High-linearity W-band Amplifiers in 130 nm InP HBT Technology

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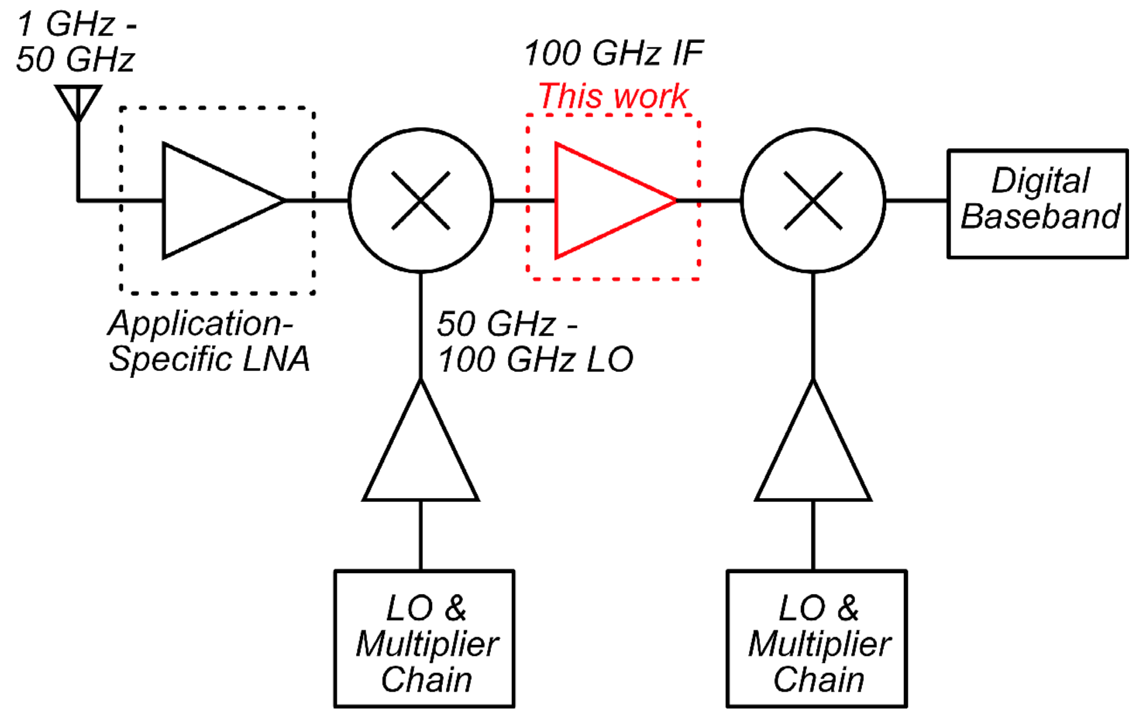
Motivation

1-50 GHz High-Dynamic-Range Dual-Conversion Receiver



100 GHz IF for widely tunable receiver bandwidth

System dynamic range limited by IF chain IP3 & noise

Design Goals

System Requirements:

High IIP3 > 24 dBm (100 GHz, >5 GHz BW)

Gain > 6 dB

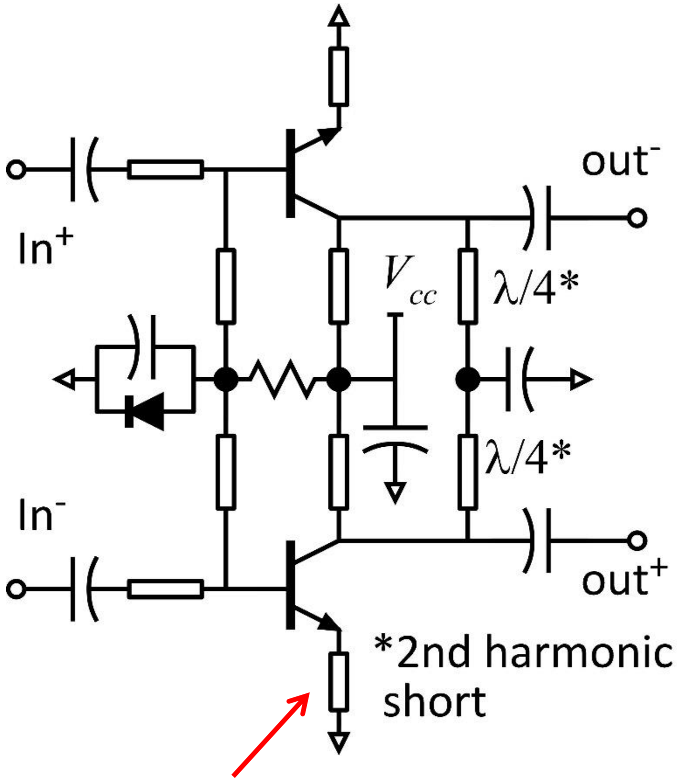
Preferably with:

Low Noise Figure

Limited chip space/power consumption

Design Strategy

How do we achieve such high IP3 at 100 GHz?



*2nd harmonic short

Approach:

High speed 130 nm InP HBT technology

Common emitter

Pseudo-differential

2nd Harmonic output short-circuit

Strong inductive degeneration
- Sacrifices gain for linearity
- Partly converges noise & S_{11} tuning

TSC 130 nm InP HBTs

Extremely high-speed technology

$$f_{max} = 1.1\ THz$$

How does this contribute to linearity?

High speed: 13.5 dB MAG/MSG at 100 GHz (2 mA/µm of L_E)

High maximum available/stable gain

Can sacrifice gain for linearity: inductive emitter degeneration.

