Ultra Wideband Power Amplifiers in 130 nm InP HBT Technology

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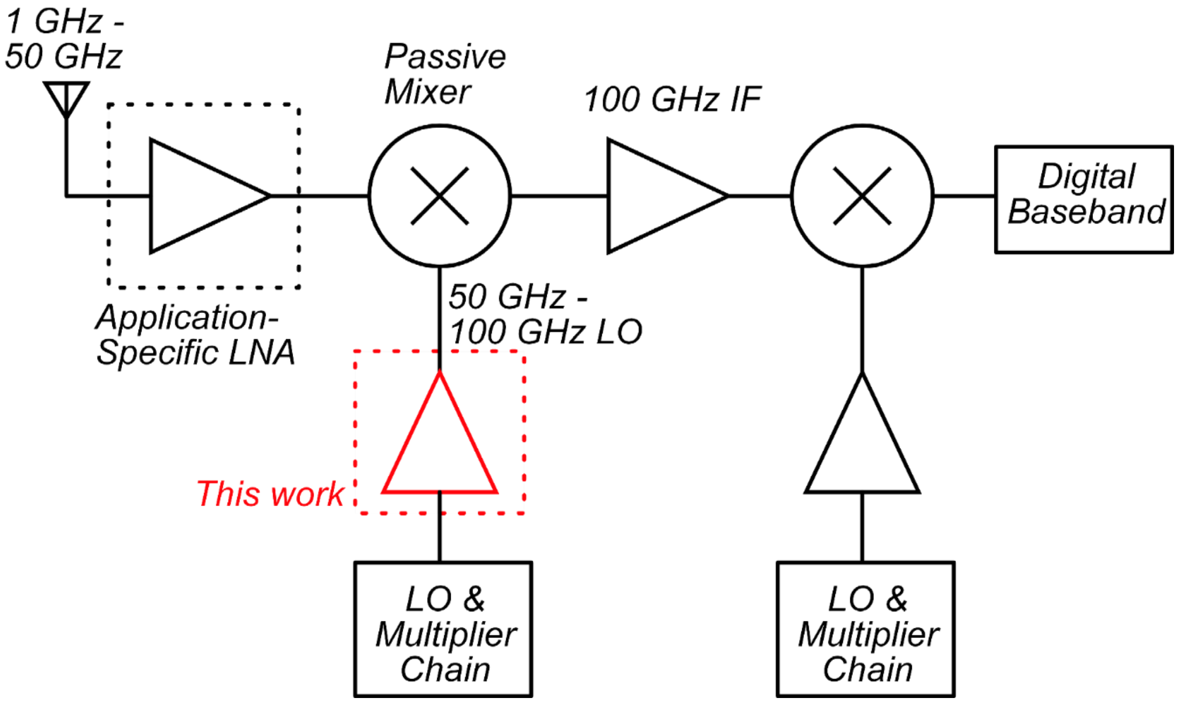
Motivation

Broadly-tunable high-dynamic-range dual conversion receiver



Passive mixer IP3 determined by LO drive power

Receiver bandwidth limited by LO driver bandwidth

Design Goals

Need to design a power amplifier with:

Wide bandwidth (~50 GHz -100 GHz)

High output power (> 21dBm)

Preferably with:

Limited size

High power efficiency

Design Strategy

How can we achieve such a large bandwidth without sacrificing performance?

2 Key Factors:

1) **1.1 THz f_{max} 130 nm InP HBT technology**[1]

Low device C_{cb} of $0.82\,\frac{fF}{\mu m(L_E)}$

Enables larger output tuning bandwidth

2) **Sub-λ/4 balun series power combining**[2]

Simultaneous output matching & power combining

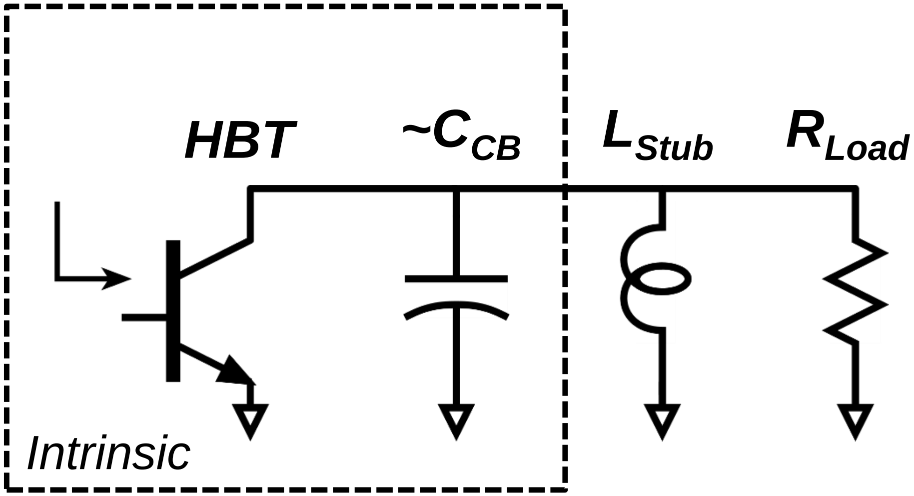
Compact, wide-band, low-loss power combining

M. Urteaga, et. al. *DRC* 2011[1], H. Park, et. al. *IEEE JSSC, 2014*[2]

TSC 130 nm InP HBTs

High speed: $1.1\ THz\ f_{max}, 520\ GHz\ f_{\tau}$

Low base-collector capacitance: $0.8\ \frac{fF}{\mu m(L_E)}$

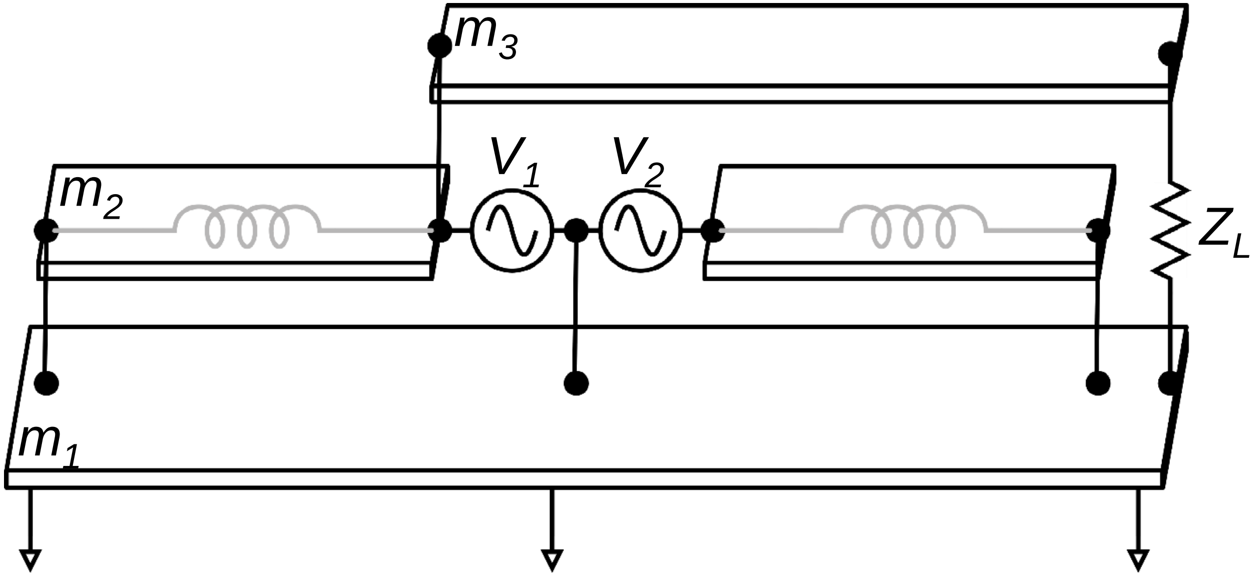


Max output tuning bandwidth:

$$\Delta f_{output} = \frac{1}{2\pi R_{Load} C_{CB}}$$

Low C_{CB} → High Δf_{output}

Sub-λ/4 Baluns



3-metal transmission line power combiner (m_1, m_2, m_3)

