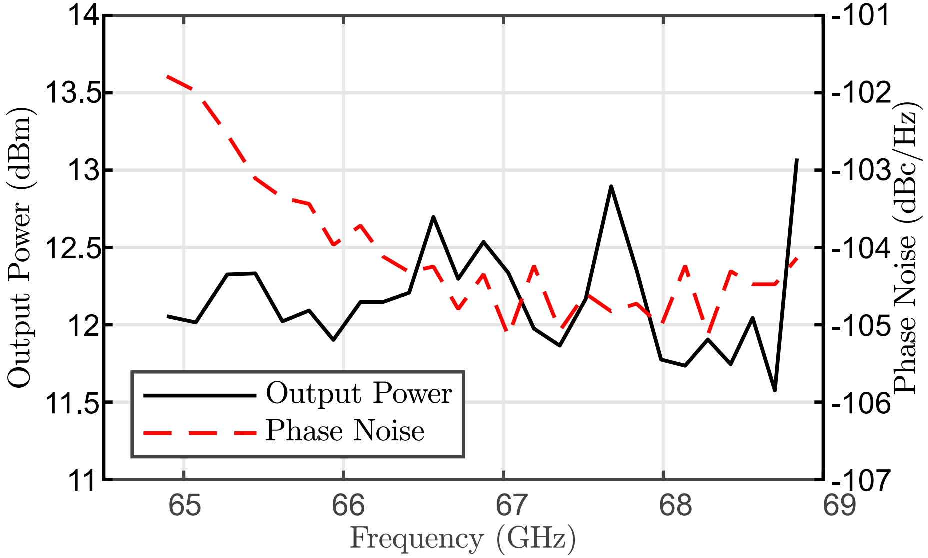
- Phase noise measurement
  - Phase Noise Analyzer (PNA) FSWP by R&S
  - Behind /16 frequency dividers
    - +24 dB due to frequency conversion
- Output power measurement
  - Power Meter (PM) with waveguide power sensor
  - Integrated termination removed
  - Single-ended measurement
    - +6 dB for total output power (4 SE outputs)



Power and Phase Noise Meas.

- 410 mW power consumption @ 5 V supply (incl. CN)
  - 9.9% dc-to-RF efficiency

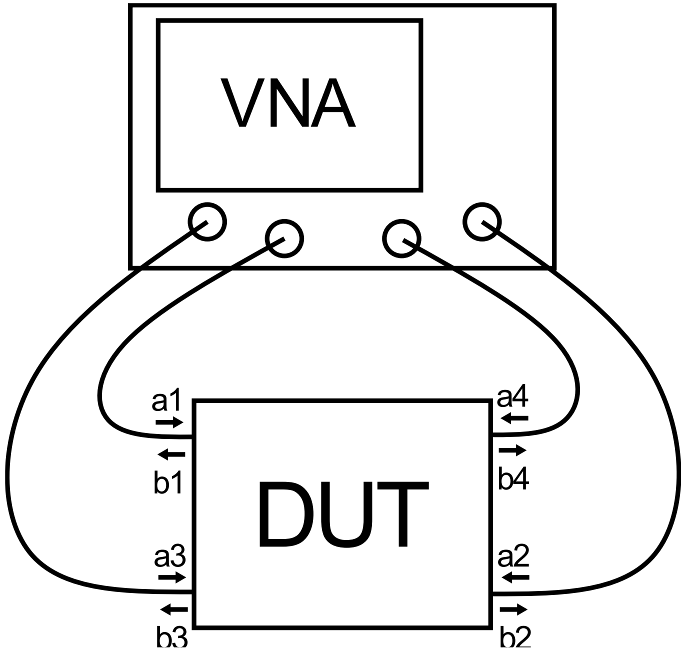
- High output power
  - Up to 10 dBm per differential VCO
  - 13 dBm total power output



- Very good phase noise performance
  - Up to -105 dBc/Hz @ 1MHz offset frequency