Degeneration also converges tuning for optimum noise and minimum S_{11}

Pseudo-Differential

Single-ended design:

Ground Via Inductance prevents true RF ground
Power supply lines de-tune output network
Poor power supply isolation
Instability, unwanted interstage coupling

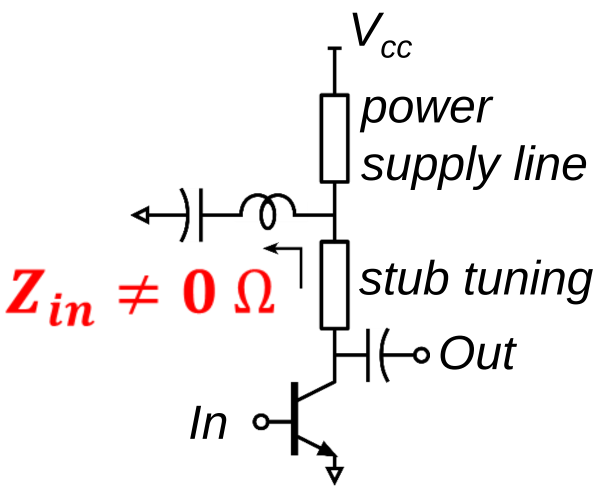
True differential design:

Provides RF virtual ground
Must be stable for differential *and* common-mode
Emitter stub likely capacitive in common-mode

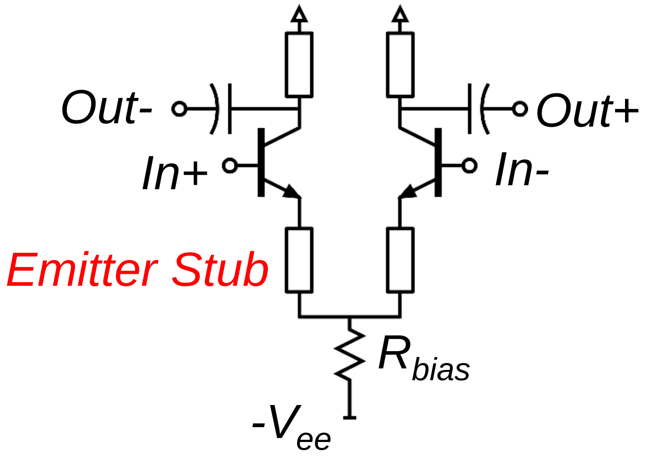
Pseudo-differential design:

No common-mode instability problem
Power-supply is virtual ground

Single-ended



Differential



2^{nd} Harmonic Short Circuit

High-linearity: **Want** linear gain at design frequency ω_o

$$\omega_o: V_{out}\ \alpha\ V_{in}$$ ☺

Don't want 3^{rd} order distortion IM3 near design frequency ω_o

$$\omega_o: V_{out}\ \alpha\ {V_{in}}^{3}$$ ☹

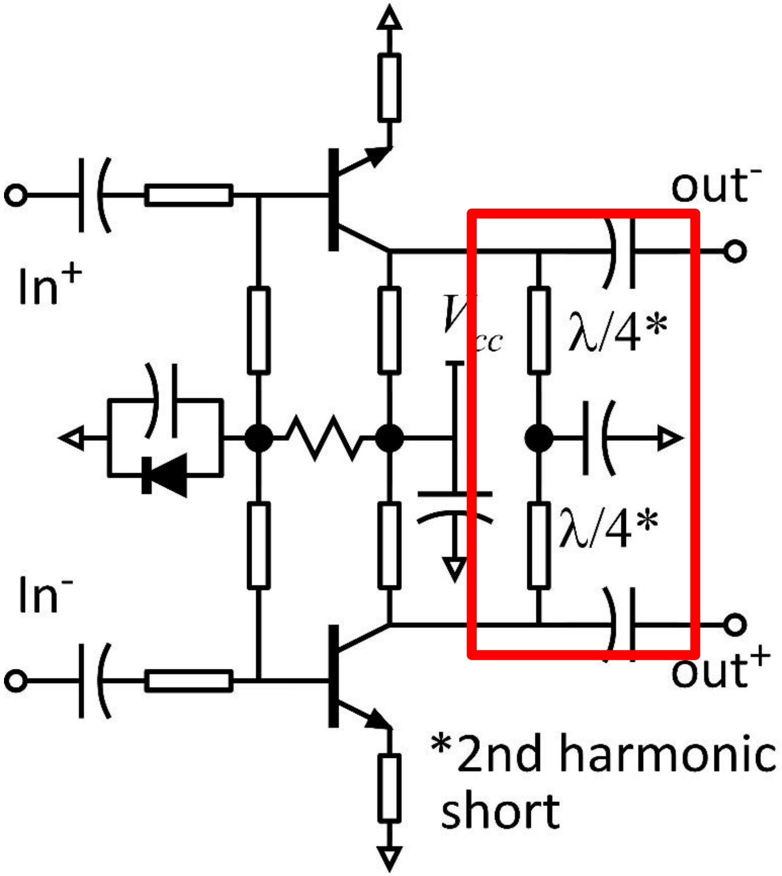
What about 2^{nd} order distortion IM2 at frequency $2\omega_o$?

$$2\omega_o: V_{out}\ \alpha\ {V_{in}}^{2}$$ **?**

IM2 itself is out-of-band, but mixing with fundamental adds extra cubic term to V_{out}

2^{nd} harmonic tone contributes to IM3, degrades IP3

2nd Harmonic Short-Circuit



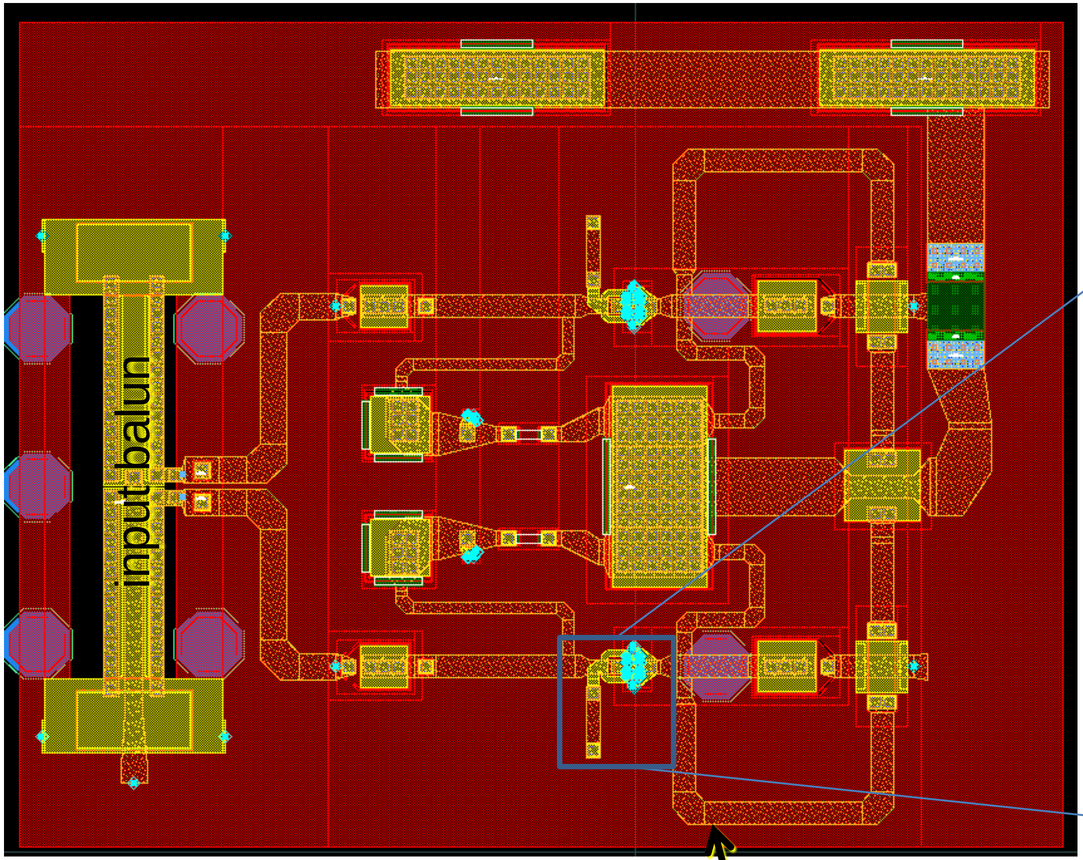
λ/4 transmission line:
open circuit at ω_o
short circuit at $2\omega_o$