HBT outputs V_1 & V_2 combined on m_3

T-line between m_1 & m_2 provides shunt inductive tuning

For more info, refer to **H. Park, et. al.,** ***IEEE JSSC, 2014***

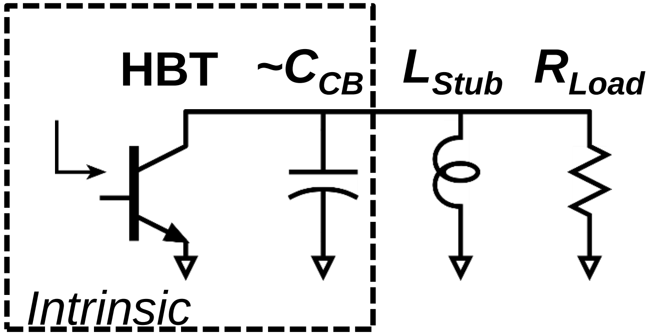
Amplifier Design

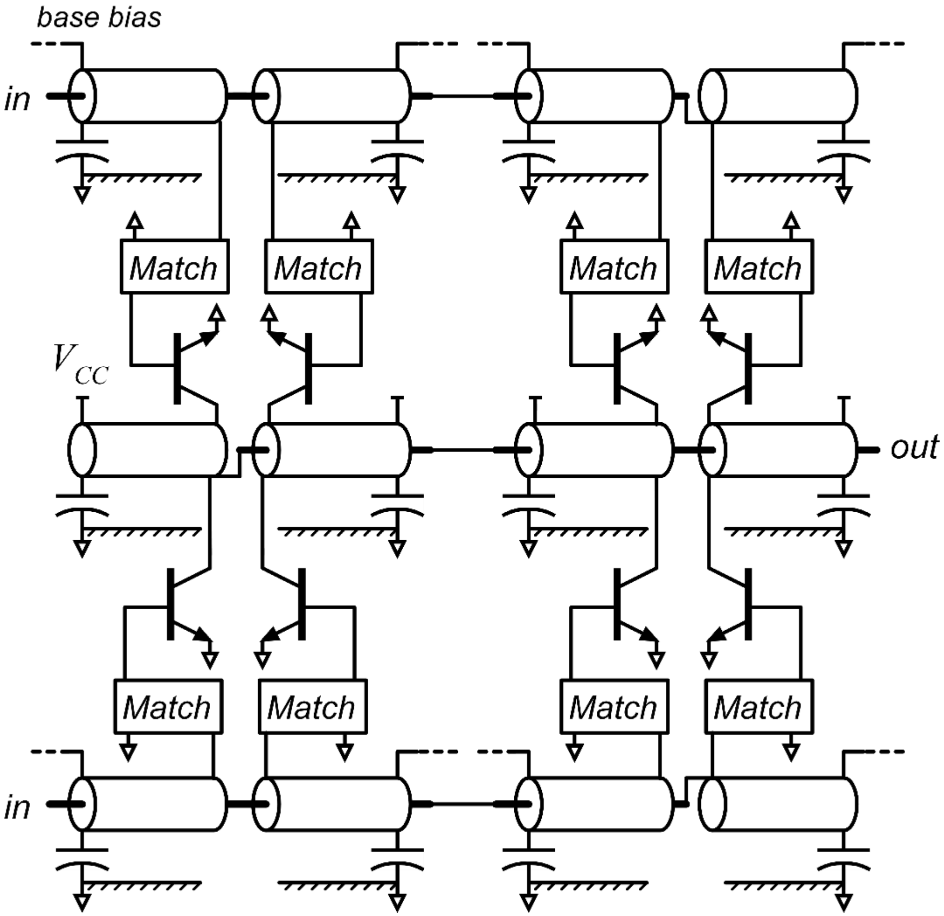
4:1 Series, 2-way parallel combining

Baluns designed to provide inductance to cancel C_{out}

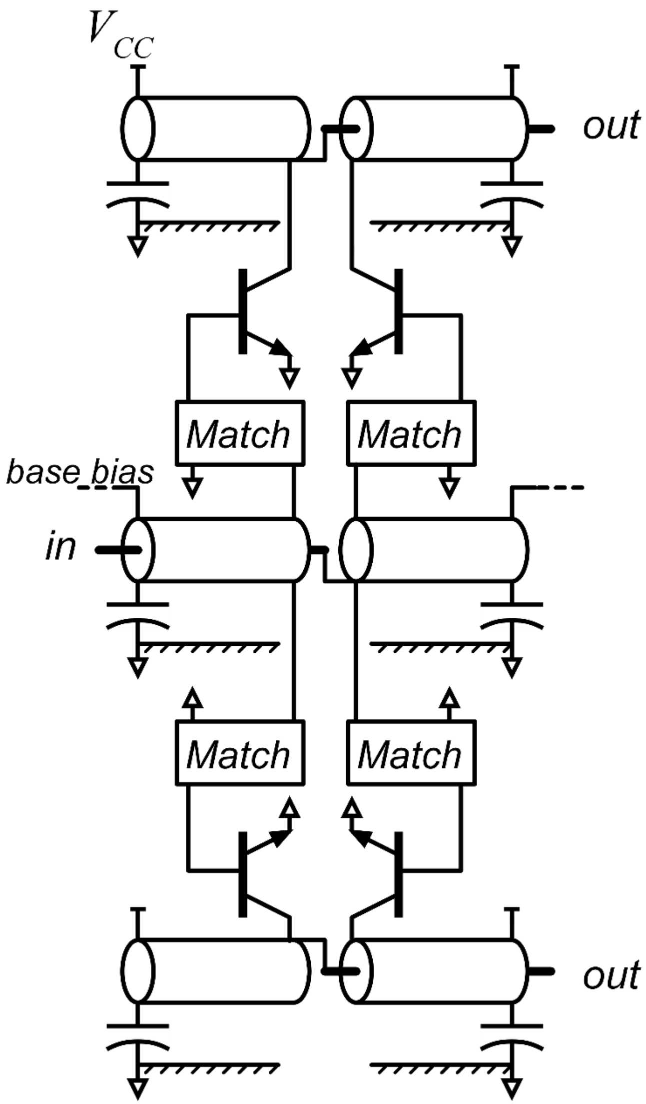
Minimum amount of tuning elements

Recall, for max tuning BW:





