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A High-Dynamic-Range W-band Frequency-Conversion IC for Microwave Dual-Conversion Receivers

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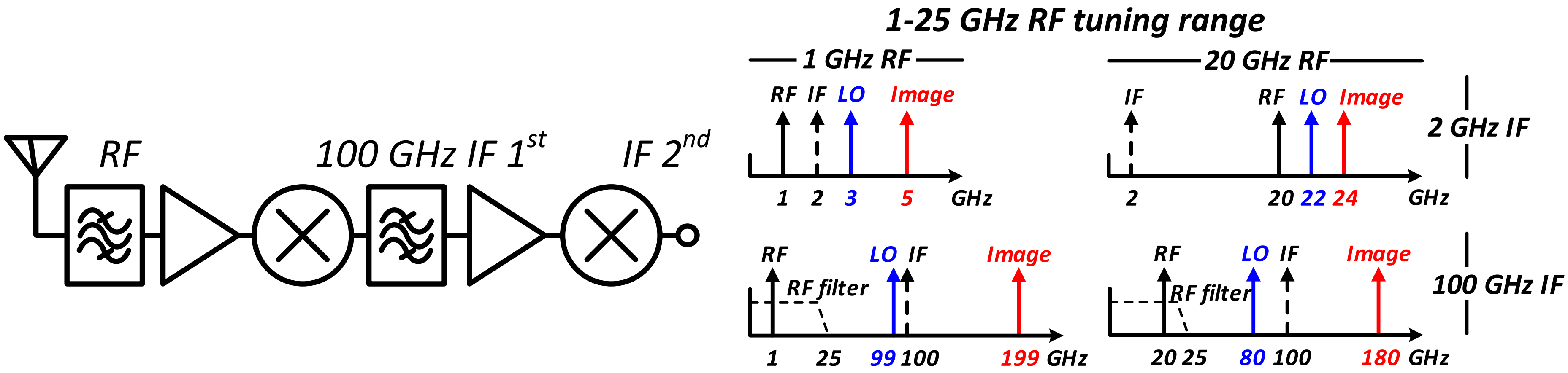
CSICS 2016 Austin, TX

Dual-Conversion Receiver



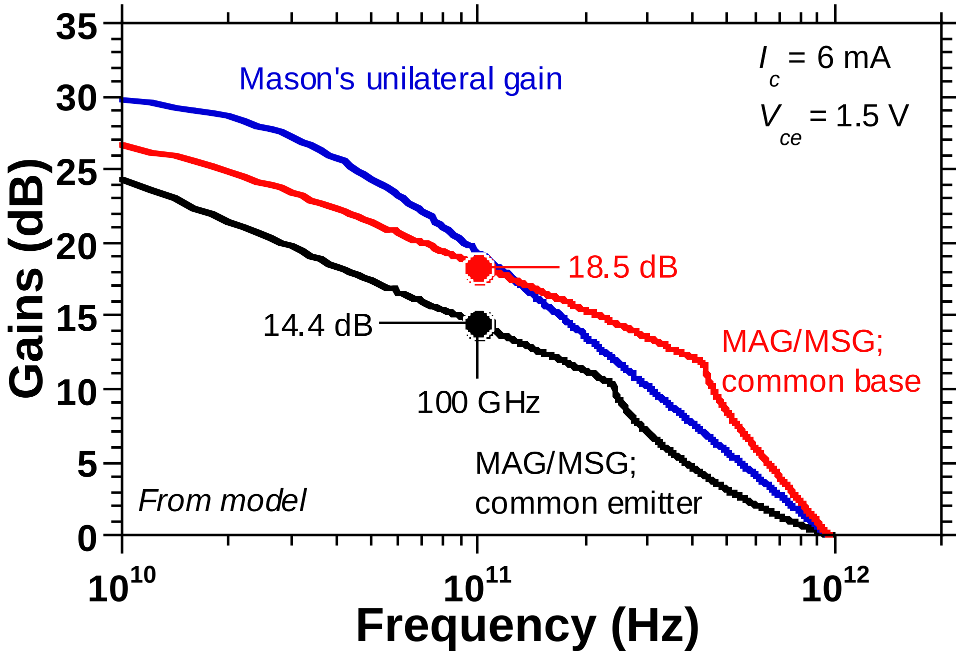
<u>Classical RF architecture: extend to micro/mm-wave frequencies</u>

- Up-convert to 1st IF (100 GHz), down-convert to 2nd IF (or baseband)
- Image response moved out-of-band
- Very wide tuning range, no image response.

<u>Applications:</u>

- Instrumentation
- Wideband surveillance: 1-25 GHz (possibly 1-50 GHz)
- Single IC serving many applications: application-specific LNA + common module

THz HBTs → 1-25 GHz Dual conversion



Teledyne 130 nm InP HBT

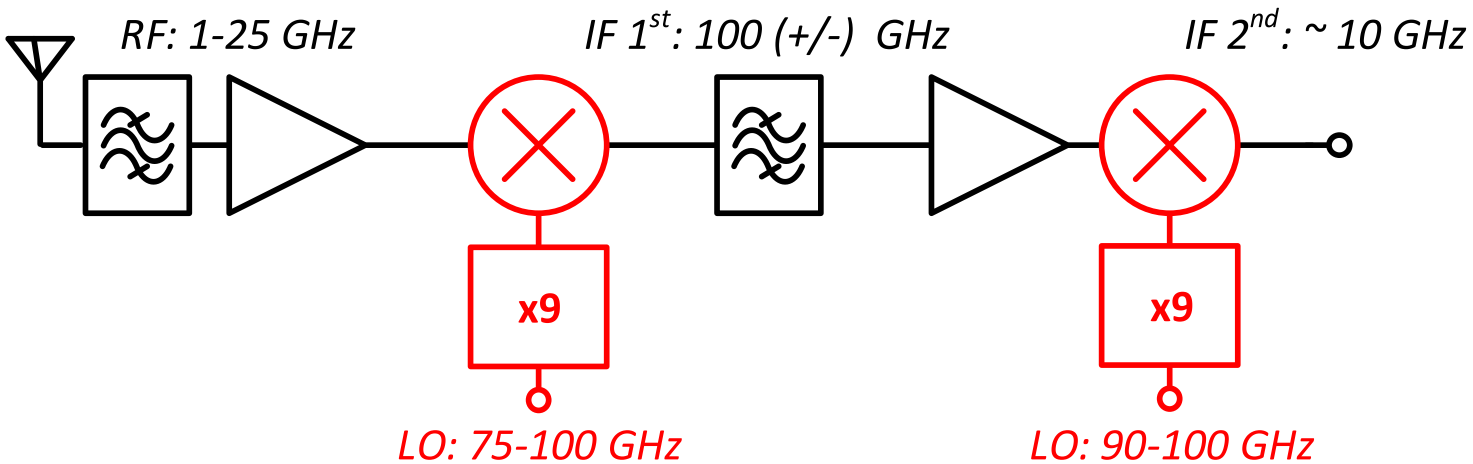
- 1.1 THz f_{max}.
- CE: 14.4 dB MSG @100 GHz
- CB: 18.5 dB MSG @100 GHz

Dual conversion at microwave:

- 100 GHz 1st IF would enable over 1-60 GHz spur-free tuning
- High speed IC technologies: 100 GHz IF feasible

THz transistors enable microwave dual-conversion receivers

Frequency Conversion Blocks



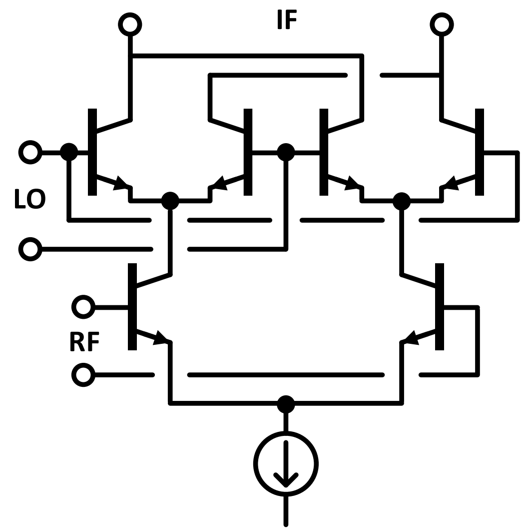
Need high dynamic range & wide tuning range

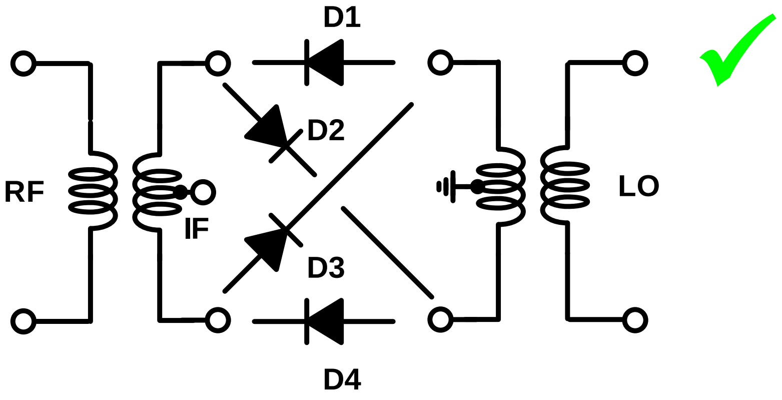
This presentation: the frequency conversion blocks

High Dynamic Range Mixer

<u>Transistor mixer:</u>
Low IP3
High noise figure
Poor dynamic range

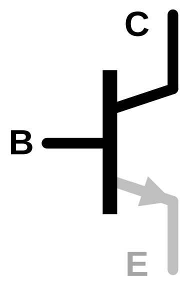
<u>Diode mixer</u>:
High IP3
Lower noise figure
Higher dynamic range



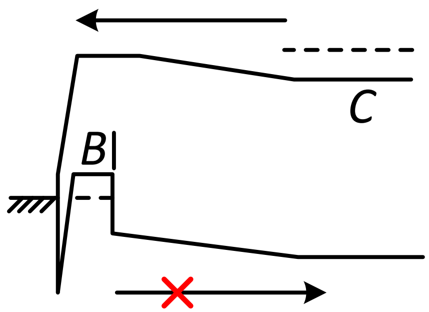


<u>Design challenges:</u>
High speed diode
Wide bandwidth balun
Wide tuning range + high power LO

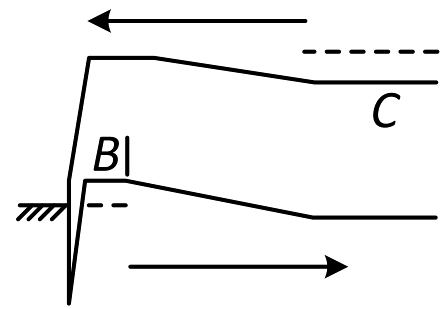
High Speed DHBT BC Diode



DHBT



Band diagram



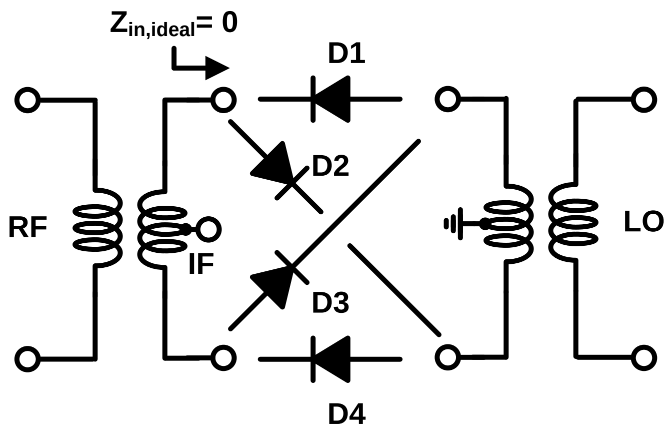
SHBT band diagram

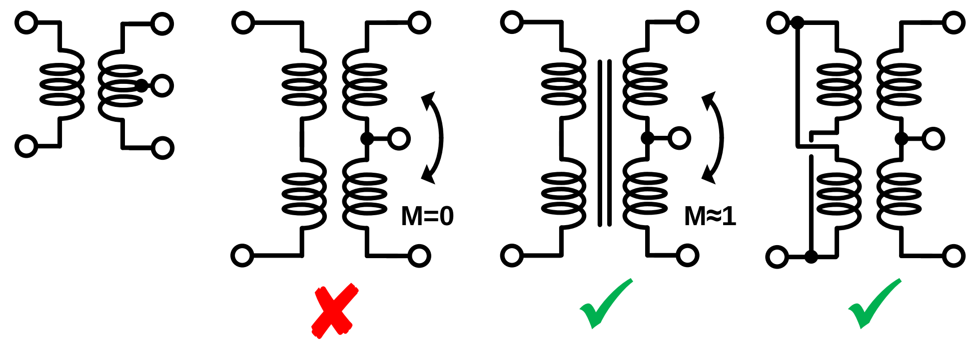
Double-heterojunction base-collector diode