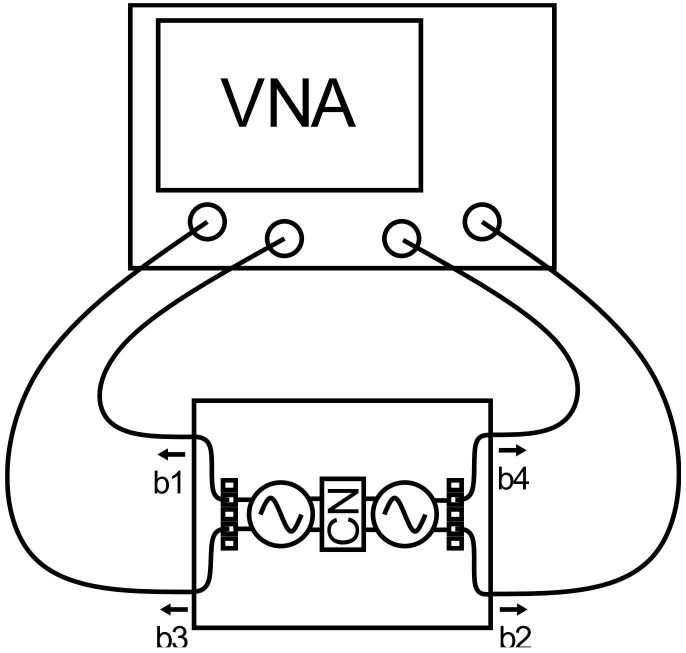
Relative Phase Meas.

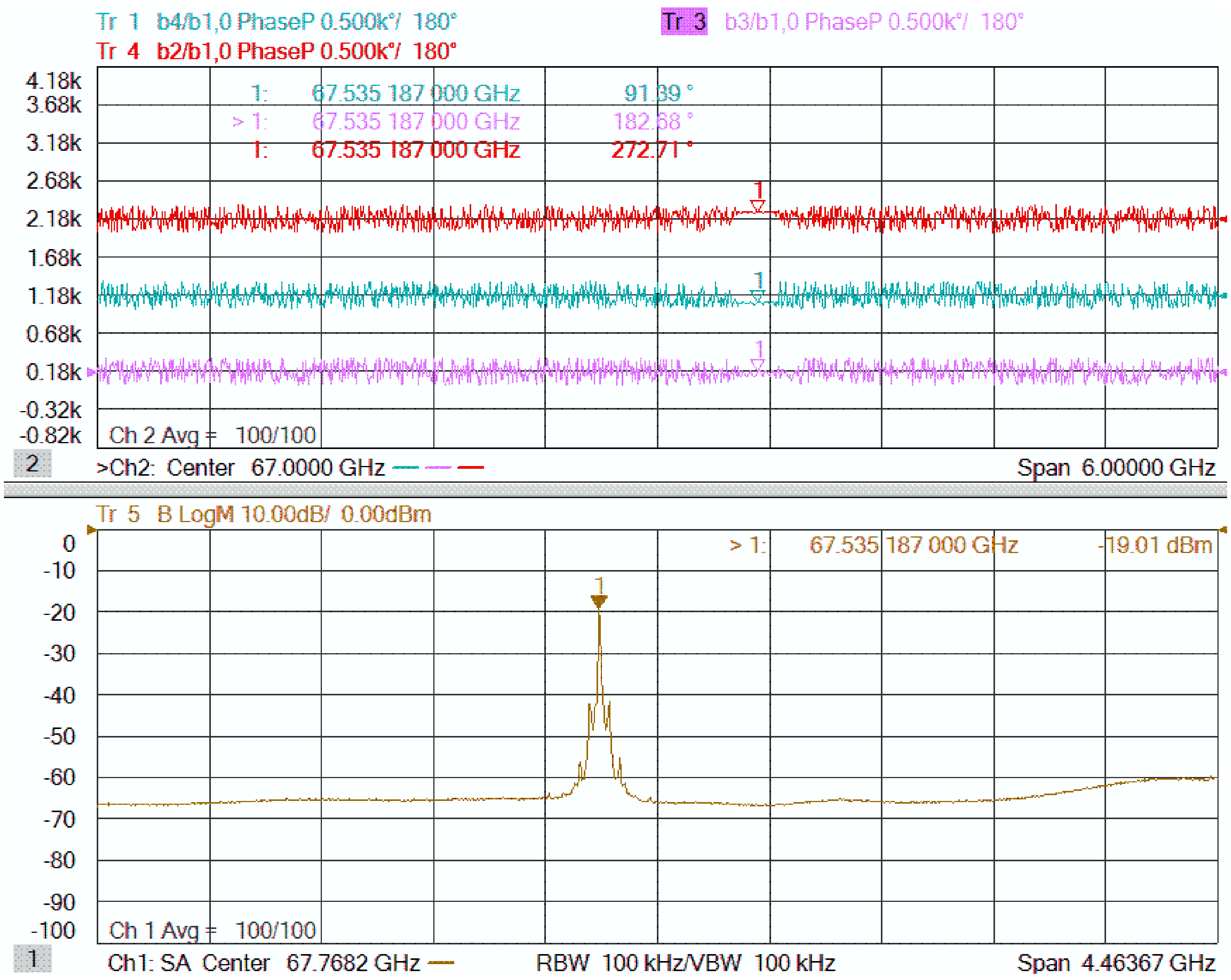
- Relative phase between output pads
  - 4-ch Vector Network Analyzer (VNA) PNA-X by Keysight
  - Differential GSGSG probes
  - SOLT calibration on cal. substrate
  - Disabled RF output signals (a1 – a4) after calibration