Pre-amplifier Stage

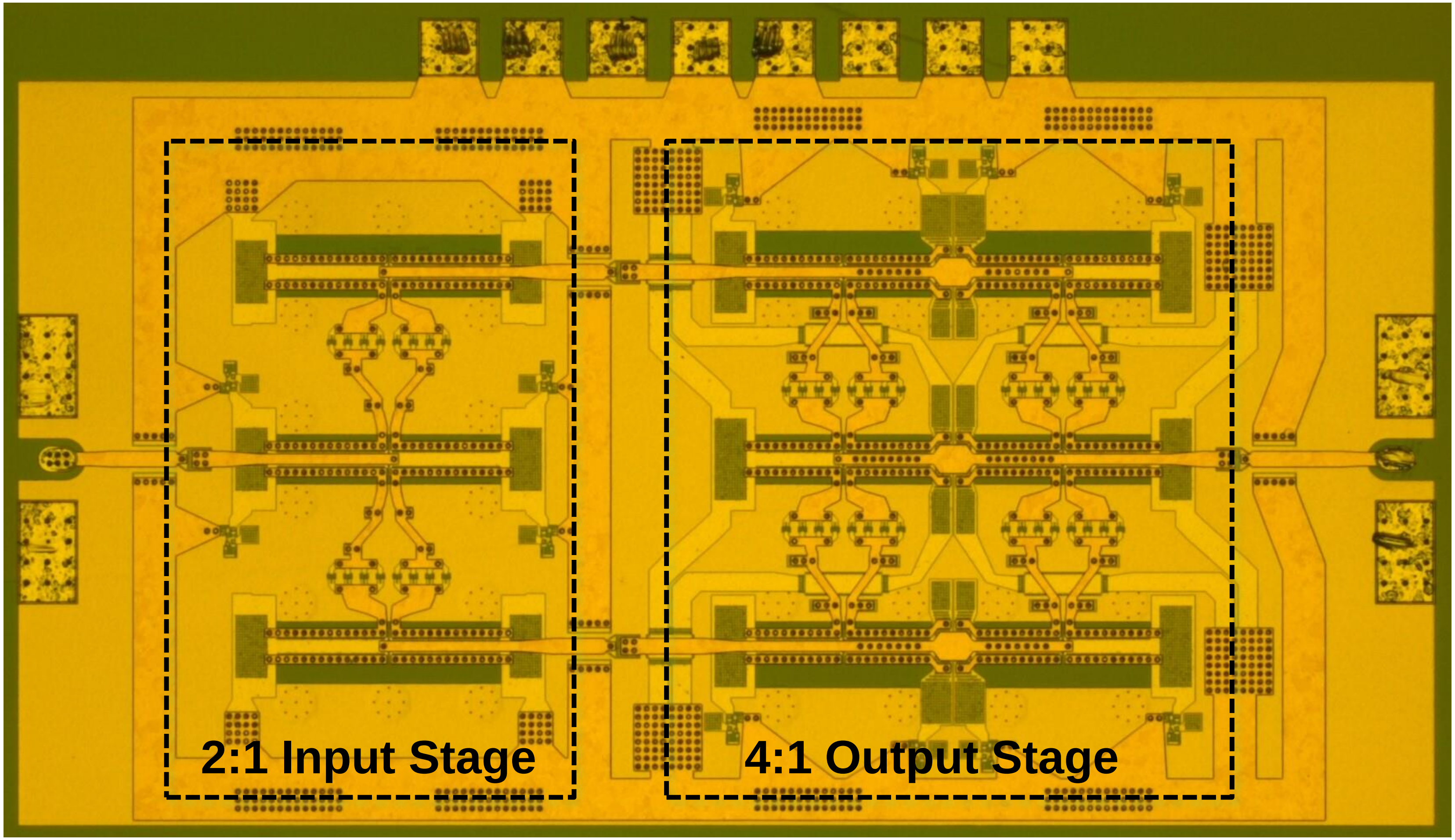


2:1 Series, 2-way parallel splitting

Designed so stage 1 outputs line up with inputs stage 2

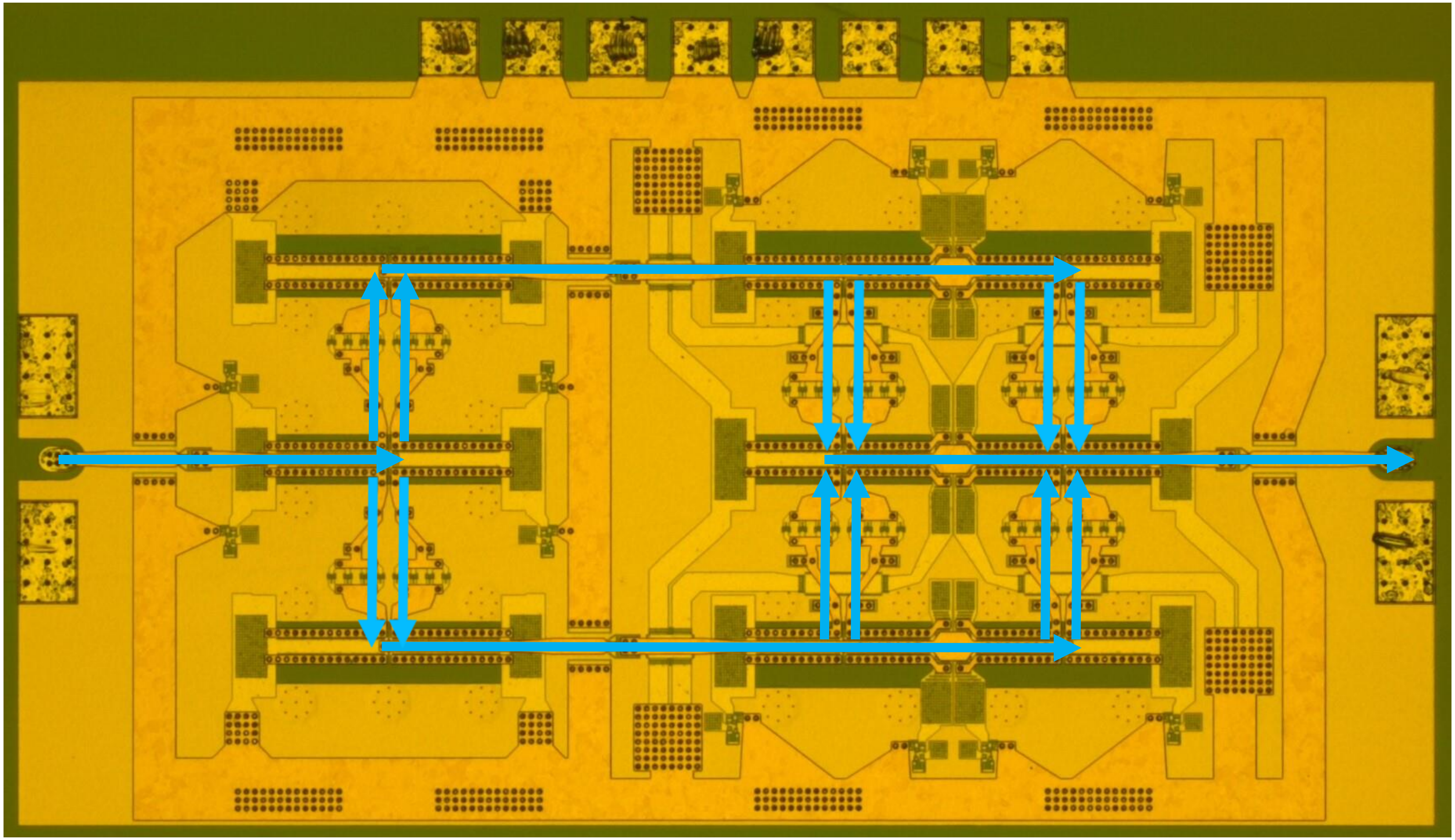
Provides additional gain & eliminates need for lossy splitter