- Hole minority carrier storage is eliminated by large energy barrier to holes
- Electron minority carrier storage time is small

→ Schottky-like high-frequency characteristics

Balun For Diode Mixer





<u>Common-mode impedance</u> $Z_{cm,RF}$ <u>must be zero</u>

<u>IF port is required</u>

Simple center-tapped transformer has wrong Z_{cm}

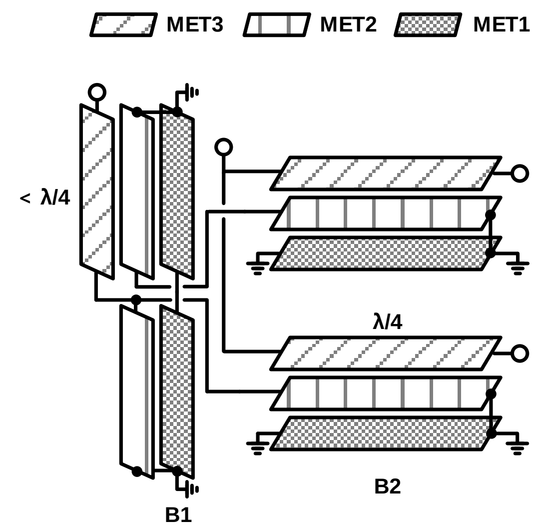
- Two transformers in *series*.

Ferrite loading gives correct Z_{cm}; can't use on IC

Options: two *parallel* transformers, or balun.

<u>Proposed balun</u>

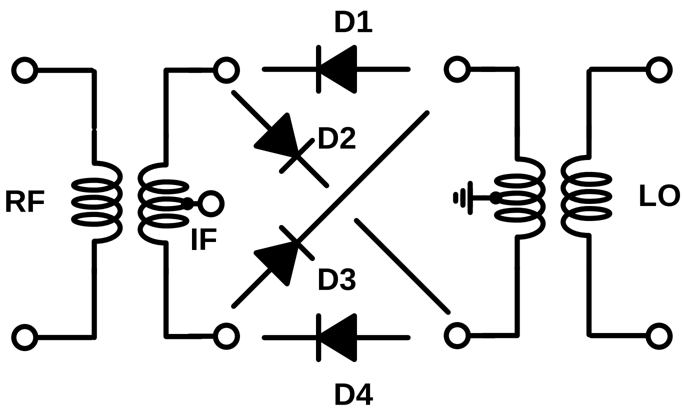
- Sub-quarter wavelength balun (B1) [3]
- Section B2 provides the IF port and $Z_{cm,RF}$=0

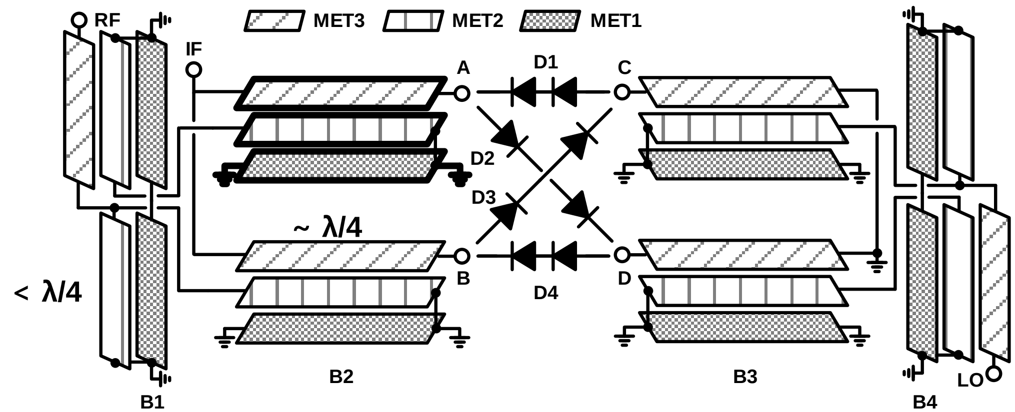


Proposed balun

[3] H. Park, et al., *IEEE J. Solid-State Circuits* (UCSB)

Diode Mixer

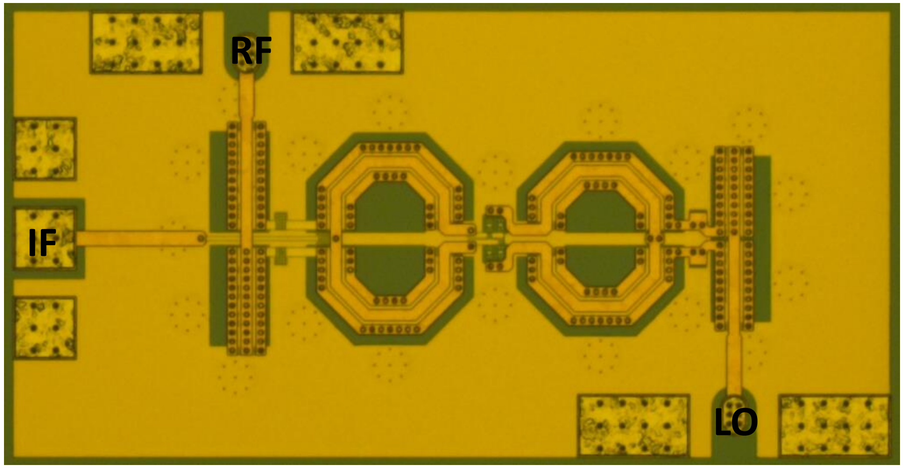




Four series-connected BC diode pairs

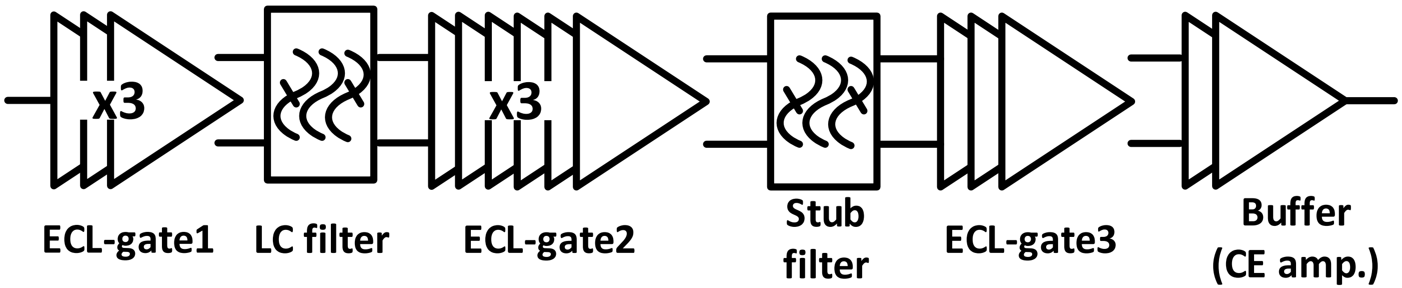
RF and LO baluns

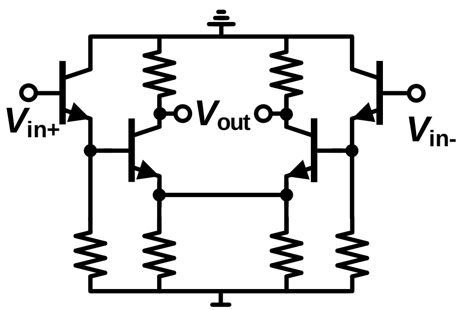
Balun loss < 4 dB over W-band



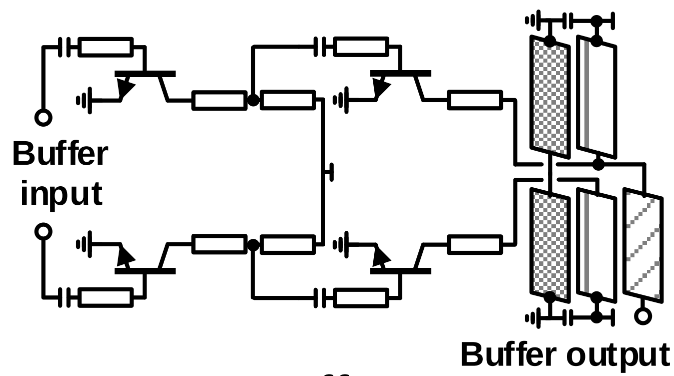
Size: 700 um x 300 um (excl. pads)