Eliminates IM2, which removes an IM3 mechanism

~2-3 dB IP3 improvement

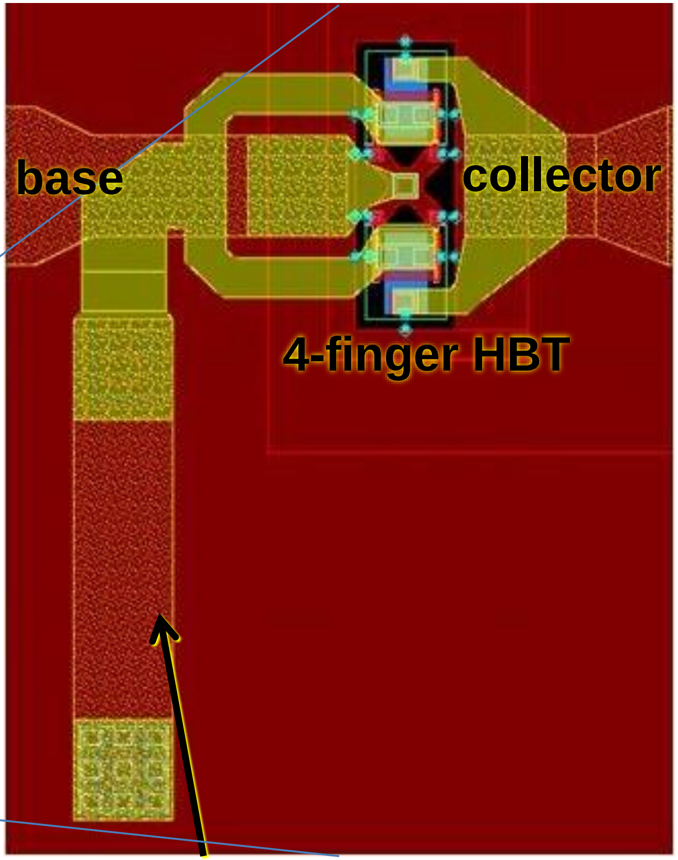
IC layout

Amplifier layout



2nd harmonic short

Degenerated HBT

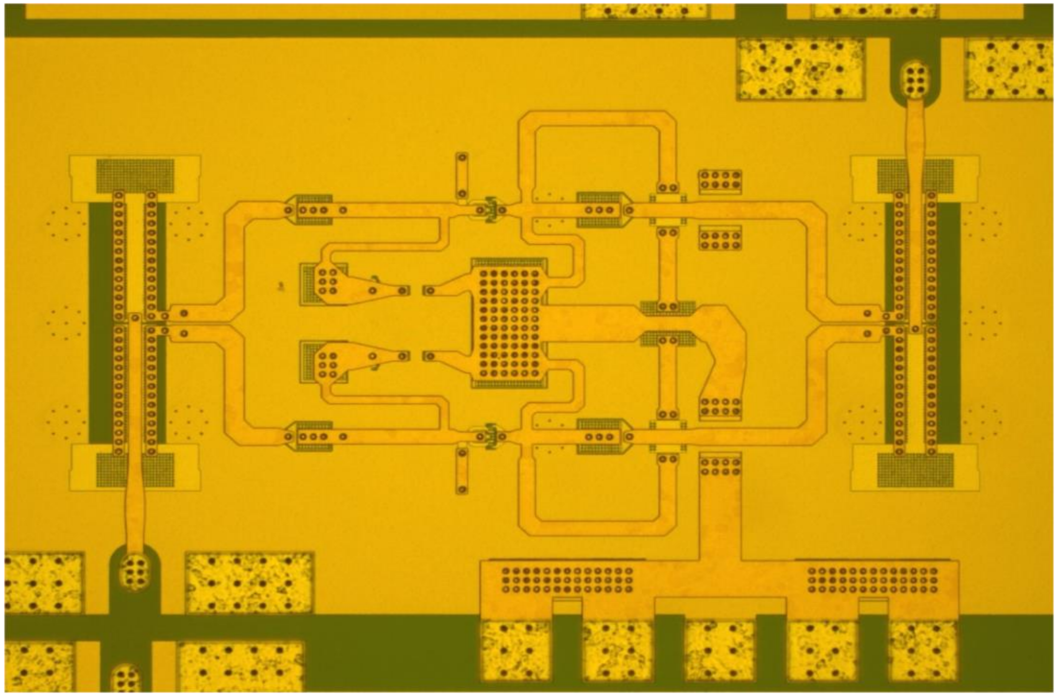


Emitter inductance

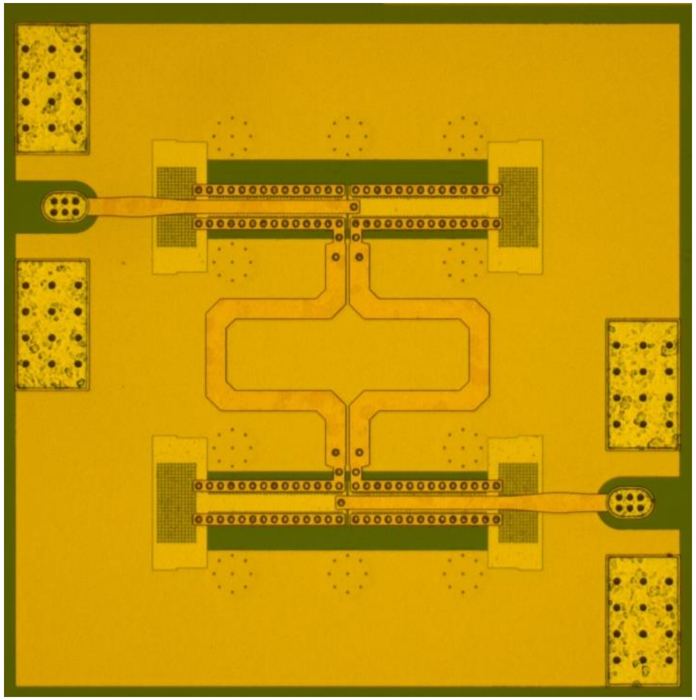
Die layout