Power Amplifier IC

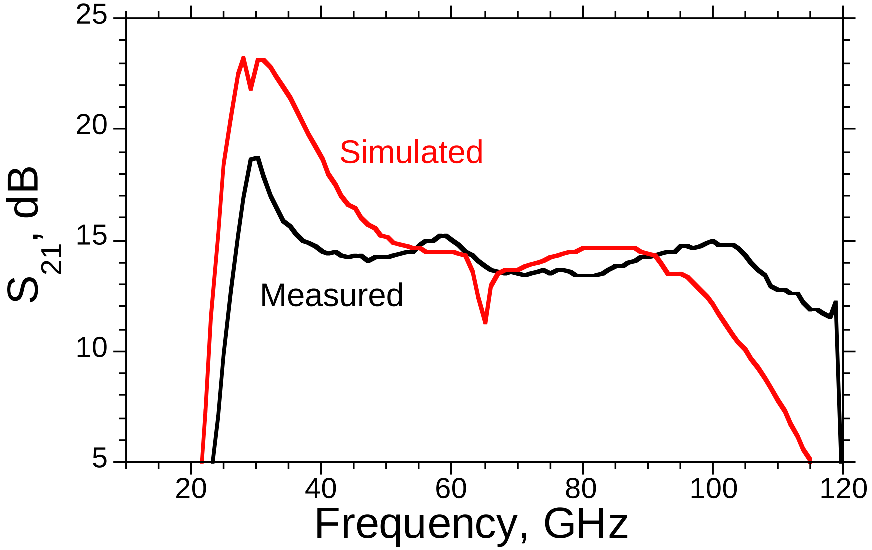


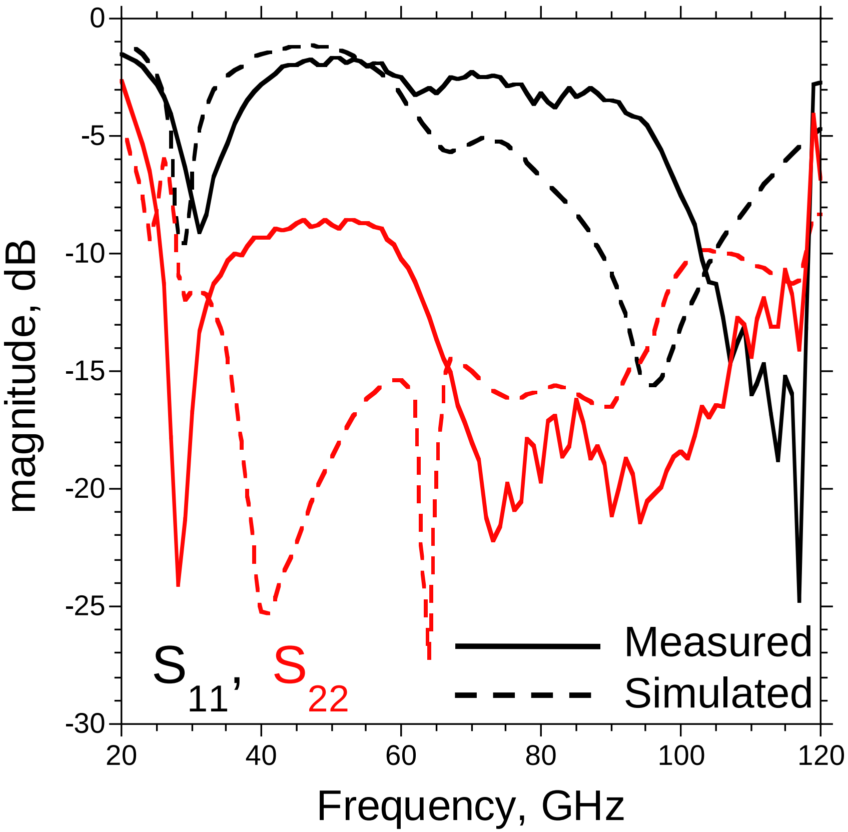
IC Area: 0.9 mm X 1.68 mm = 1.51 mm^2

Signal Path



Small Signal Bandwidth



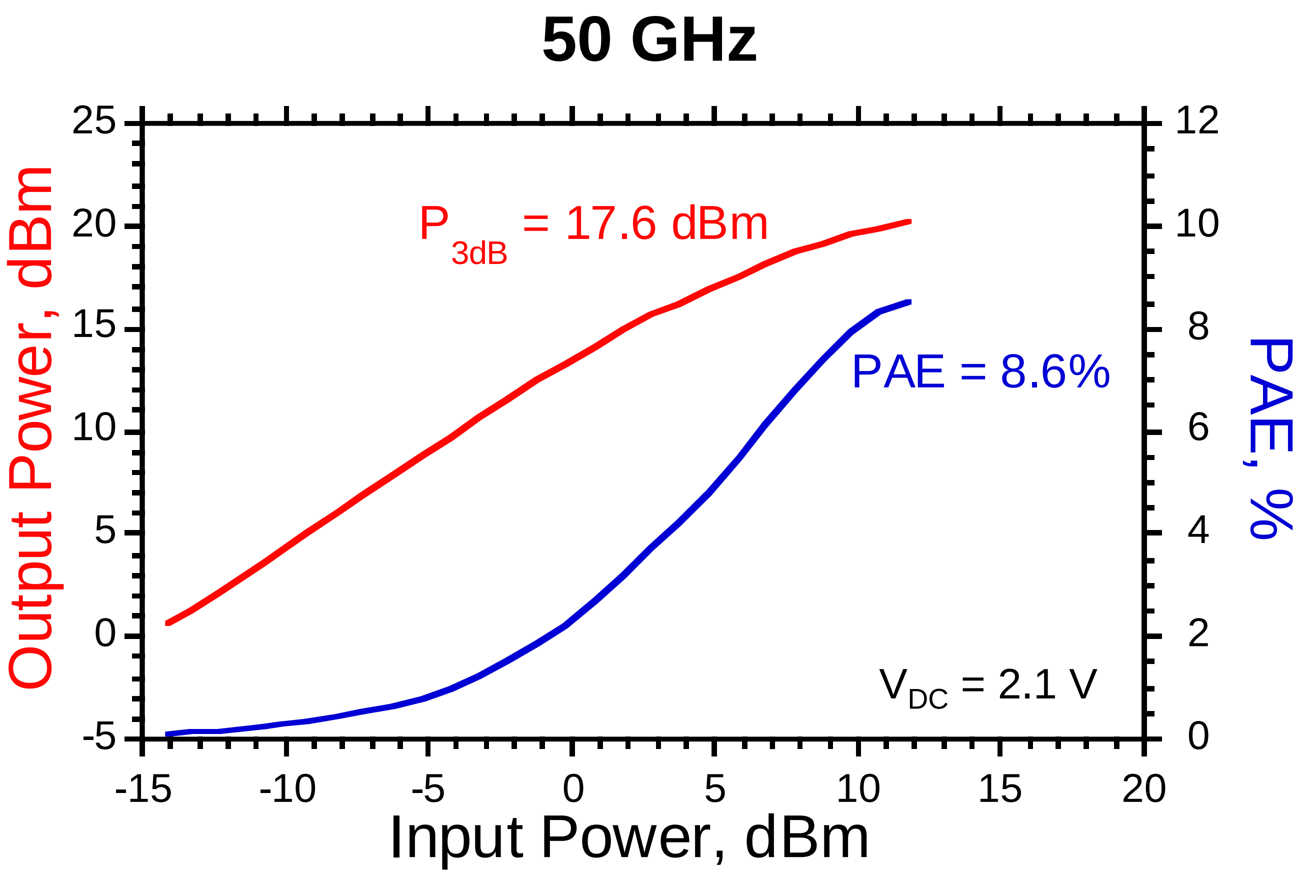


90 GHz small signal bandwidth

Broad output matching bandwidth

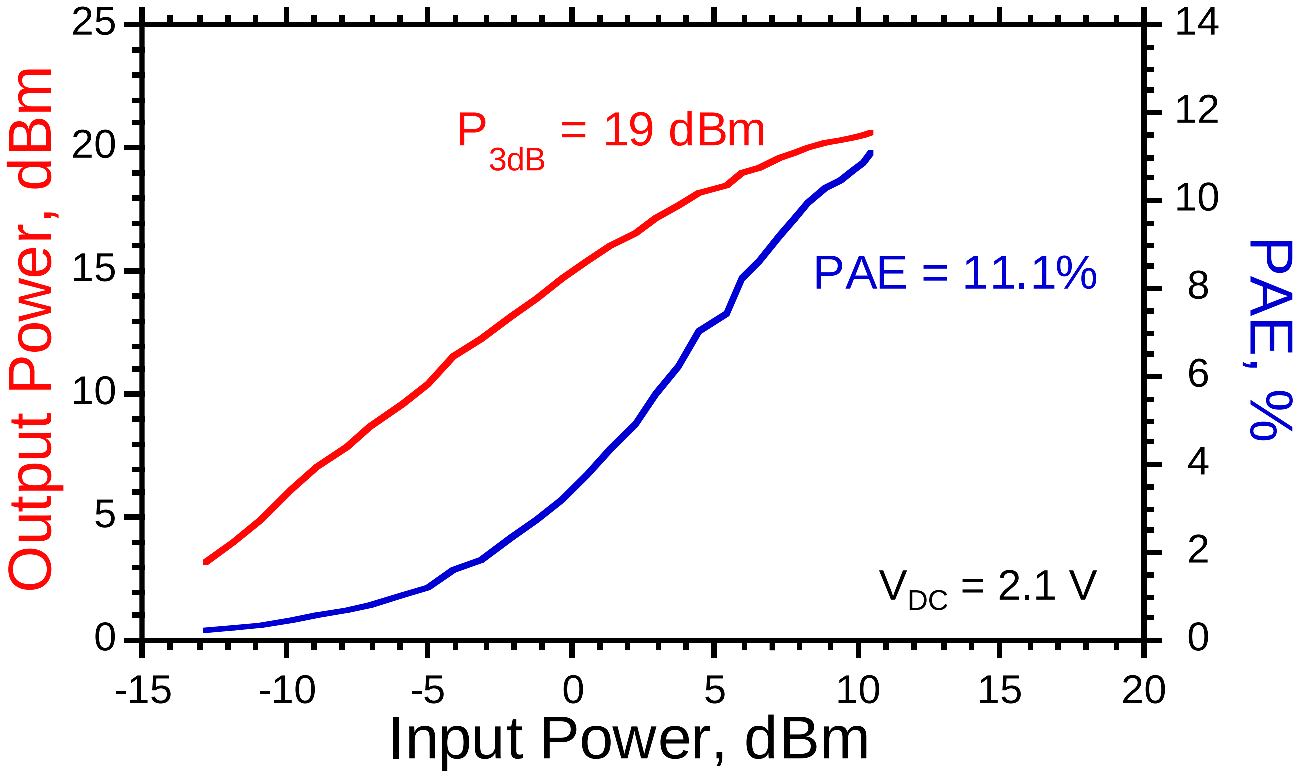
Input matched only near 100 GHz

Large Signal Bandwidth



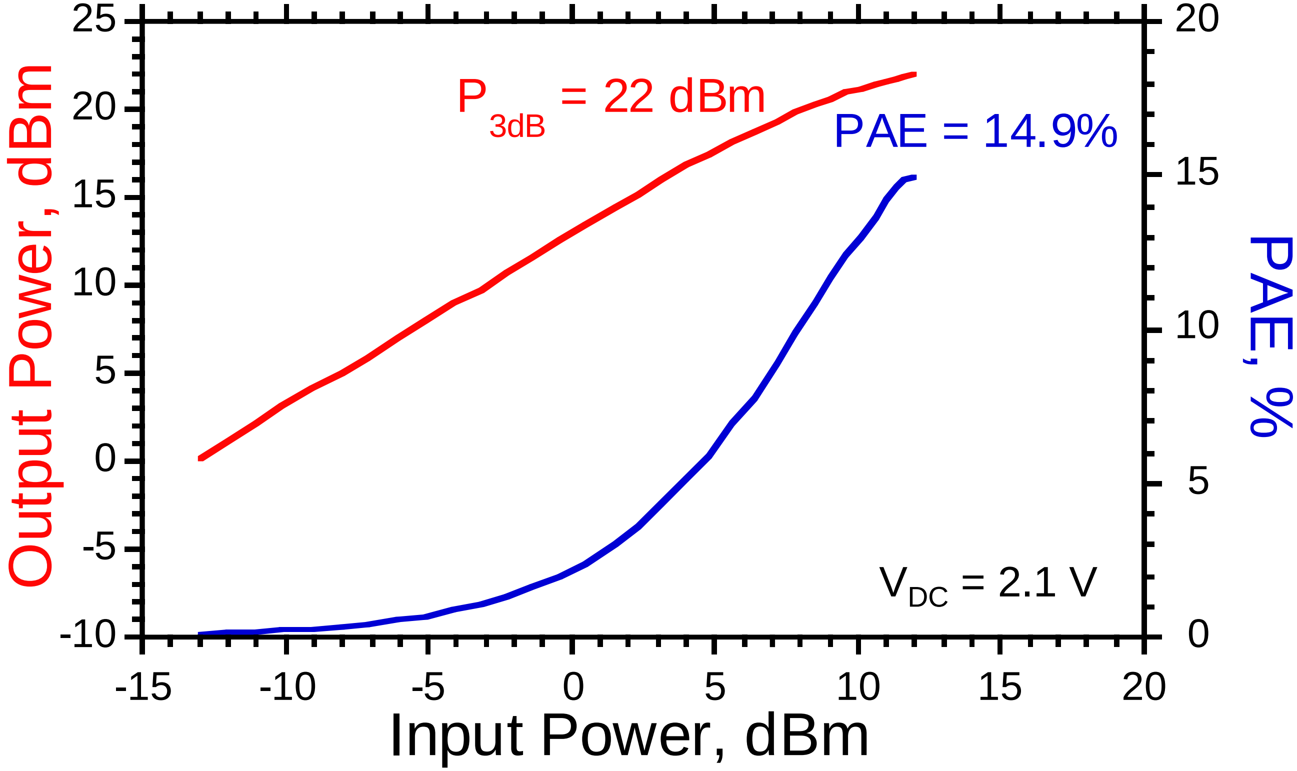
Large Signal Bandwidth

80 GHz

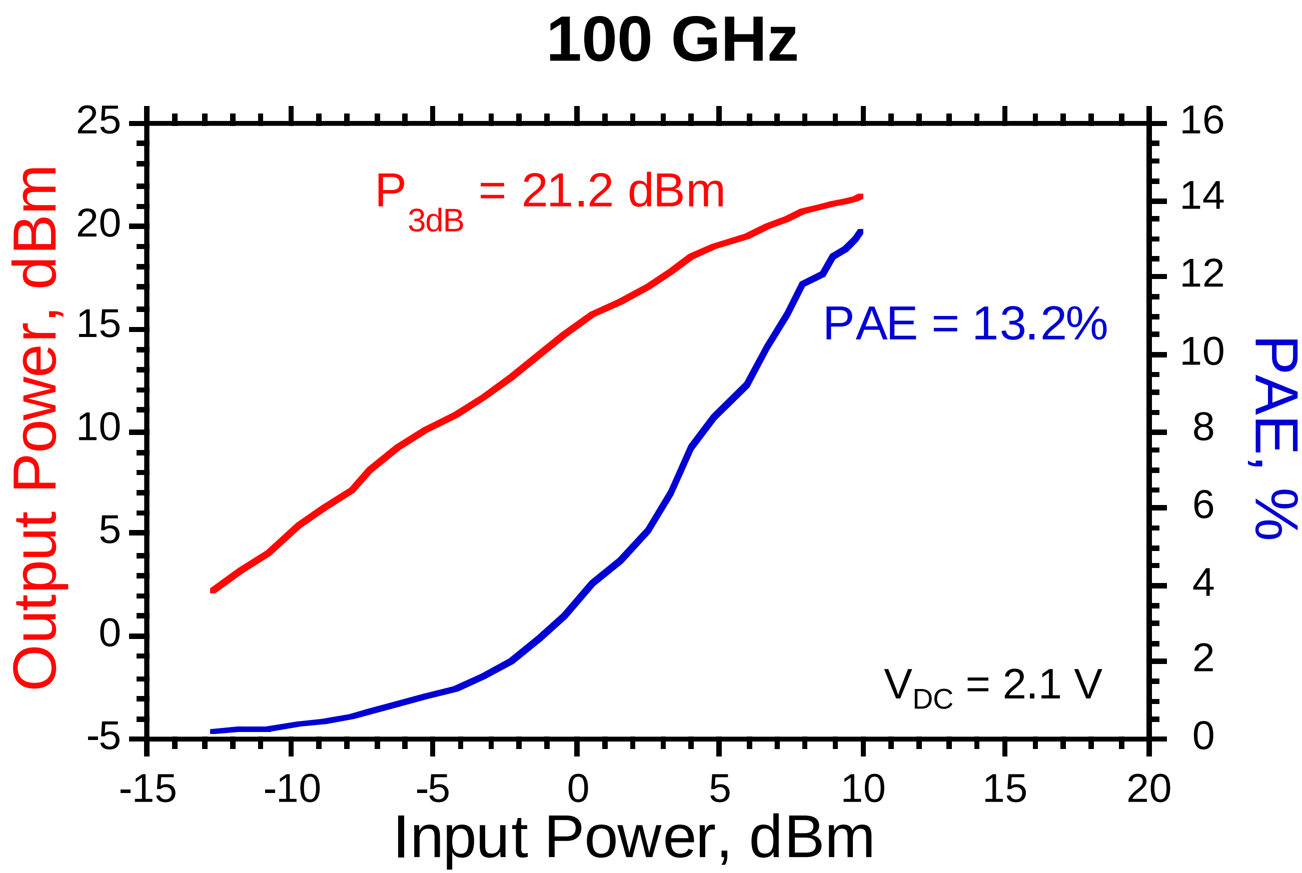


Large Signal Bandwidth

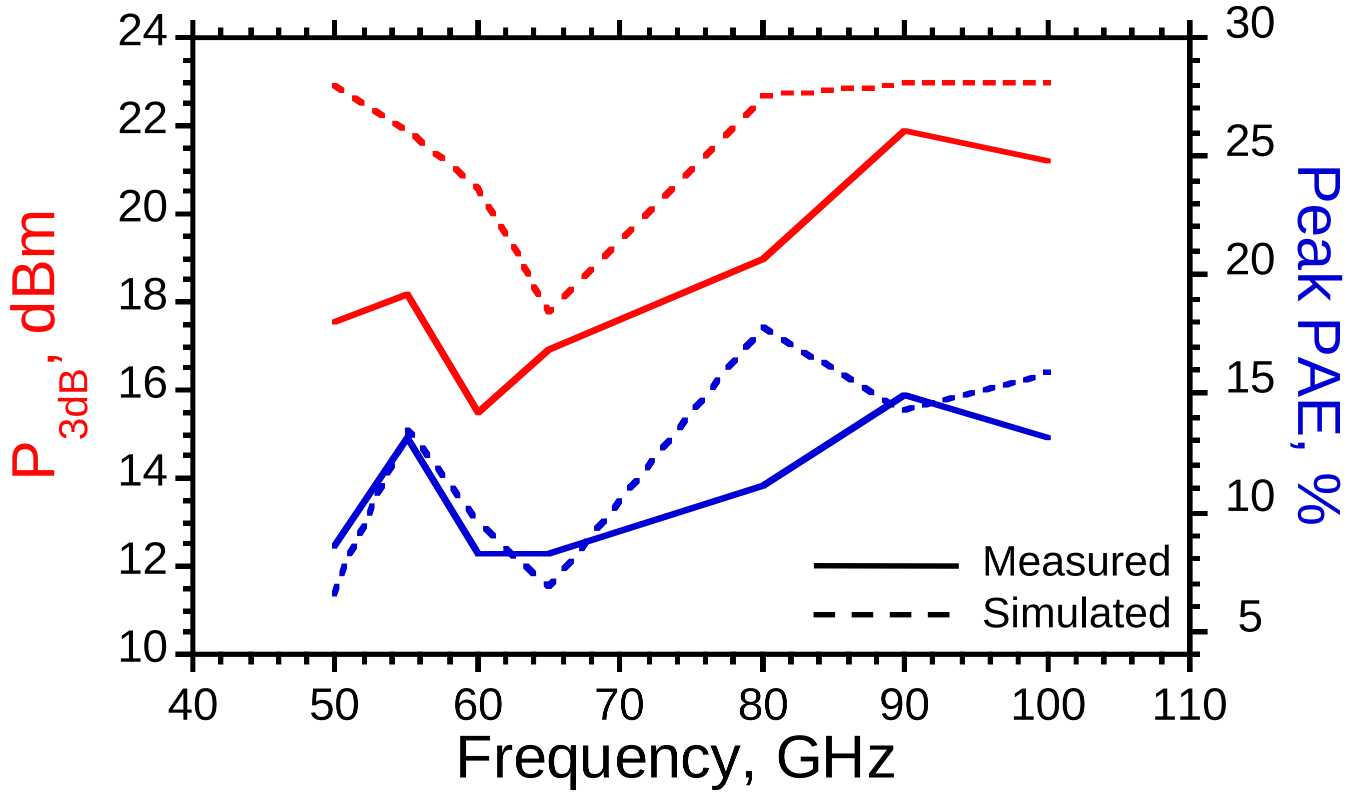