LO Mulitiplier Chain





ECL-gate



Buffer

ECL-gates generate squarewave → Strong third harmonic, wide bandwidth

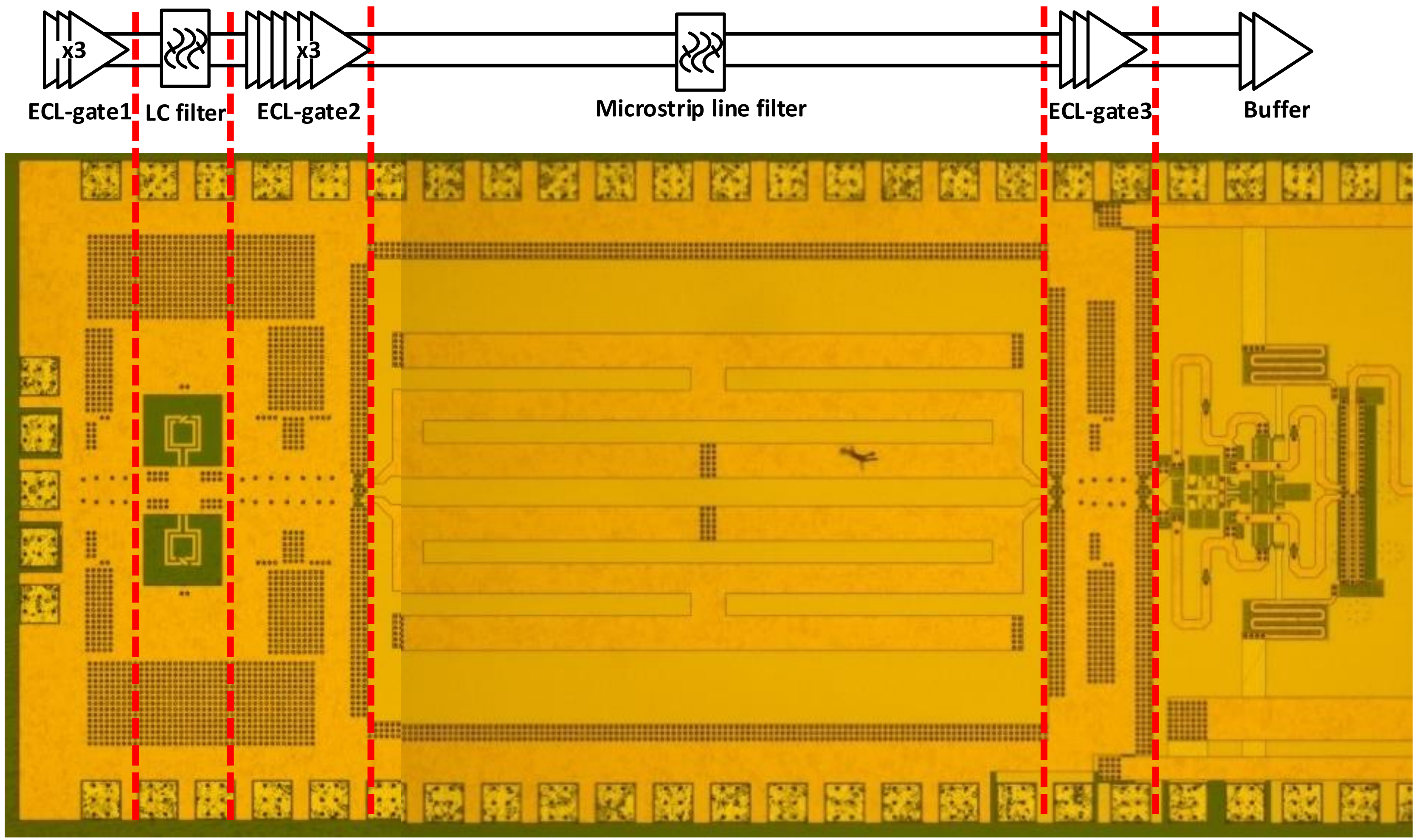
Chebyshev LC filter: 20-34 GHz

Microstrip line bandpass filter: 60-100 GHz

3-stage ECL pre-amplifier

Buffer: two-stage pseudo-differential common-emitter amplifier > 8 dBm

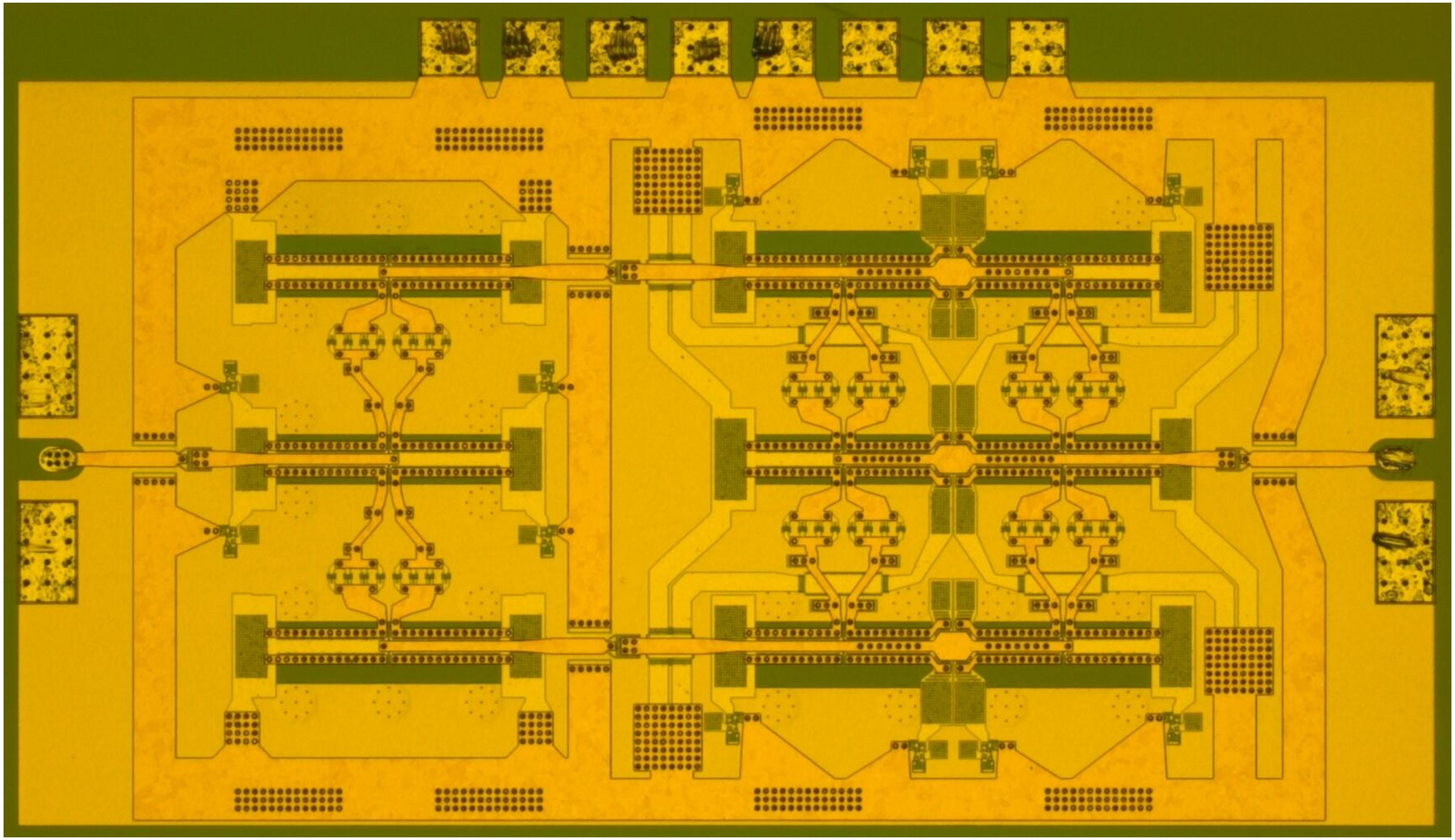
LO Mulitiplier Chain



Measured P_{out} : 8-11.5 dBm over 75-105 GHz tuning bandwidth
Power consumption: 270 mA from -4 V supply, 64 mA from 2 V supply

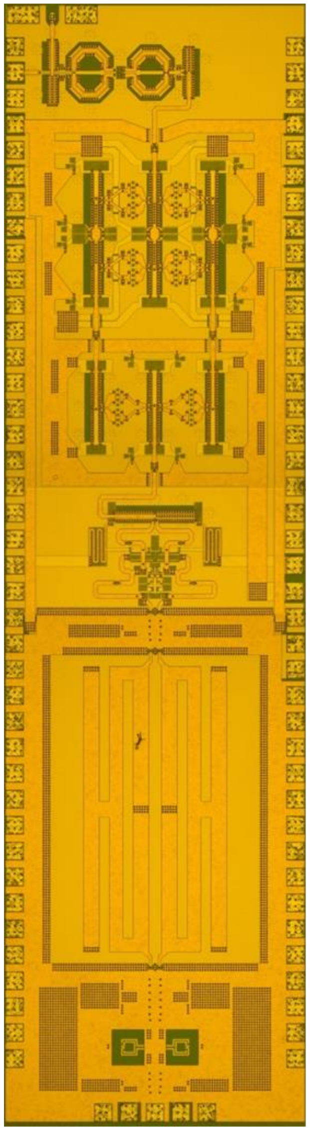
High-Power LO Driver

Wide bandwidth > 60-100 GHz, > 19 dBm output power

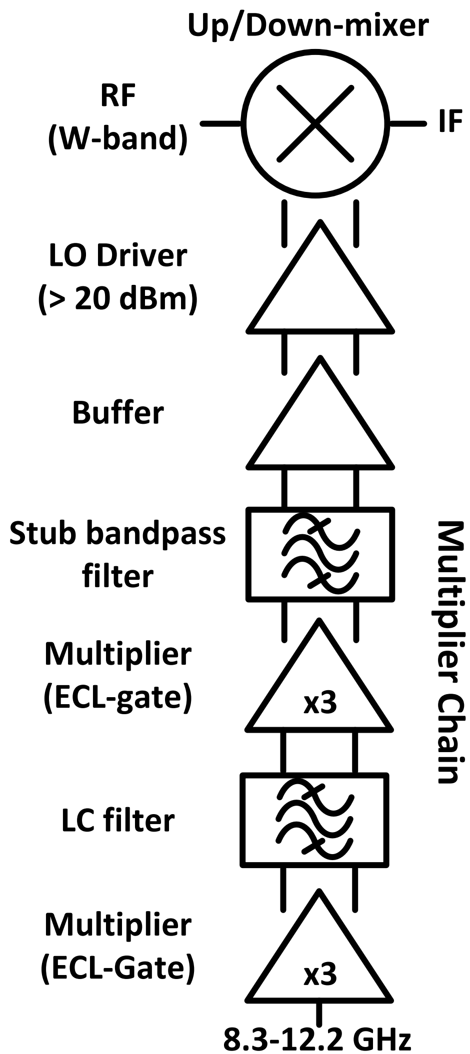


R. Maurer, et al., “Ultra-wideband mm-Wave InP Power Amplifiers in 130nm InP HBT Technology,” in *2016 IEEE CSICS*
*<u>*Presented in SESSION F on Oct. 25*</u>