Input & output baluns: single-ended on-wafer probing

Back-to-back balun test structure for de-embedding



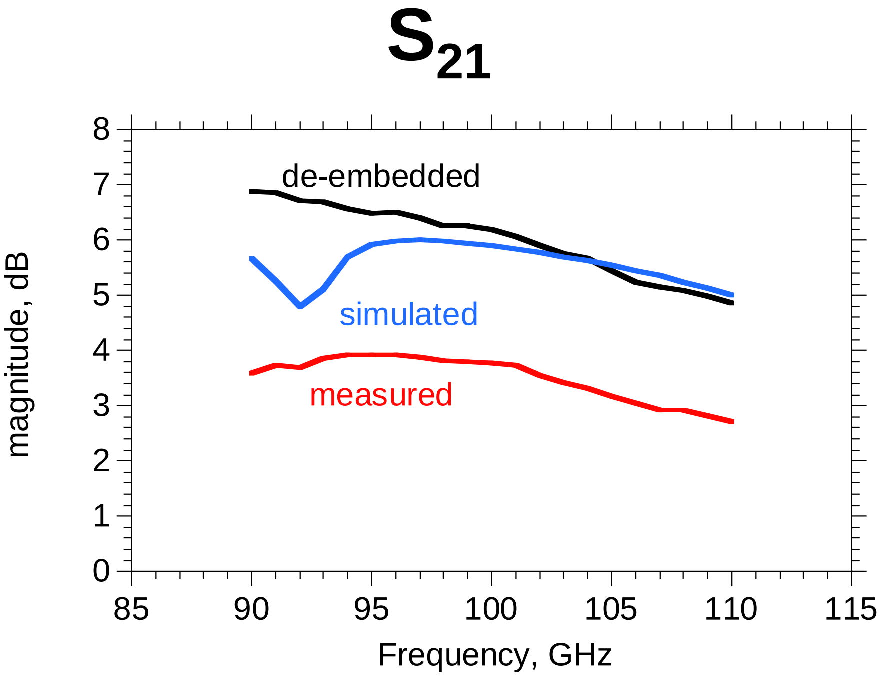
Overall Die: 1.1 mm x 0.72 mm
Differential Amplifier: 0.46 mm x 0.47 mm

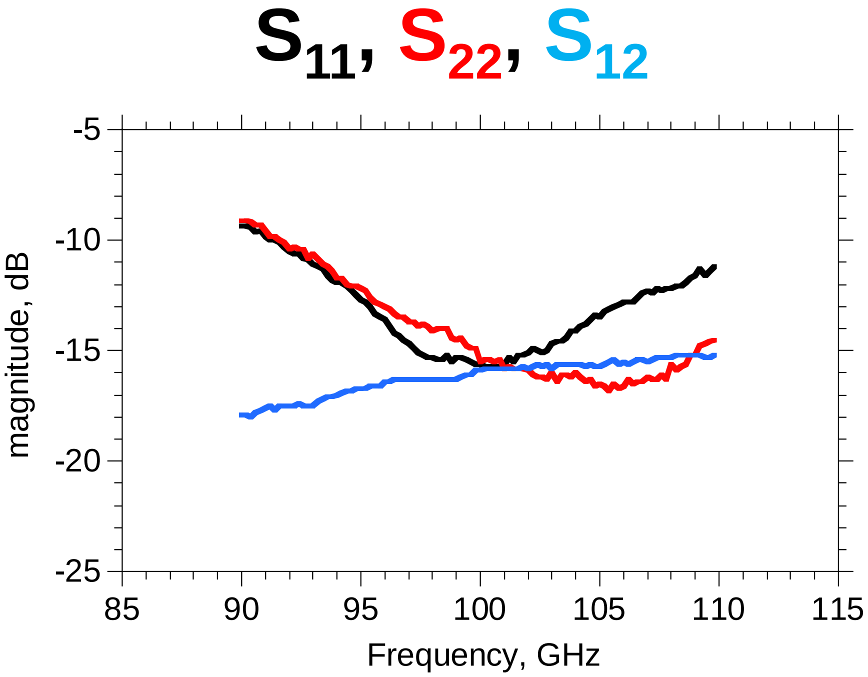


Back-to-back Baluns
S_{21} = -2.4 dB @ 100 GHz

P_{DC} = 200 mW (100 mA, 2V)