90 GHz (Peak Performance)



Large Signal Bandwidth



Large Signal Bandwidth



PAE > 8% from 50 GHz to 100 GHz

3-dB compression of output power >15.5 dBm

Comparison

Broadband / High Performance mm-Wave Power Amplifiers

Technology	Freq. (GHz)	BW_{3dB} (GHz)	Max S_{21} (dB)	P_{out} (dBm)	Peak PAE (%)	Topology	Ref
0.25 µm InP HBT	86	23	9.4	20.37	30.4	2-way Power Combining Balun	1
0.14 µm GaN HEMT	90	35	21	24.5	13.2	4-stage Balanced Amplifier	2
65 nm Si CMOS	94	33	18	12	4.5	4-way Combining 6-stage CS	3
0.15 µm GaN HEMT	91	~7	16	31.2	20	3-stage	4
130 nm InP HBT	90	**90**	15	22	14.9	2-stage 2-way power combining balun	This Work

H. Park, et. al. *CSICS* 2013[1], A. Margomenos, et. al. *EuMIC* 2012[2],
K. Wu, et. al. *Trans. THz Sci. & Tech.* 2014[3], A. Brown, et. al. *IMS* 2011[4]

Ultra-Wideband Power Amplifier

Broadband power amplifier designed as LO Driver for high dynamic range mm-wave dual conversion receiver

Uses low-C_{CB}130 nm InP HBTs and sub-λ/4 baluns

Peak PAE of 14.9%, P_{out} of 22 dBm at 90 GHz

PAE > 8% and P_{3dB} >15.5 dBm from 50-100 GHz

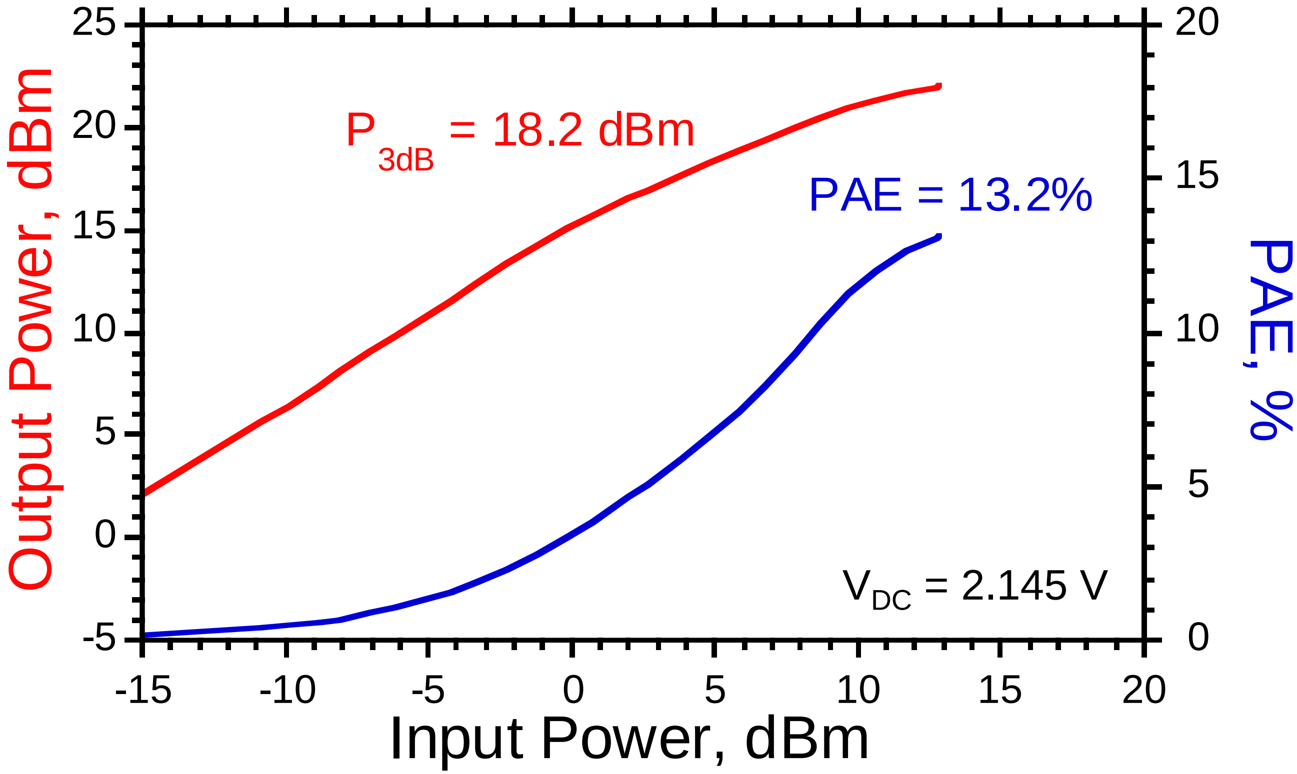
S_{21} = 15 dB, 3-dB Bandwidth from 24 GHz – 114 GHz