Frequency Conversion IC



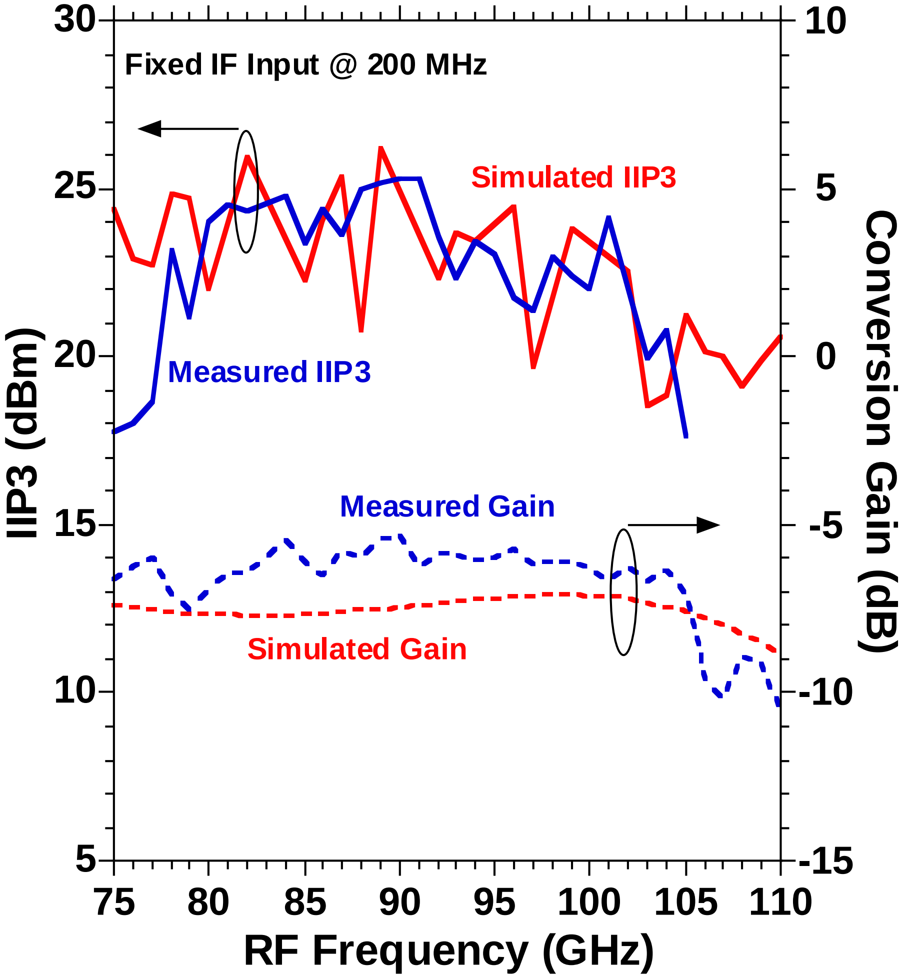
Size: 4300 um x 1160 um

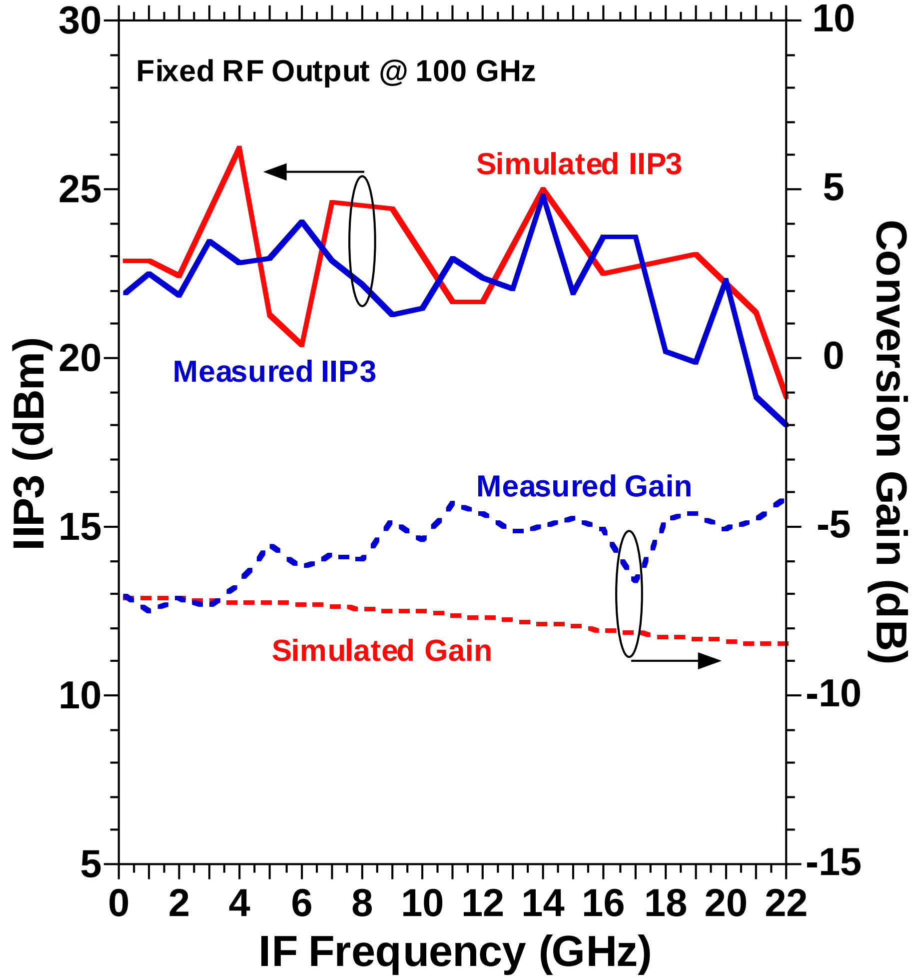


Integrated frequency conversion IC
- Diode mixer
- High power LO driver
- x9 multiplier chain
- ***136*** emitter fingers
- ***326*** passive components

Total power consumption: 2 W
- Multiplier chain and LO driver

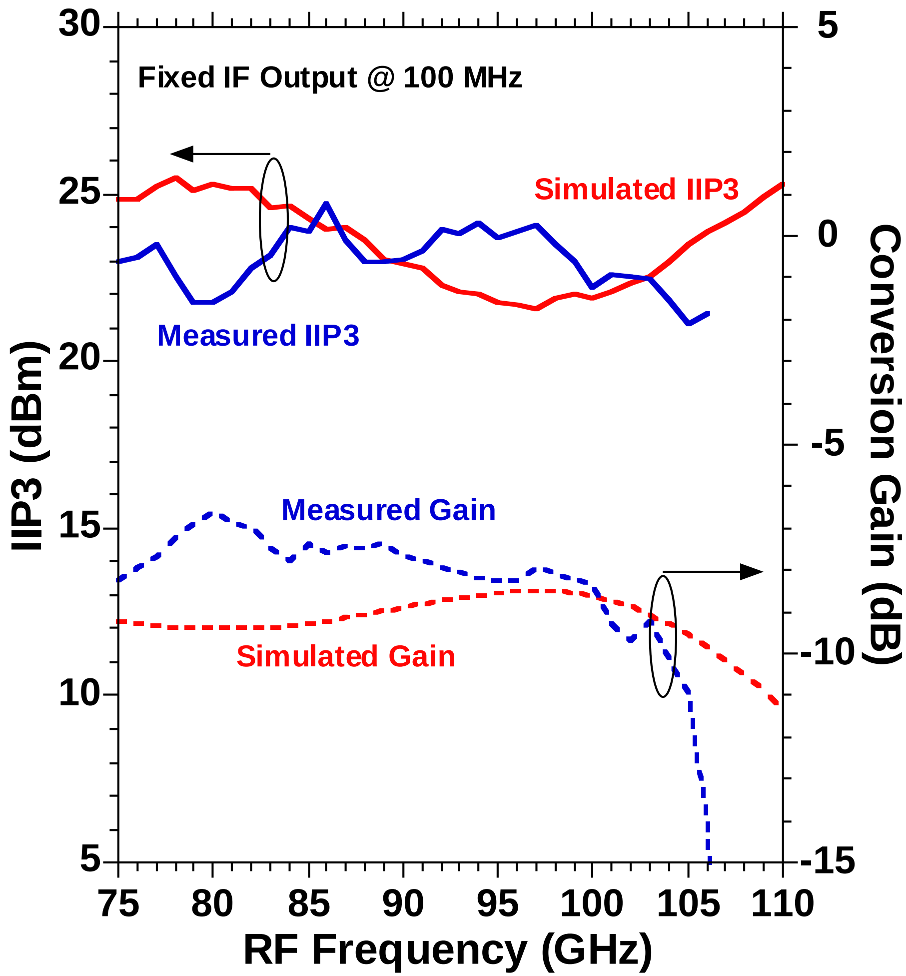
Up-Conversion Measurements

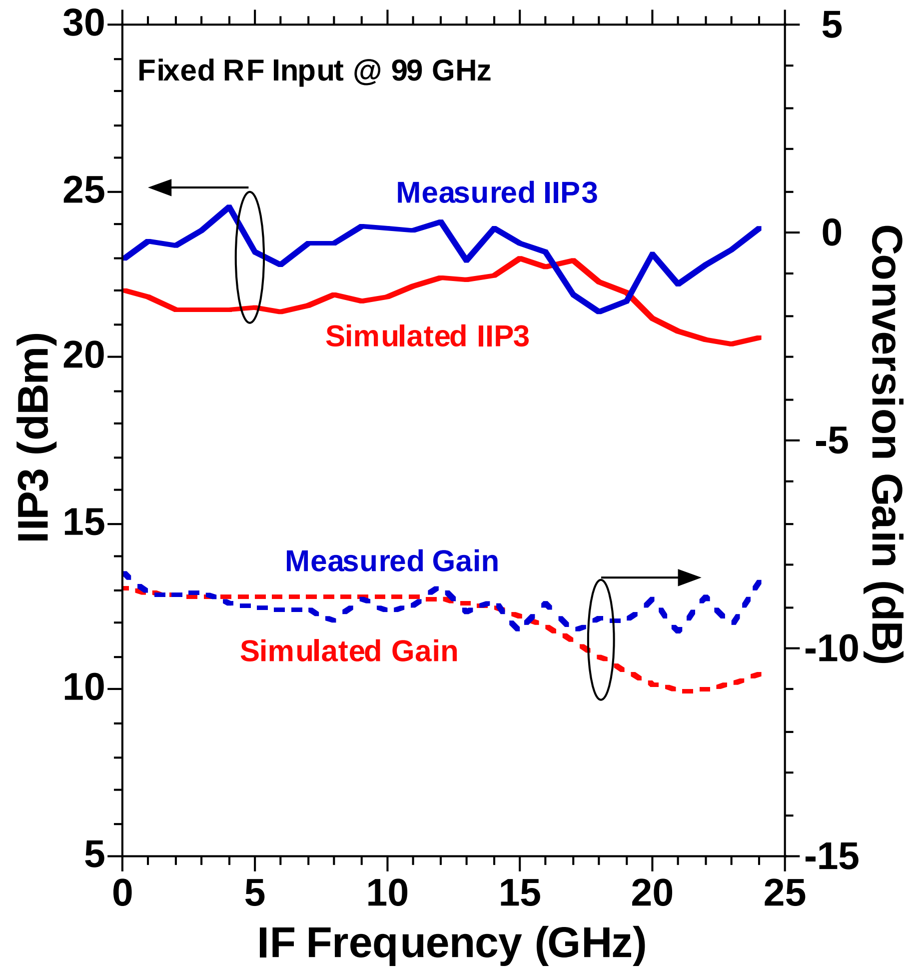




7 dB conversion loss and 23 dBm IIP3

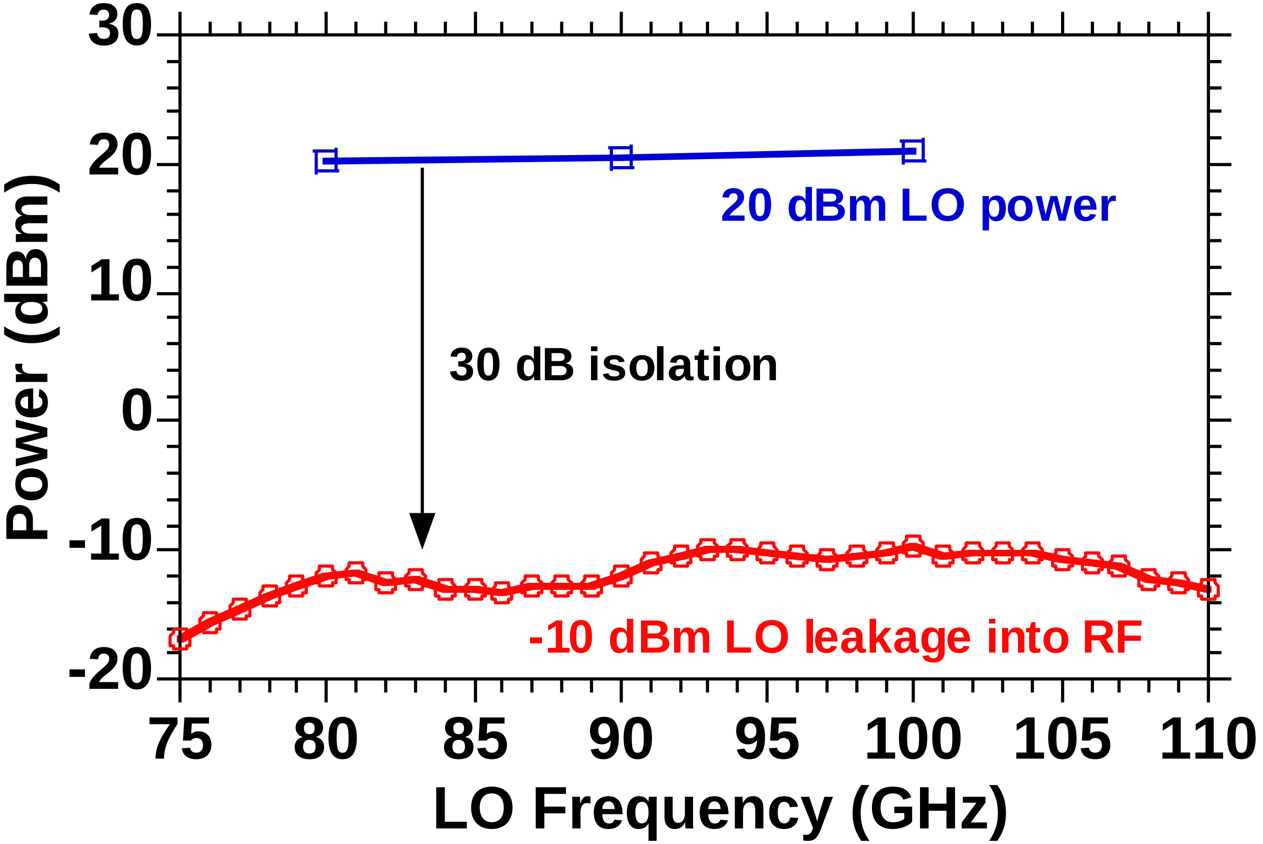
Down-Conversion Measurements





8 dB conversion loss and 23 dBm IIP3

LO Leakage



30
20
10
0
-10
-20
Power (dBm)
75
80
85
90
95
100
105
110
LO Frequency (GHz)
20 dBm LO power
30 dB isolation
-10 dBm LO leakage into RF