S-Parameters

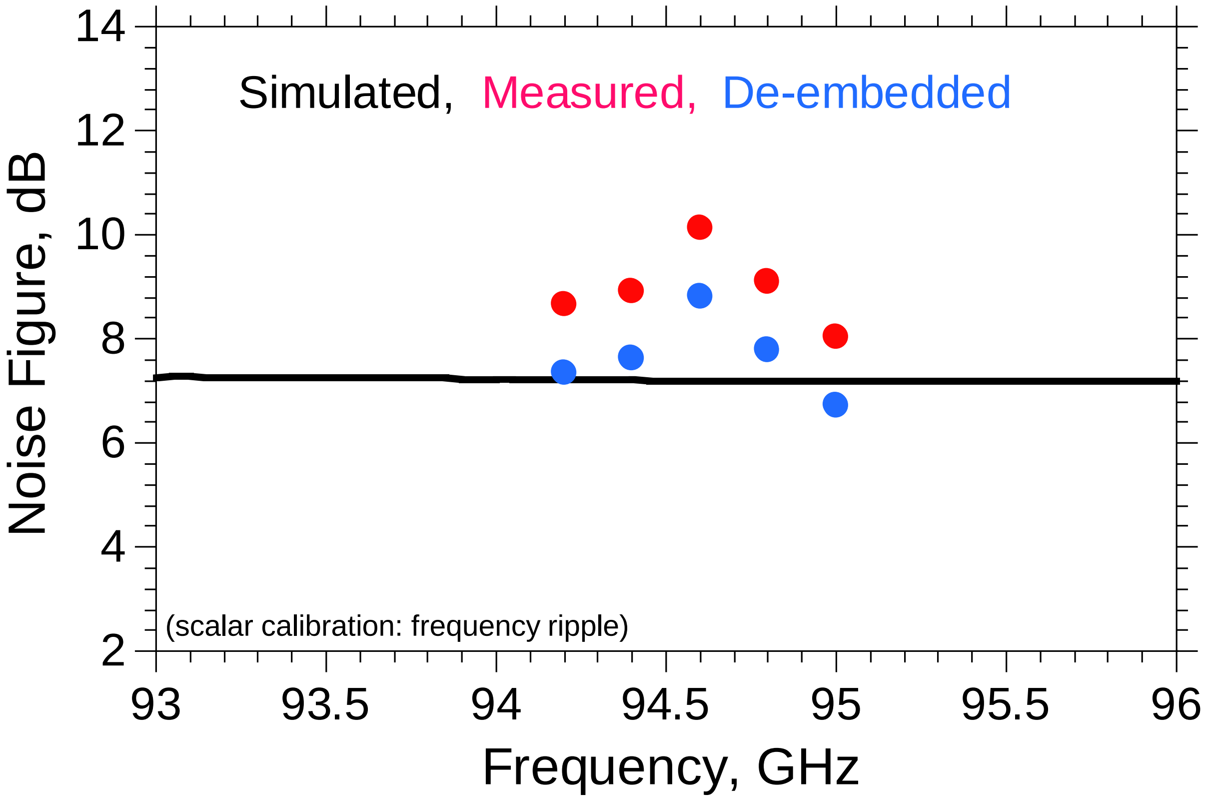




Simulated: amplifier without baluns
Measured: amplifier with baluns
De-embedded: measurements corrected to remove balun attenuation

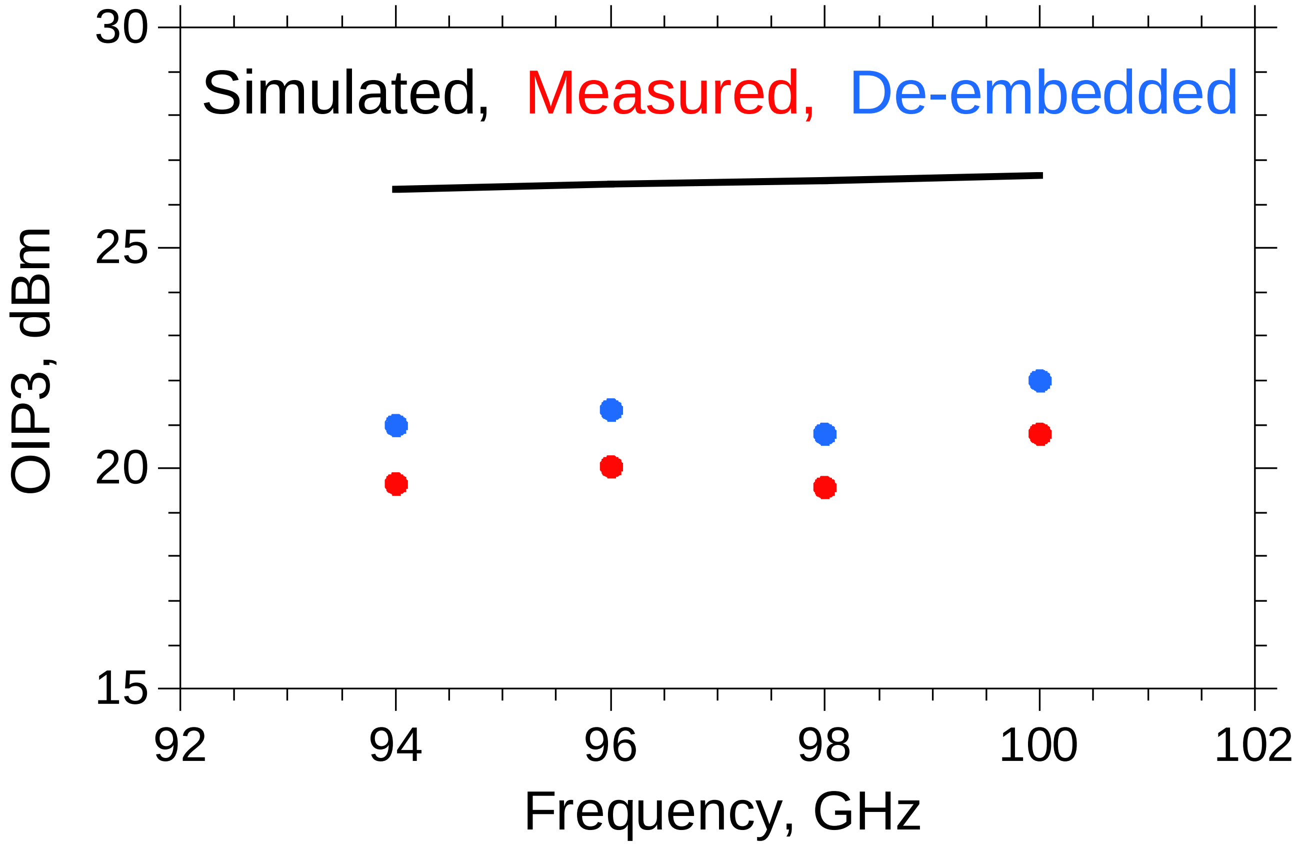
Measured S_{21} of 6-7 dB, close to simulation