Relative Phase Meas.

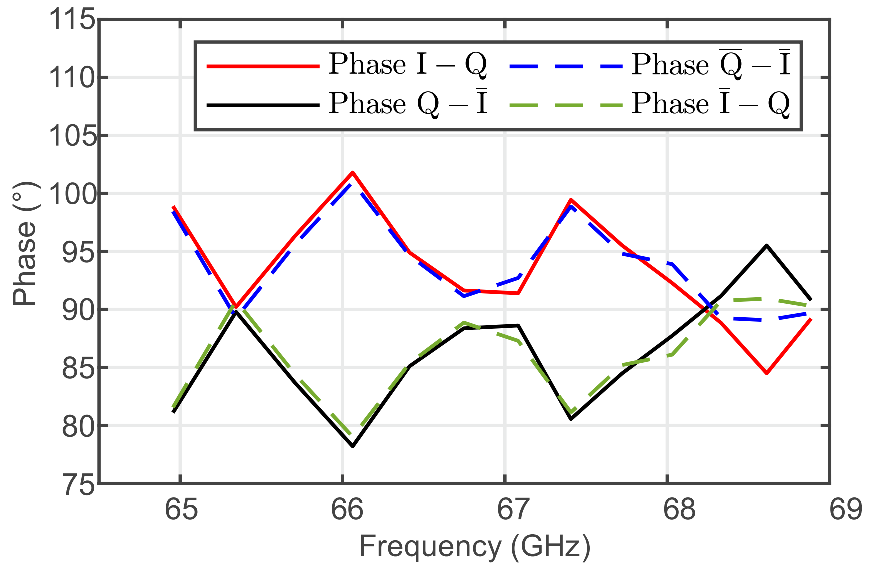
- Relative phase between output pads
  – Input signals b1-b4 evaluated on VNA
  – Phase of received signals (b2 - b4) in relation to common signal (b1)
    - E.g. phase of (b2/b1) ~ 270°
  – Phase of differential signals (b3/b1 and b4/b2) as indicator of quality of measurement




Tr 1 b4/b1,0 PhaseP 0.500k°/ 180°
Tr 3 b3/b1,0 PhaseP 0.500k°/ 180°
Tr 4 b2/b1,0 PhaseP 0.500k°/ 180°
1: 67.535 187 000 GHz 91.39 °
> 1: 67.535 187 000 GHz 182.68 °
1: 67.535 187 000 GHz 272.71 °
4.18k
3.68k
3.18k
2.68k
2.18k
1.68k
1.18k
0.68k
0.18k
-0.32k
-0.82k
Ch 2 Avg = 100/100
2
>Ch2: Center 67.0000 GHz
Span 6.00000 GHz
Tr 5 B LogM 10.00dB/ 0.00dBm
> 1: 67.535 187 000 GHz -19.01 dBm
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
Ch 1 Avg = 100/100
1
Ch1: SA Center 67.7682 GHz
RBW 100 kHz/VBW 100 kHz
Span 4.46367 GHz