W-band frequency conversion IC

Dual conversion: classic widely-tunable RF receiver design
Extend to microwave (3-30 GHz) → Need ~100 GHz IF

Dual conversion: feasible with wideband (THz) transistors
- 100 GHz signal frequency is only 10% of transistor f_{max}
- Enable high-dynamic-range mixers (& amps: next talk)
- 9:1, 75-100 GHz LO multiplier using digital techniques (ECL-gates)

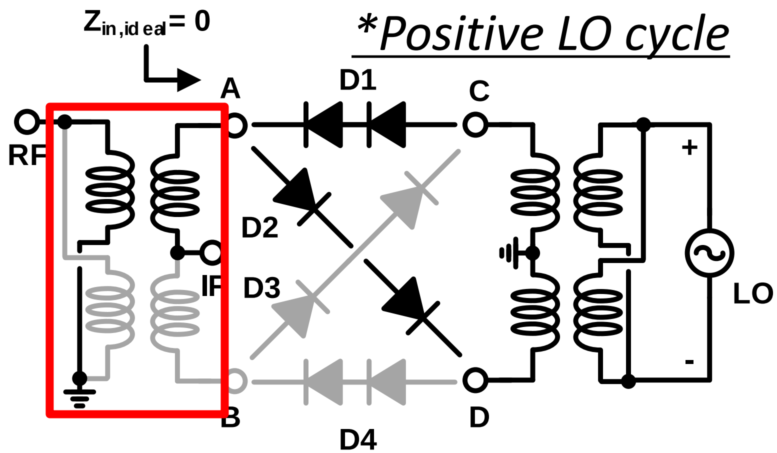
Present frequency conversion IC
- High dynamic range (7-8 dB loss ≈ noise figure, 23 dBm IIP3)
- Very wide tuning LO (1-25 GHz ↔ 76-100 GHz)
- Application: 1-25 GHz dual-conversion receiver

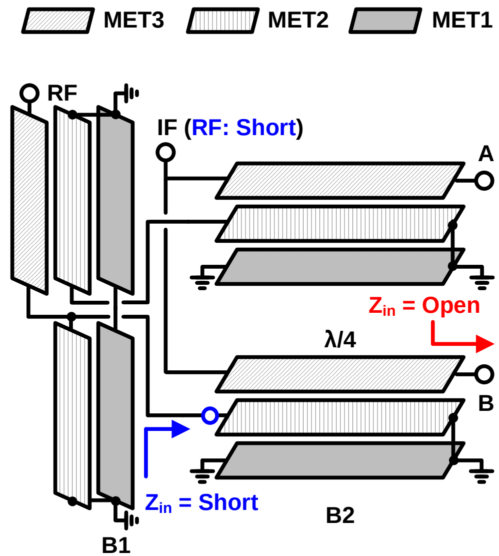
Complex IC in a 1 THz IC technology
- 136 HBT emitter fingers, 326 passive components, 16 cascaded stages
- 1st pass: good correlation between simulation & measurement

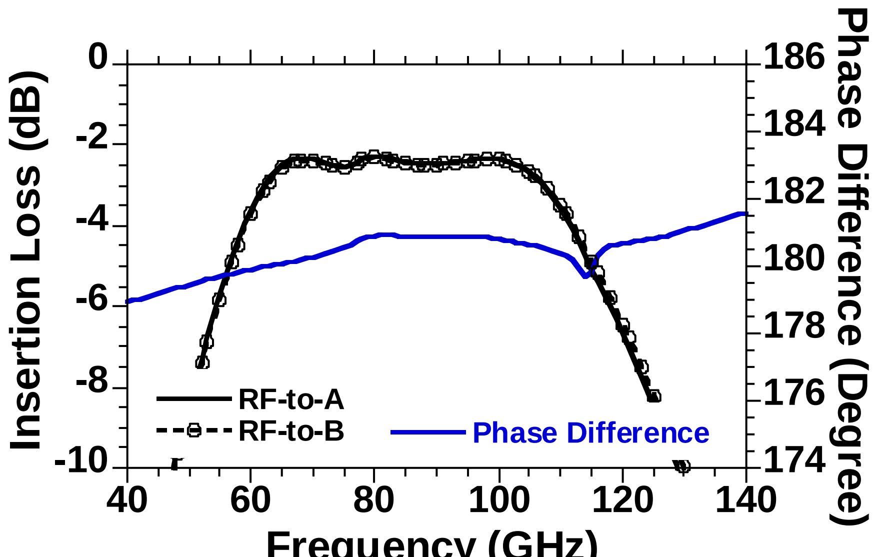
We thank Teledyne Scientific & Imaging for IC fabrication

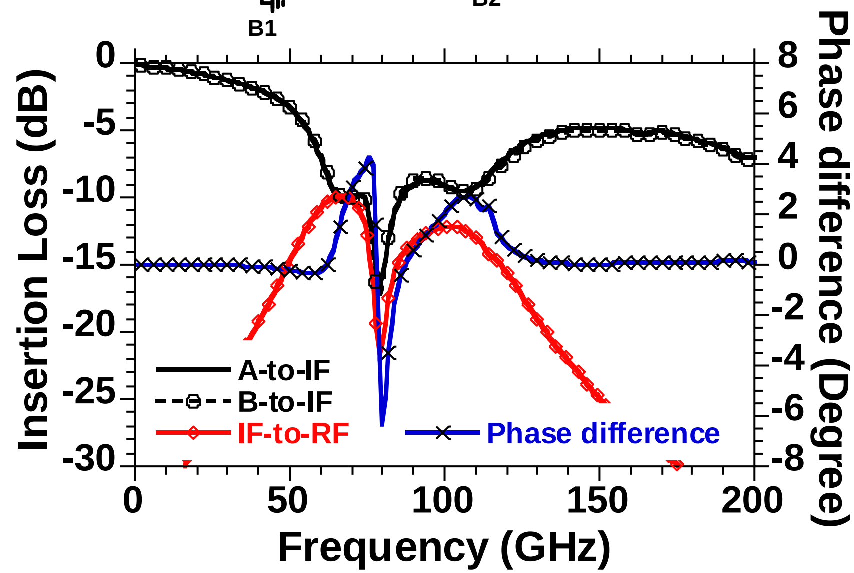
Thank you

RF Balun Design



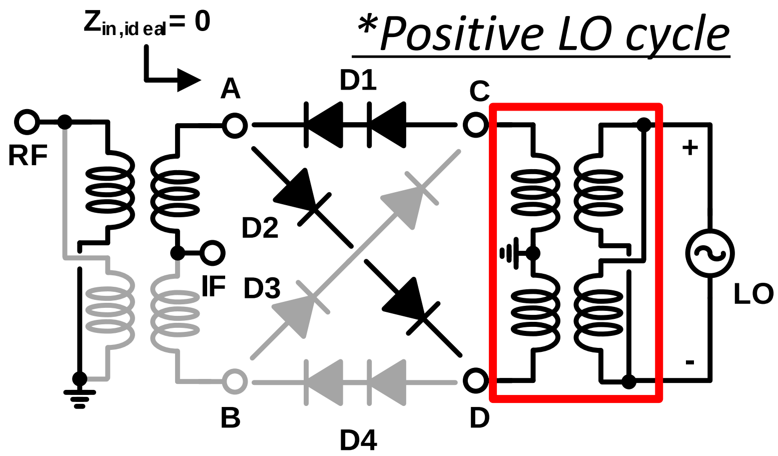


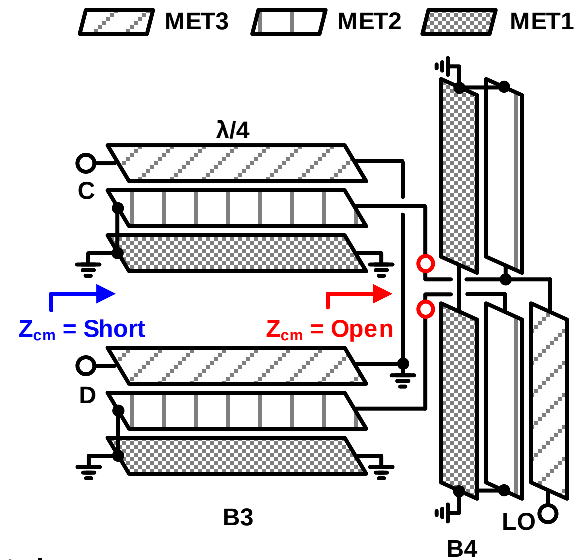


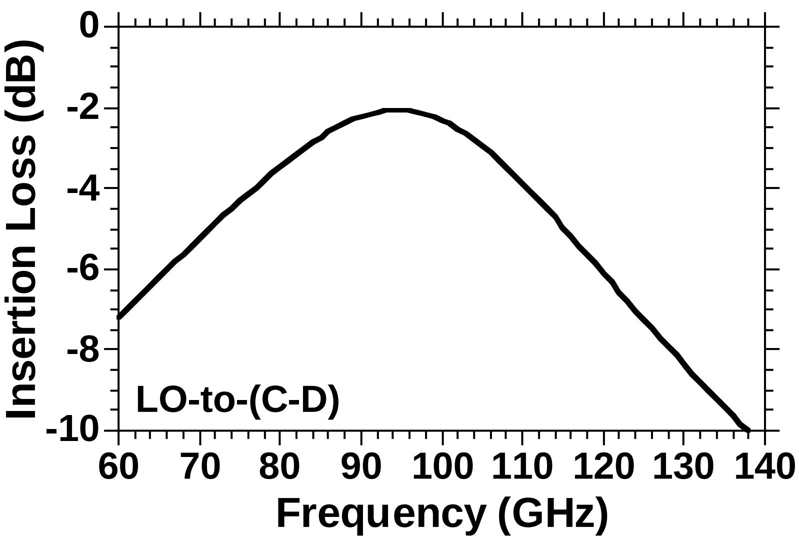


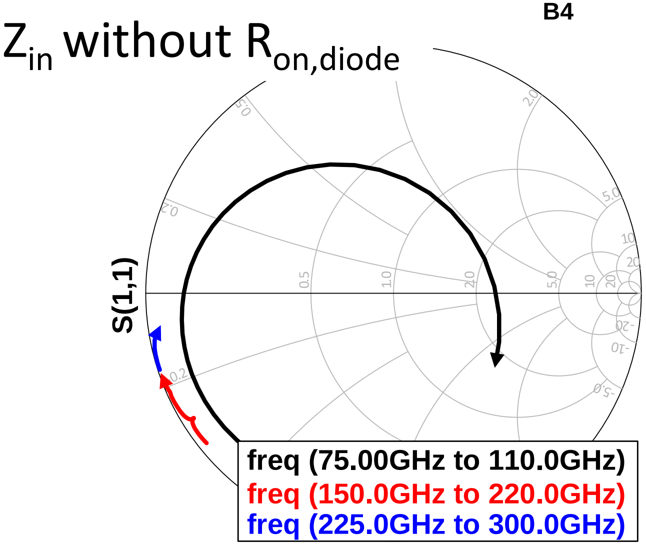
Insertion loss < 3.5 dB, phase error < 4° over W-band

