80/160-GHz Transceiver and 140-GHz Amplifier in SiGe Technology

Ekaterina Laskin¹, Pascal Chevalier², Alain Chantre², Bernard Sautreuil², Sorin Voinigescu¹

¹University of Toronto  ²STMicroelectronics

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Outline

- Motivation
- Transceiver overview
- Circuit blocks
- Passives
- Measurement setup and results
- Conclusions and future work
Motivation

- High resolution imaging transceiver
- More information about the object due to different absorption in 80 & 160 GHz bands
- Possible astronomy imaging applications
  - ALMA† band 3: 84 - 116 GHz
  - ALMA band 4: 125 - 163 GHz
- Possible dental imaging applications

† Atacama Large Millimetre Array Radio Telescope project
Transceiver Overview

- Transmit and receive in 80- and 160-GHz bands
80/160-GHz Oscillator

- 4 coupled Colpitts oscillators
- Differential @ 160 GHz, Quadrature @ 80 GHz

- peak-$f_T$ bias
- 70mA, 3.3V
160-GHz Mixer

- Double-balanced Gilbert cell topology
- On-chip transformers employed at LO and RF

- peak-$f_T$ bias
- 15mA, 3.3V
140-GHz Amplifier

- Cascodes → gain, CE stages → output power
- At 140GHz $R_E + R_B \approx 50\Omega$ → No input degeneration
140-GHz Amplifier

- Degeneration in 2\textsuperscript{nd} stage for interstage matching
- Ratioed inductors and split loads for gain control
- Biased at peak-$f_T$ for max power transfer
160-GHz Transformer

- Top 2 metal layers of a standard backend
- Optimized for lowest loss at 160 GHz
- 2-pi model used includes substrate model

2.5 μm width

20 μm

model from ASITIC
Transformer Meas. vs. Sims

![Graph showing S21 Magnitude (dB) versus Frequency (GHz) with measured and simulated data points.]
Fabrication

- STM 130nm SiGe HBT with BiCMOS9 backend
- $f_T = 230$ GHz, $f_{MAX} = 300$ GHz, + process splits
80/160-GHz Transceiver

[Image of a microchip with labels: RF, Mixer, IF, Transformers, Quadrature Oscillator, 80 GHz Tx, 160 GHz Tx, 700 μm, 650 μm]
Measurement Setup
Results - Oscillator Breakout

80-GHz Output:

-110.4 dBC/Hz @ 10MHz offset

160-GHz Output:

low-noise power supply
improper bias (60 mA)
losses not deembedded
Transmitter Output Power

- Single-ended TX power increases with VCC
- Measured using the power sensor

![Graph showing the relationship between VCC, TX Frequency, and TX Output Power.](image)
Results - Receiver

- Conversion Gain (dB)
- RF Frequency (GHz)
- Measured
- Simulated

- Fundamental: 82.3 GHz
- 2nd Harmonic: 160.5 GHz
Amplifier - Measured vs. Sim

![Graph showing measured vs. simulated S11, S21, and S22](chart)

- **S11, S21, S22 (dB)**
- **Frequency (GHz)**

**Lines and Markers:**
- **Simulation**
- **Die 1**
- **Die 2**
- **Die 3**
- **PSA**
- **P. Sensor**
Amplifier Over Temperature

- Nominal wafer, measured using power sensor

![Graph showing amplifier gain over temperature](image)
Amplifier Process Splits

- Same die location on 14 wafers with varied $f_t/f_{MAX}$

![Graph showing frequency vs. gain for 14 wafers with varied $f_t/f_{MAX}$](graph.png)
Amplifier Linearity - 130GHz

![Graph showing S21 and P1dB at 130 GHz](image)
Conclusions

- First 80/160 GHz imaging transceiver
- First oscillator with a differential signal at 160GHz, -10 dBm output power
- First 140-GHz amplifier in silicon with gain > 15 dB, Psat = +1dBm
- Highest frequency monolithic transformer designed and verified up to 180 GHz
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Inductor Design and Modeling

- 44-pH inductor for the oscillator tank
- Shunted top metals for low loss
- Designed using ASITIC, SRF > 400 GHz
Inductor Model Verification

Graph showing the comparison between measured and calculated values of inductance (L) and quality factor (Q) against frequency (GHz). The graph includes data points for measured and asitic (assumed) values, as well as a 2-pi model line. The x-axis represents frequency in GHz, and the y-axis represents L (pH) and Qeff. The graph shows the trend of R (Ohm) with frequency.

- Green dots with circles: Q (measured)
- Blue dots with circles: R (measured)
- Red dots with circles: L (measured)
- Green line: 2-pi model (asitic)
- Blue line with circles: measured (asitic)
- Red line with circles: asitic

Frequency (GHz)

0 10 20 30 40 50

L (pH), Qeff

0 10 20 30 40 50 60 70

R (Ohm)

0.0 0.3 0.6 0.9 1.2 1.5 1.8 2.1

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Measurement Setup

- On-wafer with waveguide probes
- $\times 12$ multiplier signal source $\rightarrow$ harmonics
- PSA+mixer or power sensor at output
Measurement Setup

- Multiplier produces harmonics of input frequency
- Power sensor integrates power of all harmonics
- PSA allows reading power of only one harmonic
- Example measurement at 156 GHz:

  input spectrum from ×12: 117 130 143 156 169

  amplifier:

  output spectrum:

- Power sensor reading includes amplified signals
Amplifier Linearity - 140GHz

![Graph showing amplifier linearity at 140GHz. The graph plots S21 (dB) vs. Pin (dBm) with two curves: red for S21 @ 140 GHz and blue for P1dB @ 140 GHz. The graph indicates the performance of the amplifier at different input power levels.]
Zoom to 1MHz BW, 100 averages
Results - Transmitter

80-GHz Output:

-100.5 dBc/Hz @ 10 MHz offset

160-GHz Output:

low-noise power supply
losses not deembedded
improper bias (60 mA)