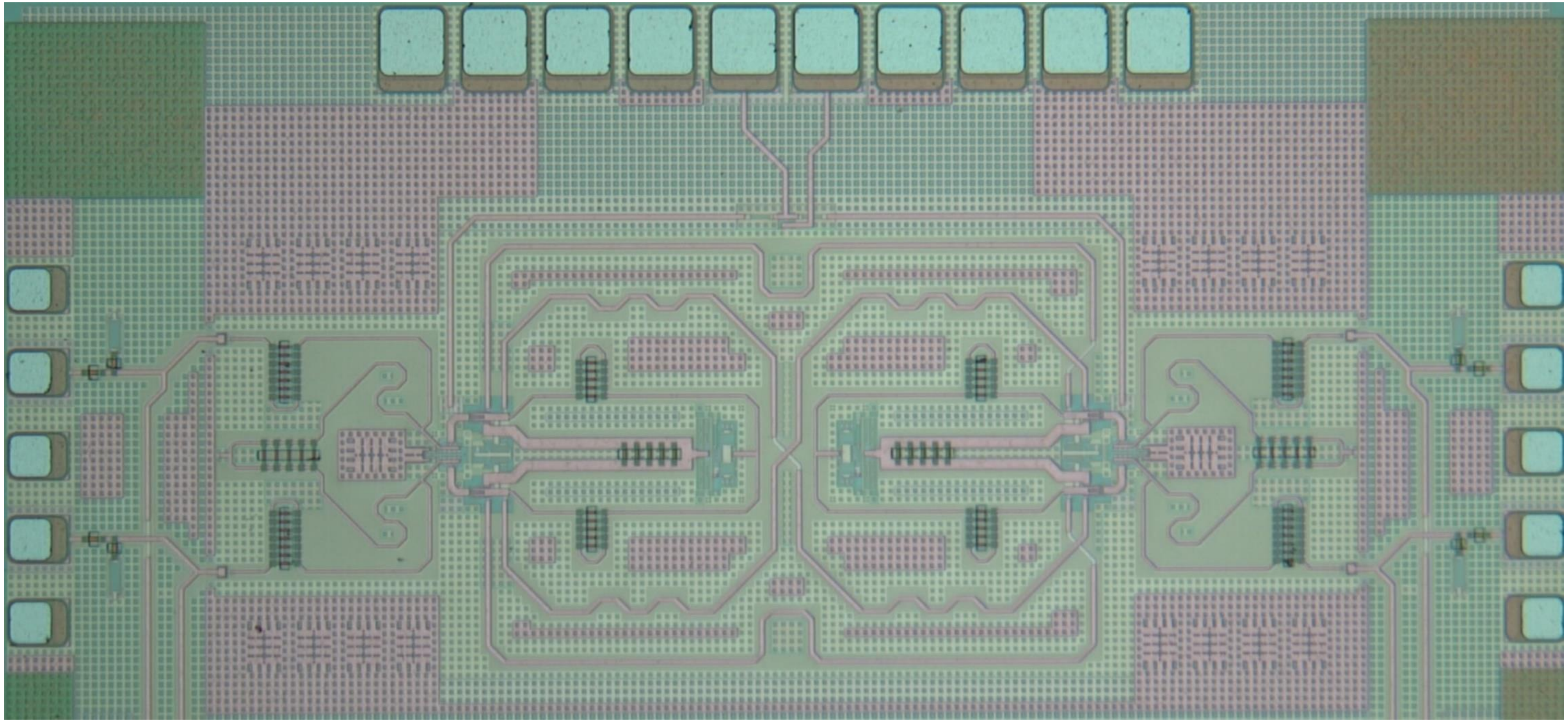
Relative Phase Meas.