LO Balun Design



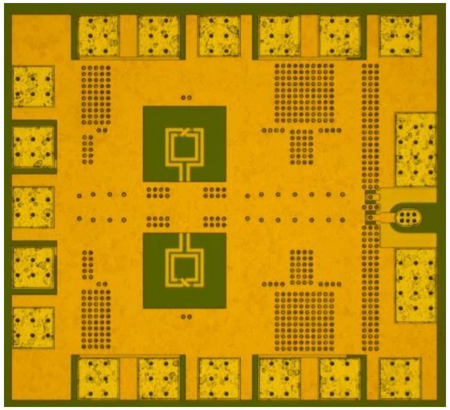


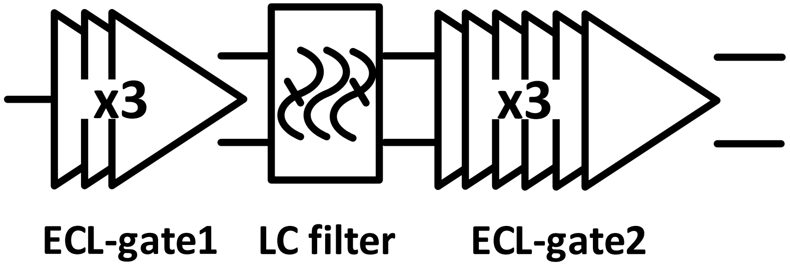




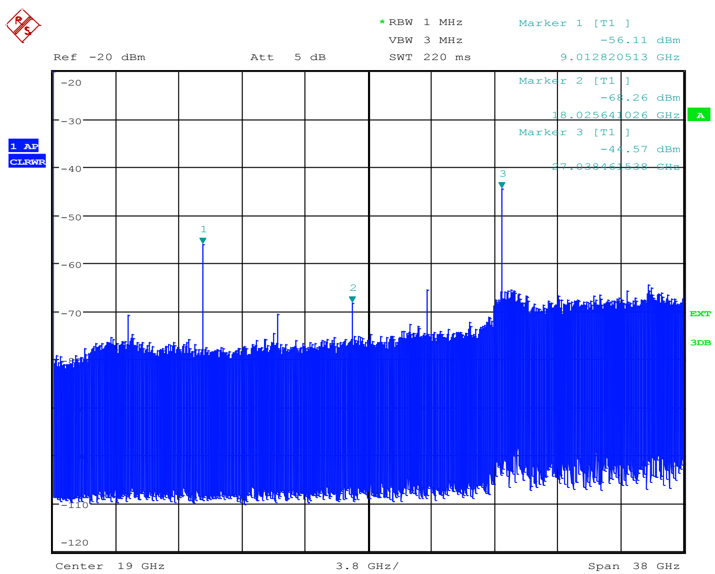
2-4 dB insertion loss over W-band

Mulitiplier x3

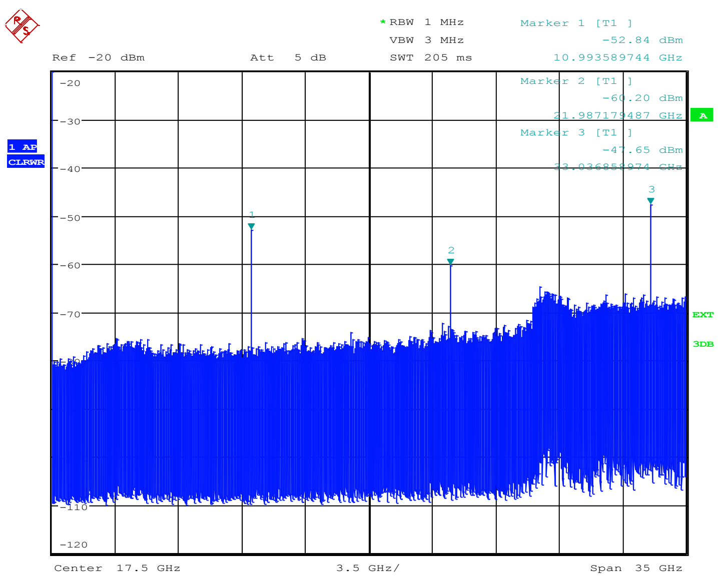




*<u>*Ground plane: top metal layer</u>*



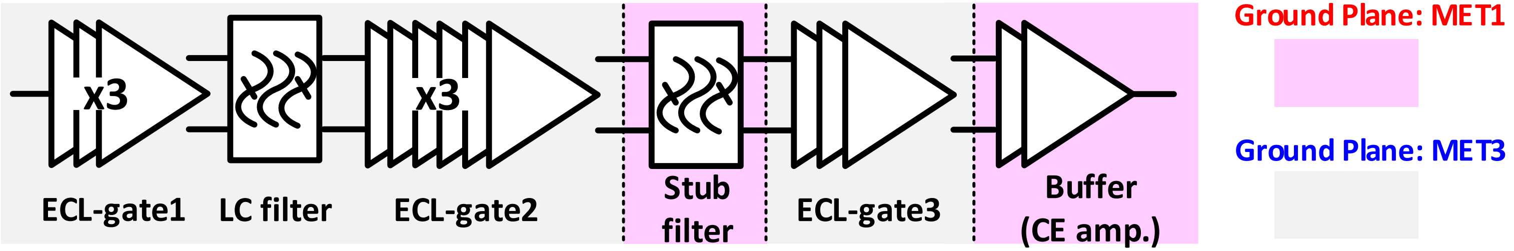
Input @ 9.0 GHz

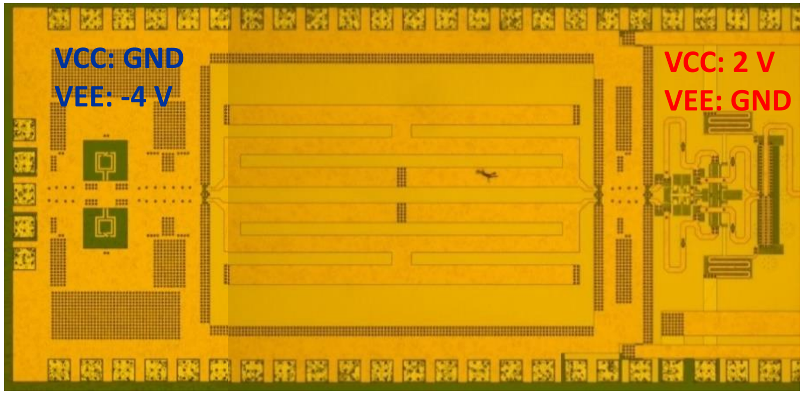


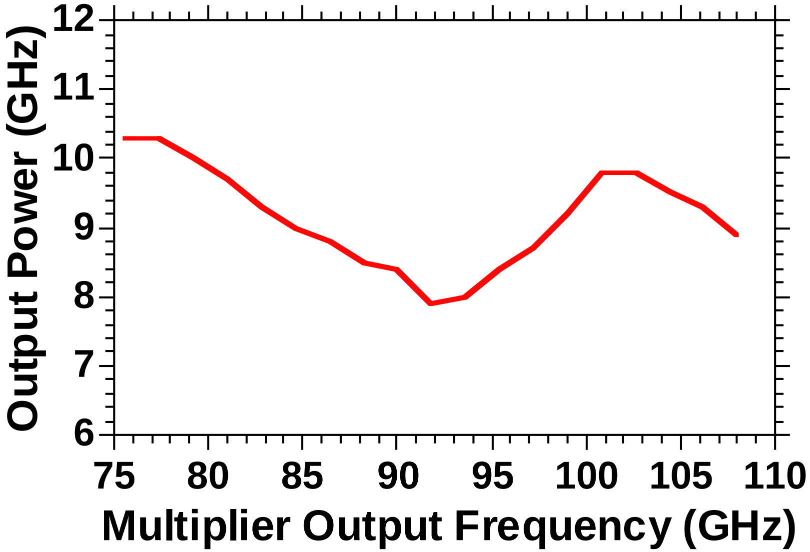
Input @ 11.0 GHz

*<u>*Cable loss is not calibrated</u>*

LO Mulitiplier Chain







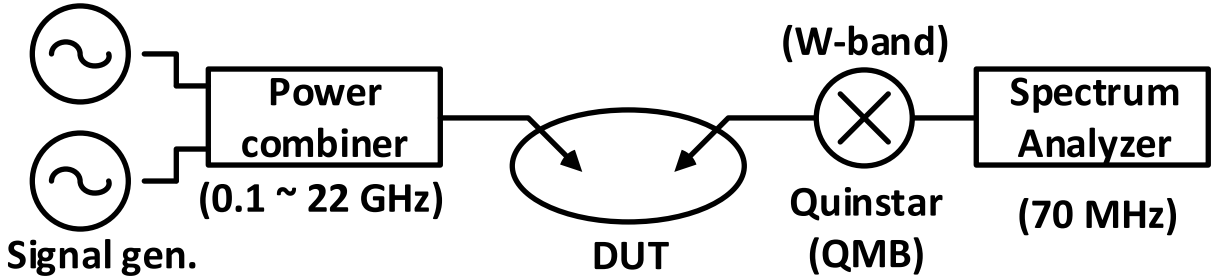
Measured P_{out} > 8 dBm

Power consumption

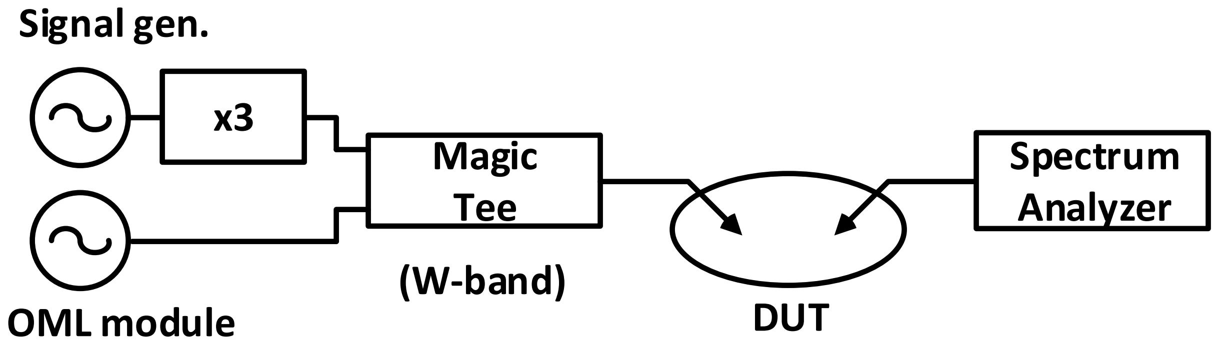
- V_{EE}: 270 mA @ -4 V
- V_{CC}: 64 mA @ 2 V

Measurement Setup

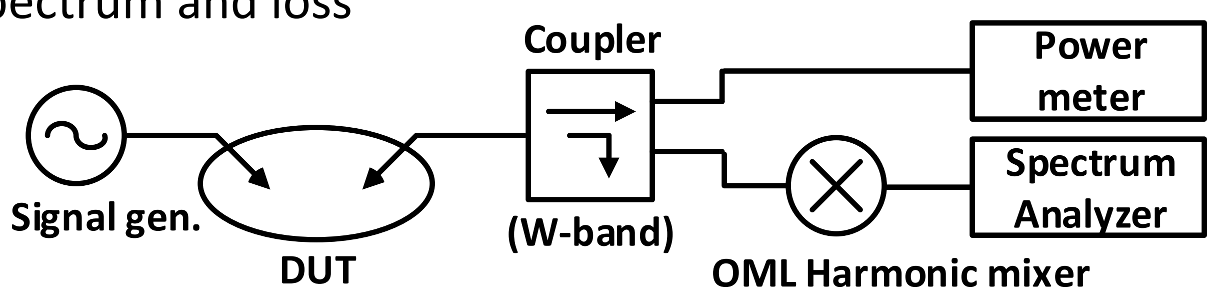
IIP3 (up-conversion)