Thanks to Teledyne Scientific & Imaging for IC fabrication!

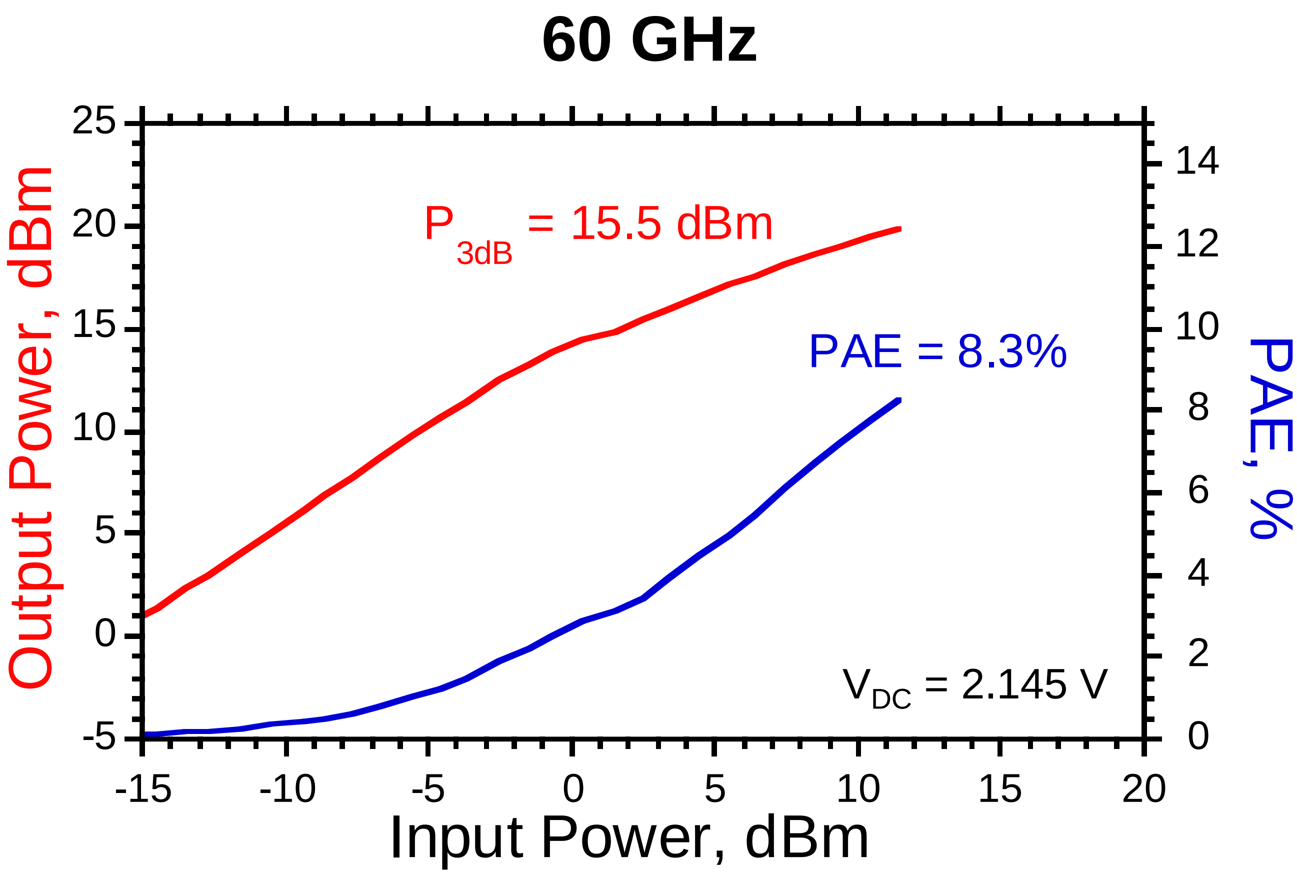
Thank you!!