- Measured output phases
- Locking range of 3.9 GHz
- Max. 11.8° phase error
- Error of diff. signals: 5.1°
  - Placement error of probes
    - 1° error = 12.4 μm

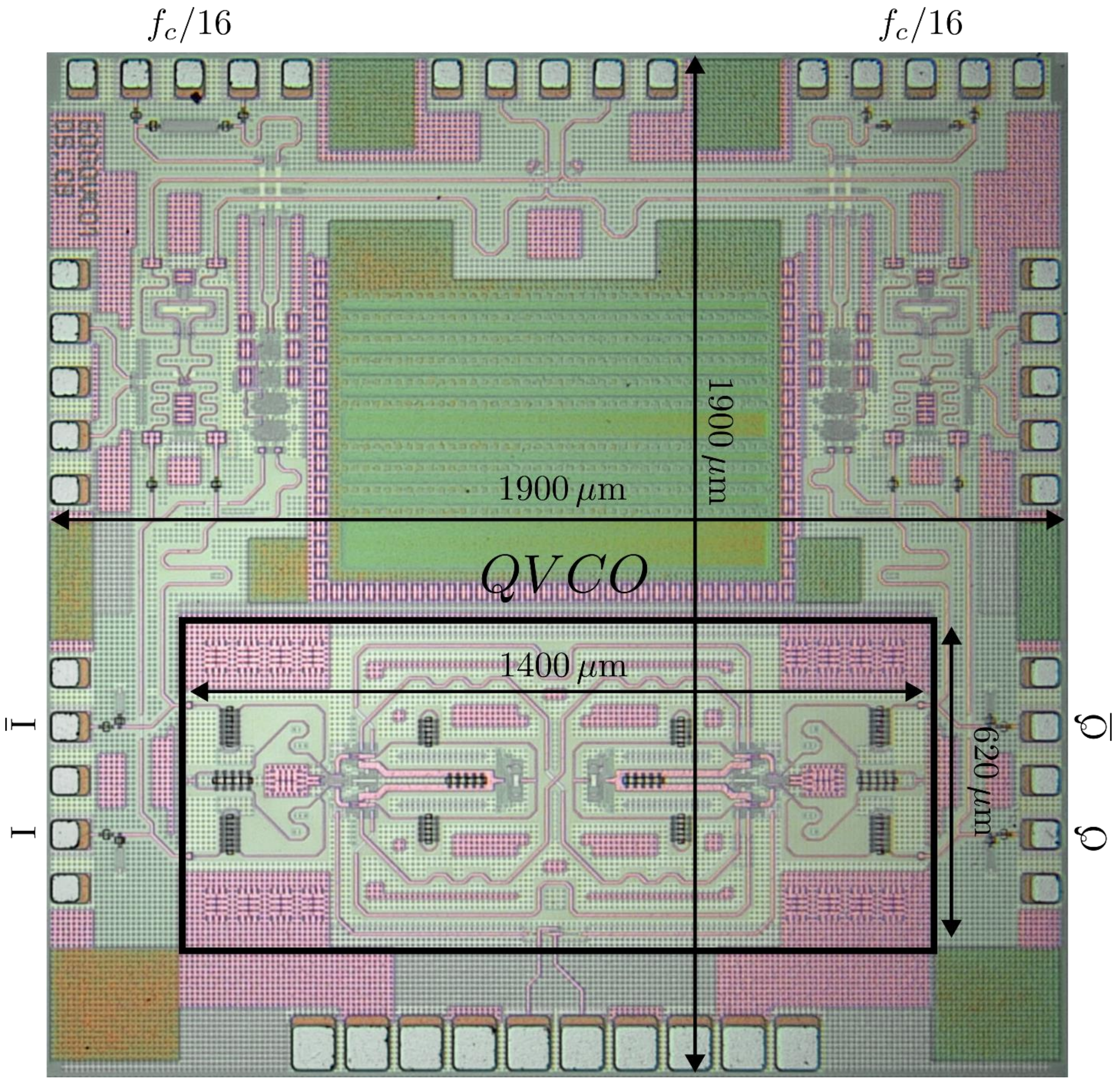


Conclusion

- 67 GHz QVCO with high output power and good efficiency
- 3.9 GHz locking range for quadrature operation
- Very low phase noise over whole locking range
- Measured output phase error of <11.8°



Thank you for your attention. Do you have any questions?


$f_c/16$
$f_c/16$
1900 μm
1900 μm
$QVCO$
1400 μm
620 μm
$\bar{I}$
I
$\bar{Q}$
Q