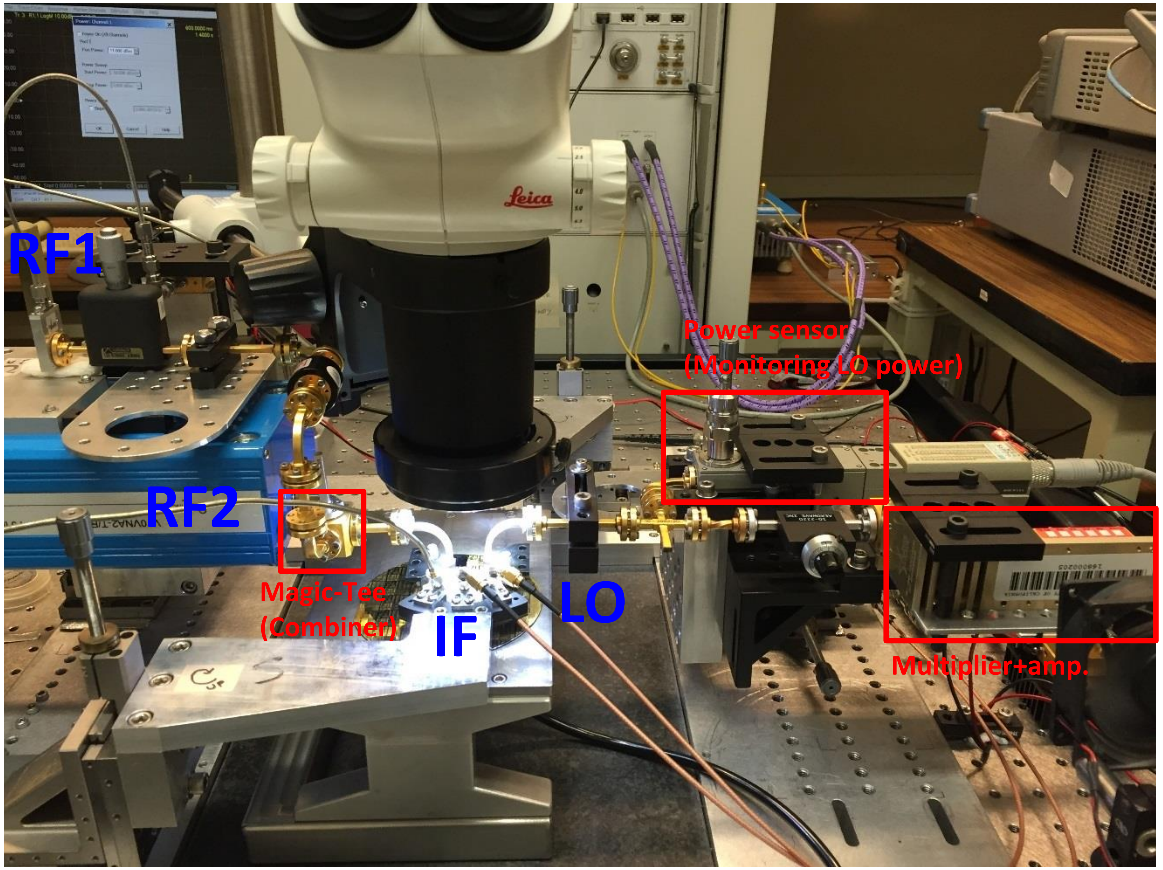
IIP3 (down-conversion)