Large Signal Bandwidth

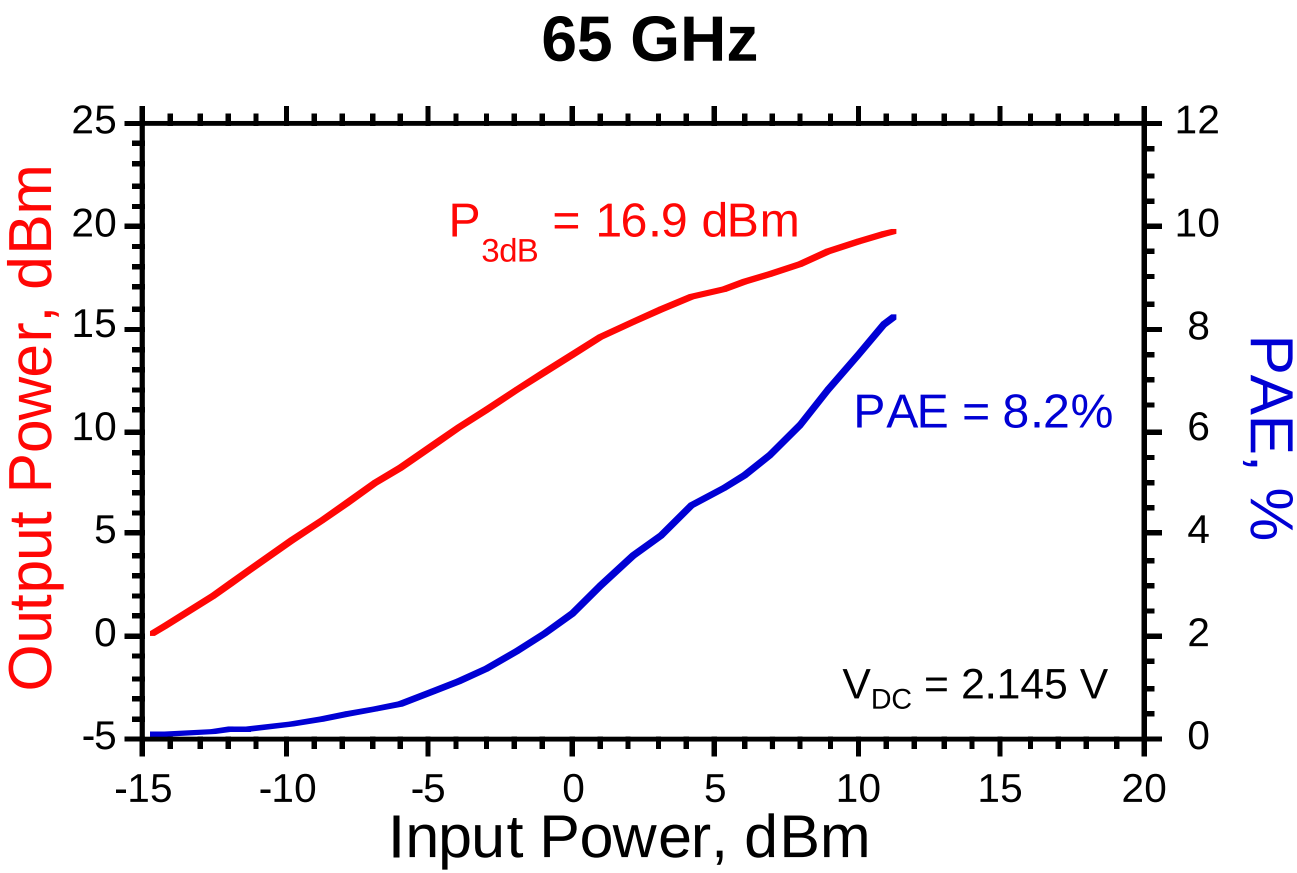
55 GHz



Large Signal Bandwidth



Large Signal Bandwidth



Ultra-Wideband Power Amplifier

Broadband Power amplifier uses 130 nm InP HBTs and sub-λ/4 baluns to achieve 50-100 GHz large sig. bandwidth

Peak PAE of 14.9%, P_{out} of 22 dBm at 90 GHz

PAE > 8% and P_{3dB} >15.5 dBm from 50-100 GHz

S_{21} = 15 dB, 3-dB Bandwidth from 24 GHz – 114 GHz

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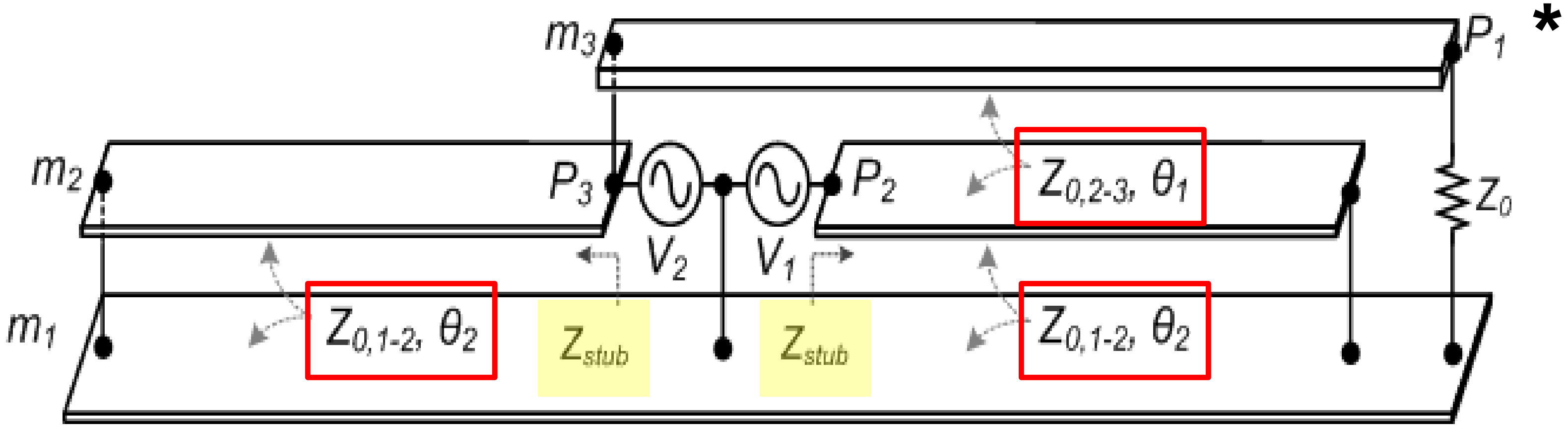
Sub-λ/4 Baluns



$$Z_{stub} = jZ_{0,1-2} \tan\theta_2$$

Inductive if $\theta_2 \ll \lambda/4$!!

Series combining of differential signals V_1 & V_2

θ_2 tailored to tune transistor C_{out}!!

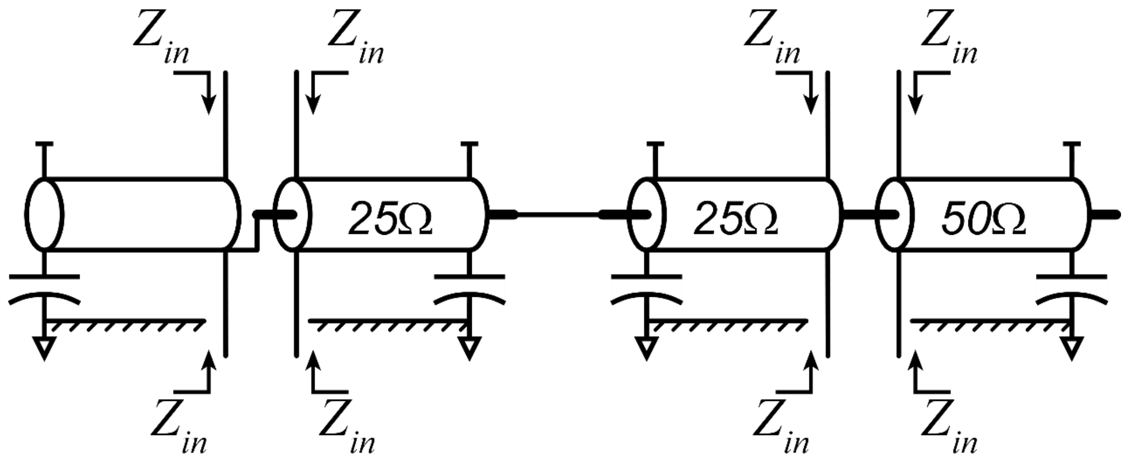
Compact, low-loss power combiners

*H. Park, et. al., *IEEE JSSC, 2014*

Amplifier Design

4:1, 2-way power combining (4 series, 2 parallel)

$Z_{in} = (25 + jX)\ \Omega$



$$J = 2\frac{mA}{\mu m(L_E)} \quad 25\Omega = \frac{(V_{max} - V_{min})}{I_{max}}$$

Determine Power cell size

Amplifier Design

Create Power Cell & Determine C_{out}

Design 2-way 4:1 output Balun such that $Z_{stub} = \frac{j}{\omega C_{out}}$

Create symmetrical Input balun, measure port Z_{in}

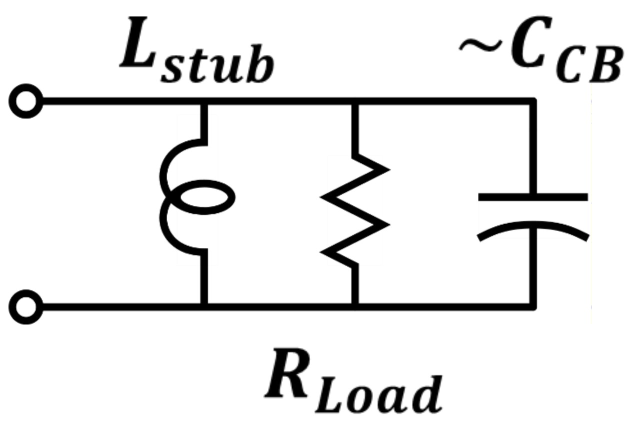
DC couple baluns to PA cell (Minimum output matching)

Design Input Match

TSC 130 nm InP HBTs

High Switching speed: $1.15\ THz\ f_{max}$, $521\ GHz\ f_{\tau}$

Low Base-Collector Capacitance: $0.82\ fF/\mu m(L_E)$
→ **High Bandwidth!**



Max output tuning bandwidth:

$$\Delta f_{output} = 1/2\pi(R_{Load})C_{CB}$$

$$R_{Load} = \frac{(V_{max} - V_{min})}{I_{max}}$$

Design Strategy

How can we achieve such a large bandwidth?

2 Key Factors:

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- Simultaneous Output match & Power combining
- Compact, Wide-band, Low-loss power combining