Noise Figure Measurements



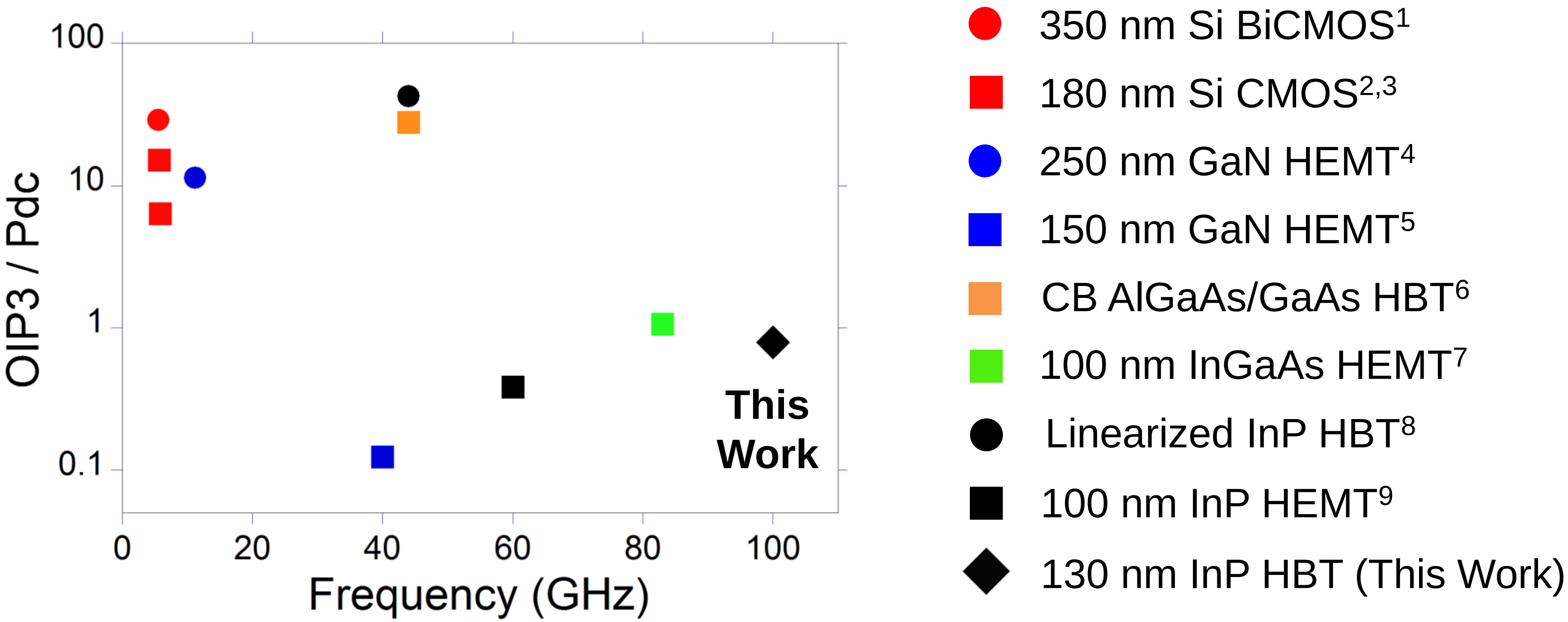
Measured noise figure of 7-8.5 dB, close to simulation

IP3 Measurements



OIP3 is 21-22 dBm, 4-5 dB lower than simulation

Comparison



Very few reported mm-wave high linearity amplifiers

High speed InP/InGaAs transistors pushing frequency limits

O. Nizhnik, et. al. *APMC* 2007[1], M. Zavarei, et. al. *ICECS* 2011[2], R. Huang, et. al. *APCCAS* 2014[3],
W. Chang, et. al. *APMC* 2013[4], K. Kobayashi, et. al. *JSSC* 2016[5], Y. Kwon, et. al. *M&GW Letters* 1996[6],
F. Canales et. al. *IMS* 2013[7], K. Kobayashi, et. al. *JSSC* 1999[8], K. Nishikawa, et. al. *IMS* 2006[9]

High-Linearity W-band Amplifier

100 GHz IFA for mm-wave dual conversion receiver

Enabled by high-speed 130 nm InP HBTs

S_{21} of 6.4 dB, OIP3 of 22 dBm, Noise figure of 7 dB

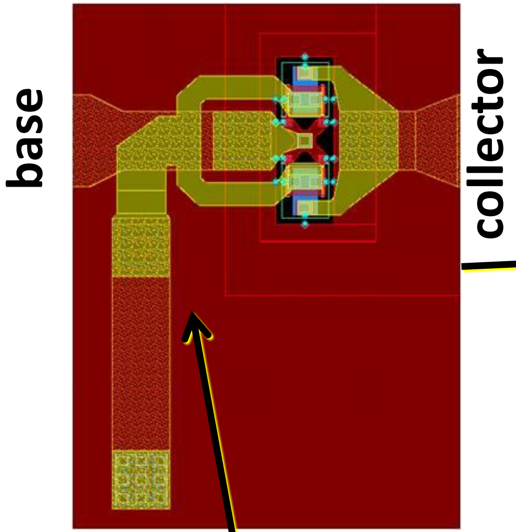
OIP3/P_{DC} ratio of 0.79 at 100 GHz

Among first reported W-band high-linearity amplifier results

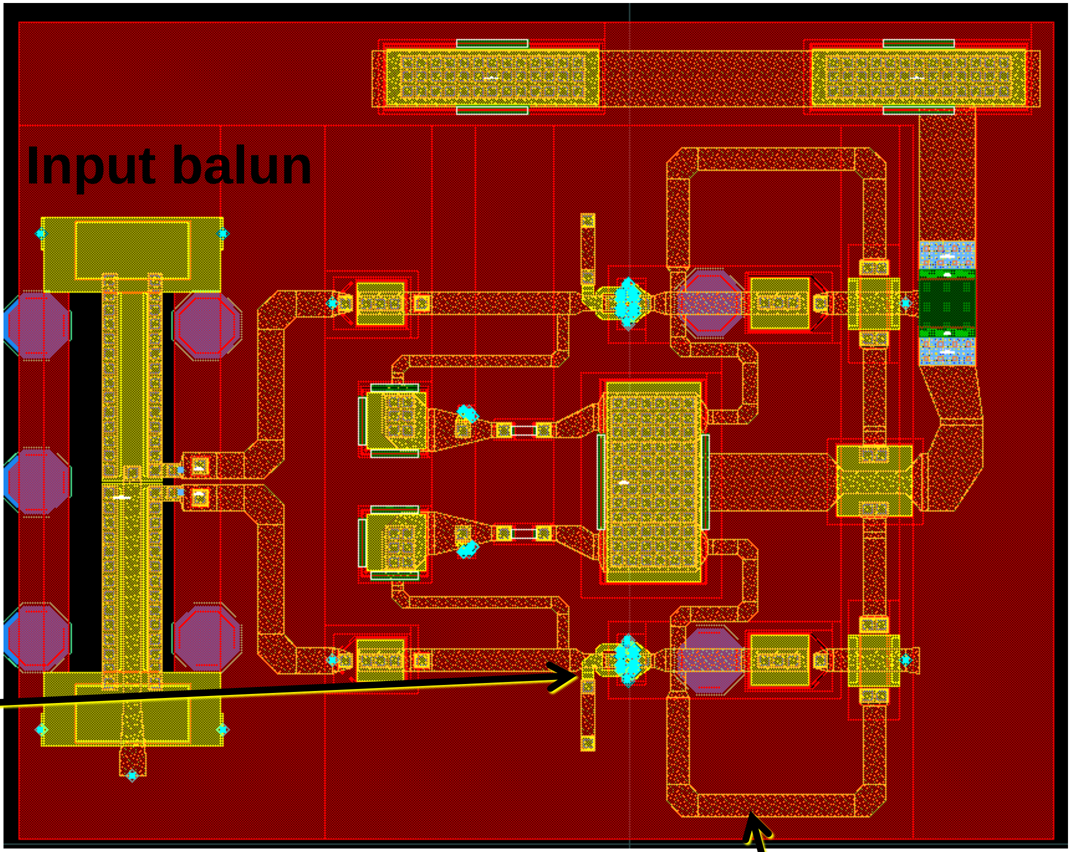
Thanks to Teledyne Scientific & Imaging for IC fabrication!