W-band spectrum and loss

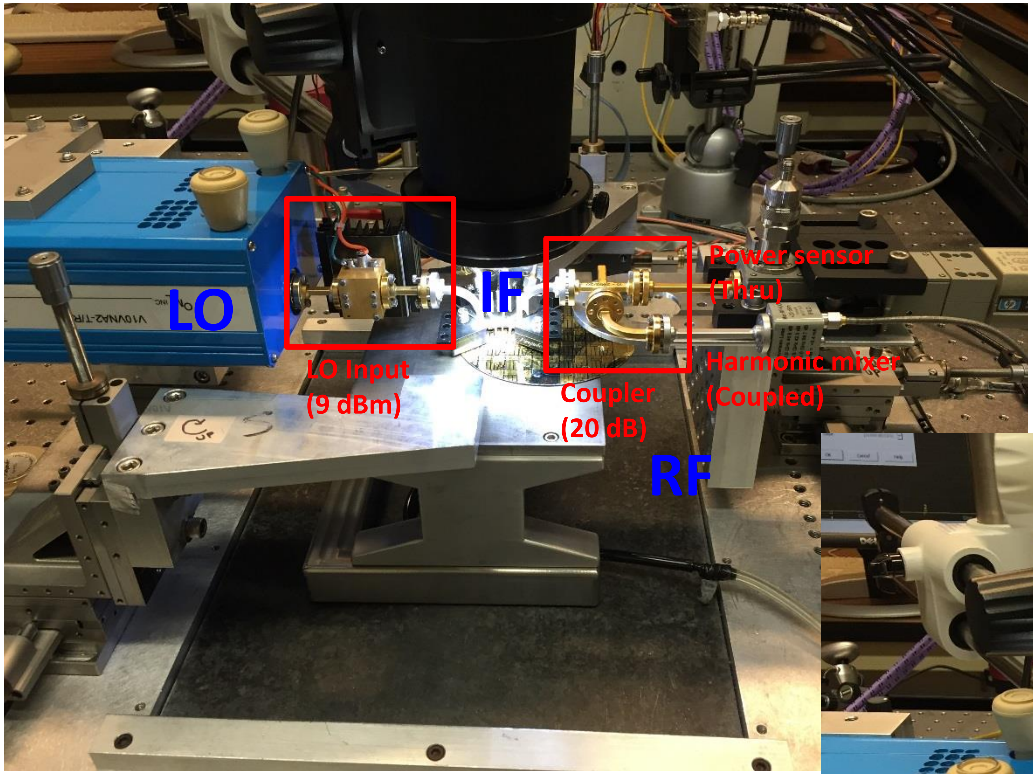


IIP3 Measurement Setup



Up-conversion

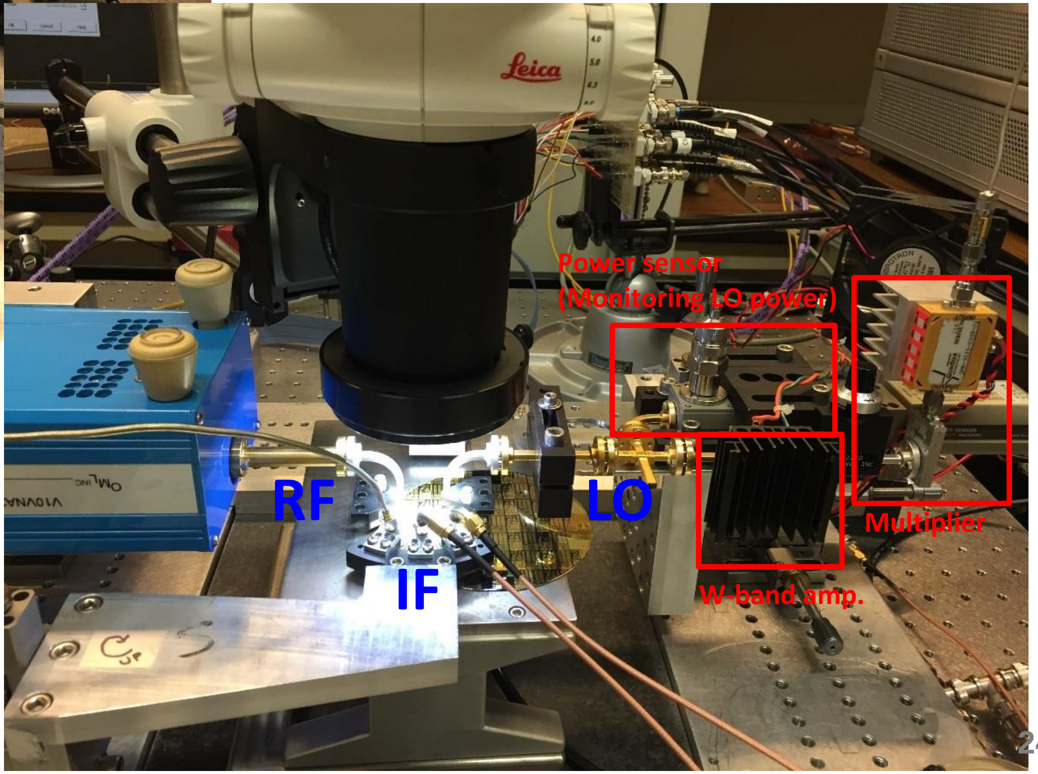
Measurement Setup



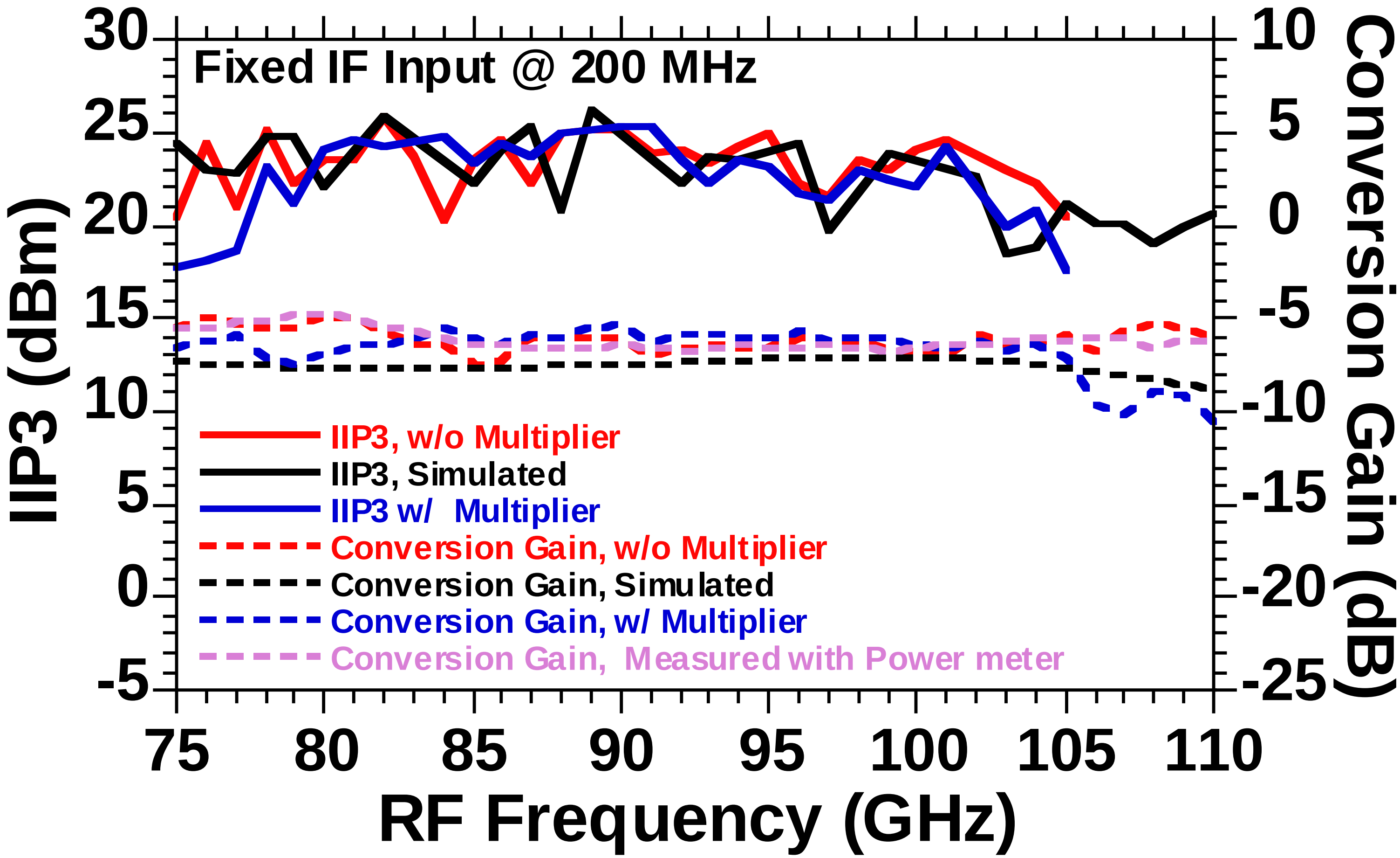
Spectrum and gain

Up-conversion

Down-conversion

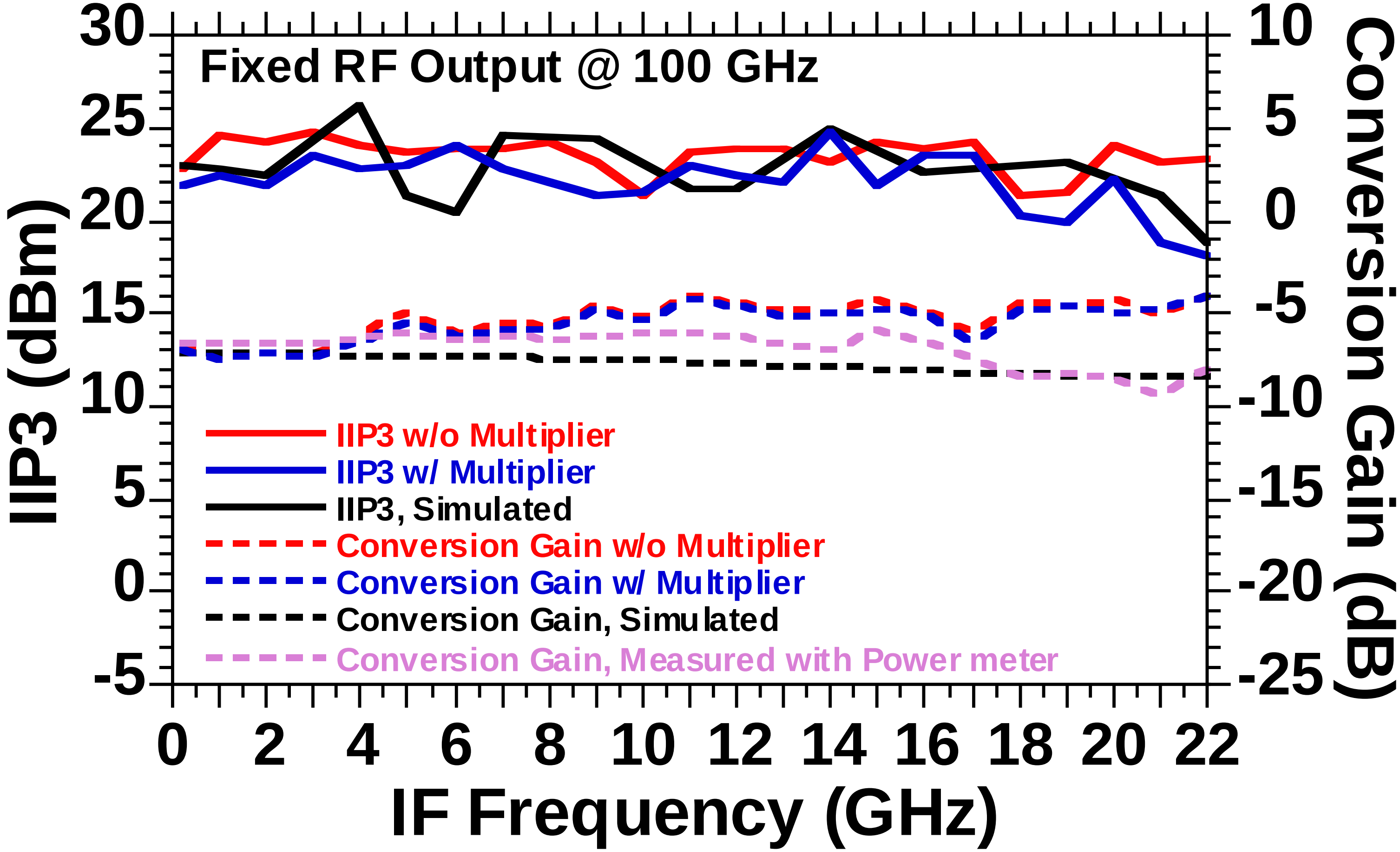


Measurements (UP)



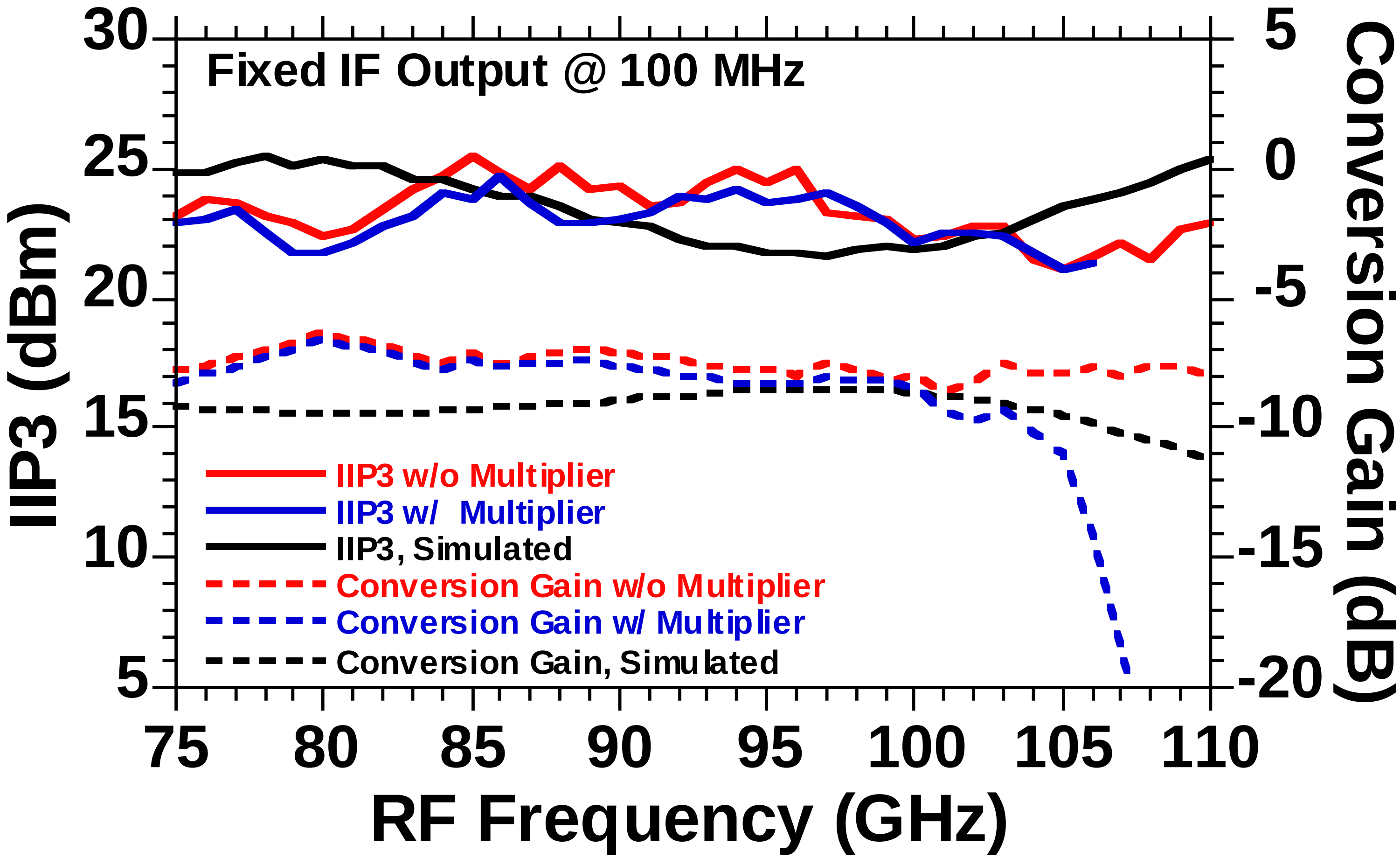
**w/o mul.: LO input power 9 dBm*

Measurements (UP)



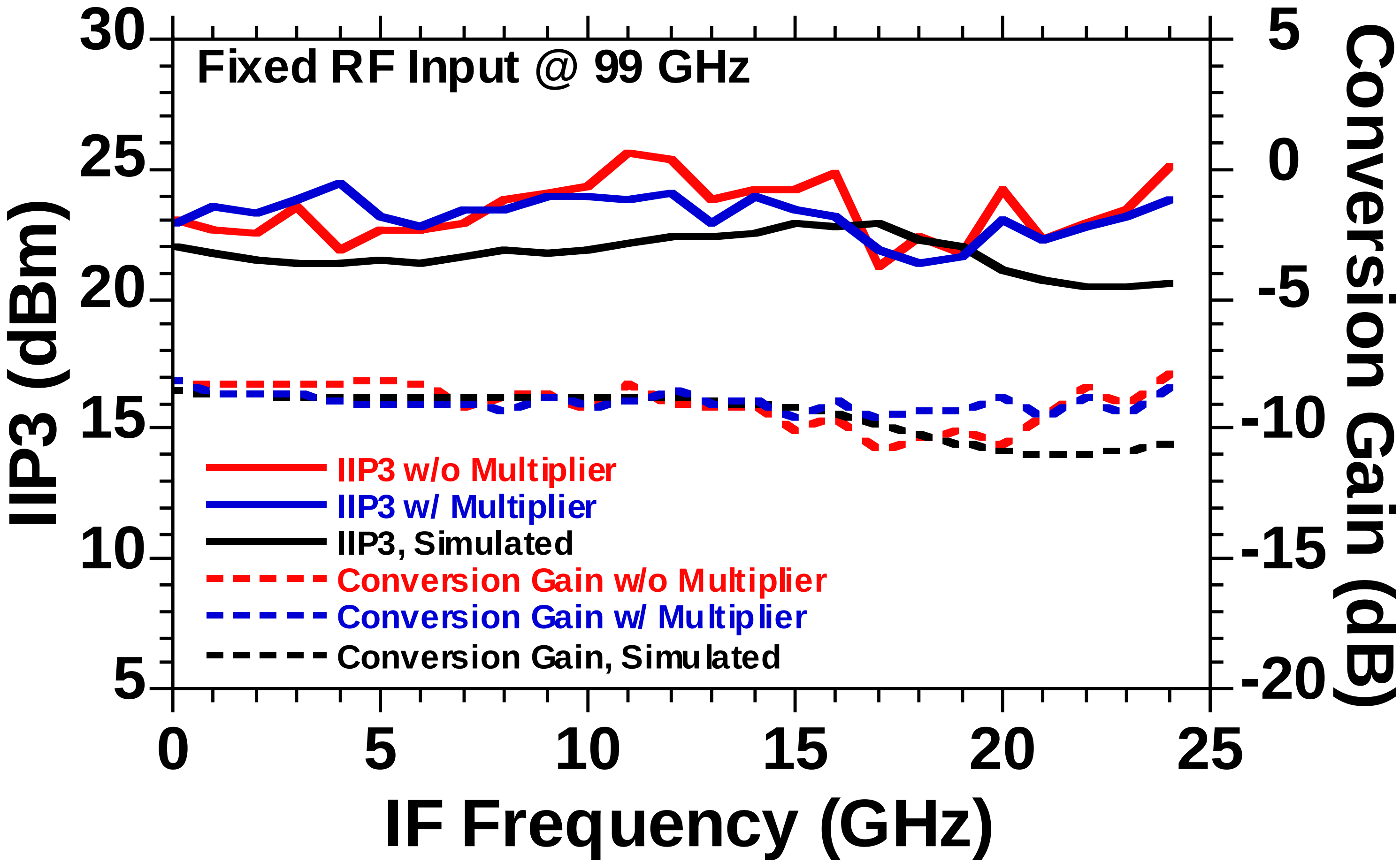
**w/o mul.: LO input power 9 dBm*

Measurements (Down)



**w/o mul.: LO input power 9 dBm*

Measurements (Down)



**w/o mul.: LO input power 9 dBm*