Thank you!!

Amplifier Design (Receiver)



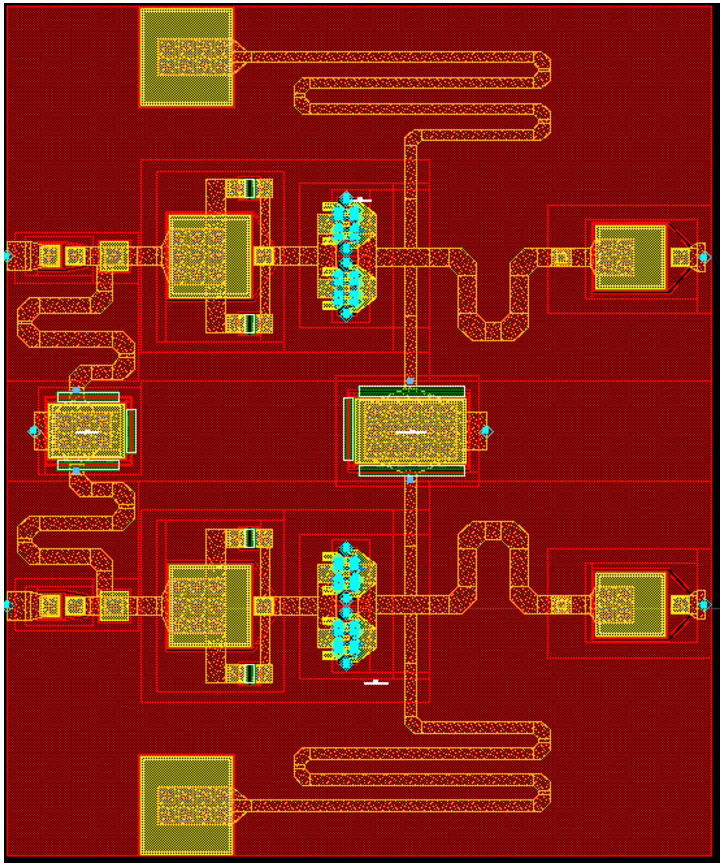
emitter inductive line



4 x 5 µm per cell

2nd harmonic short

2md generatin design



	1st design	**2nd design**
HBT Cell Size	4 X 5 µm	**8 X 5 µm**
S_{21}* (dB)	6	6.5
OIP3* (dBm)	26	31
IIP3* (dBm)	20	24
I_{DC}* (mA)	100	57
P_{DC}* (mW)	200	114
Noise Fig.* (dB)	7.3	6
Core Area (µm X µm)	414 X 502	380 X 458

(simulated)

Increased cell size + Reduced current density = Improved performance

Pseudo-Differential

Single-ended approach:

Power supply lines detune output network

Poor power supply isolation → instability, inter-stage coupling

True differential approach:

Power-supply virtual ground prevents coupling & de-tuning

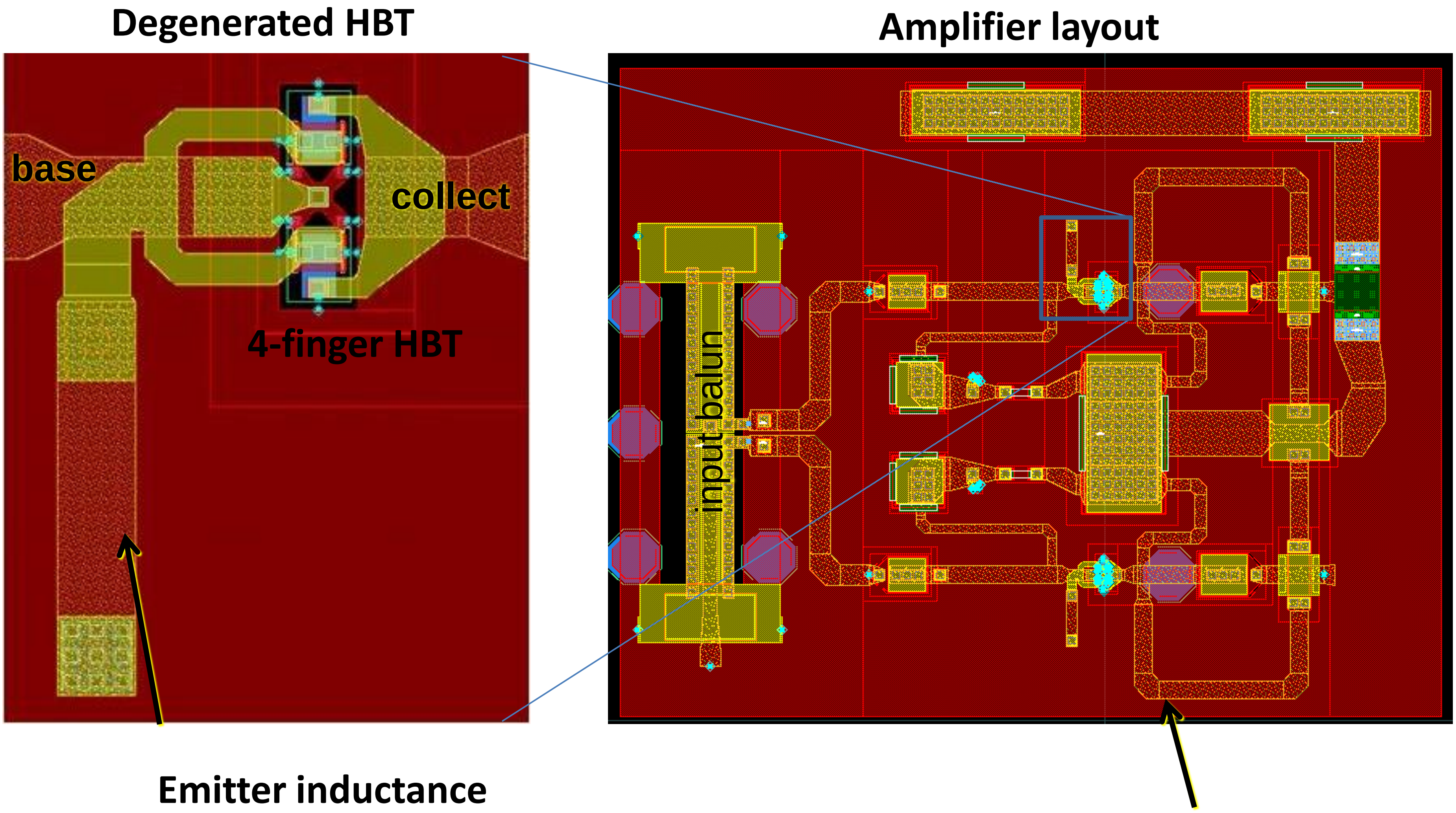
Potential for common-mode instability problems

Pseudo-differential approach:

No common-mode instability

Power-supply is virtual ground

IC layout



Emitter inductance

2nd harmonic short

2-tone W-band Measurements

On-wafer 2-tone W-band IP3 measurement testbench constructed from WR-10 waveguide components

Fundamental tone f_1 generated w/ PNA & freq. extender heads

Fundamental f_2 generated w/ synthesizer, a doubler, and a tripler

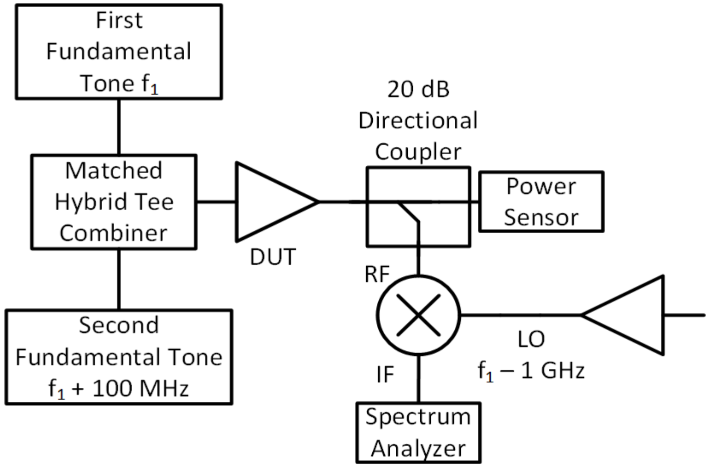
Fundamentals combined with a “magic tee” combiner

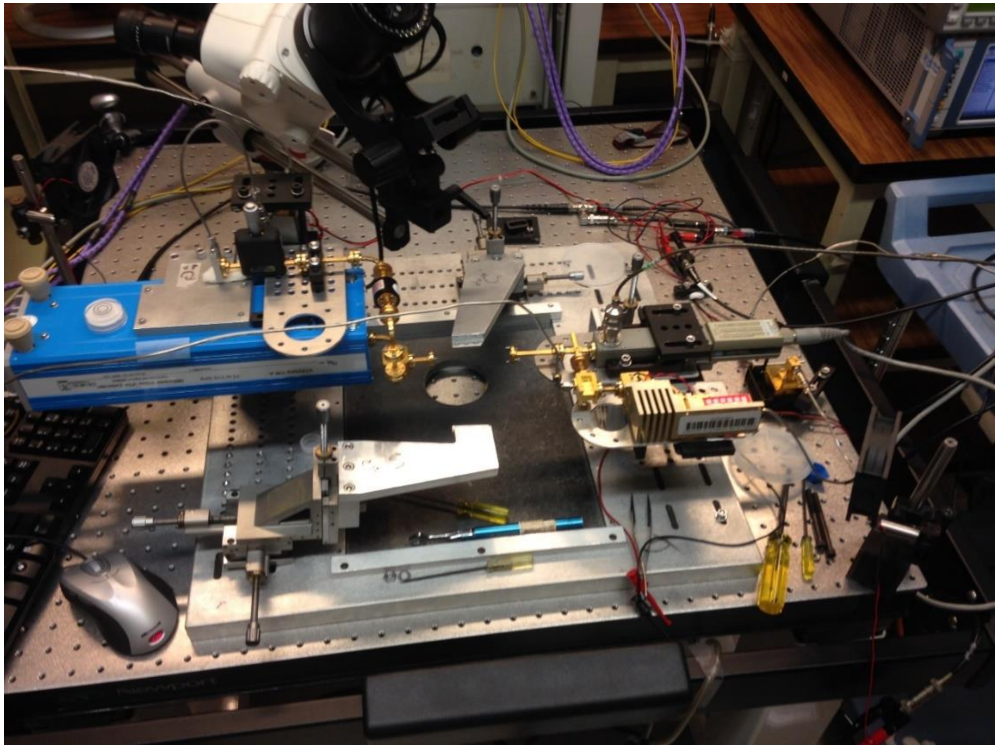
W-band output downconverted to 1 GHz IF

Fundamental output & 3rd harmonic tone observed with spectrum analyzer

2-tone W-band Measurements

2-tone IP3 Measurements





IP3 measurements performed at f_1 = 94, 96, 98, 100 GHz

f_2 kept 100 MHz above f_1

High-Linearity W-band Amplifier

100 GHz IF Amplifier in dual conversion receiver

6.4 dB gain, 15.5 dBm IIP3 (Δ 100 MHz) at 100 GHz

6.8 dB Noise Figure @ 95 GHz

OIP3/P_{DC} ratio of 0.79

Among first reported results for IP3 in W-band