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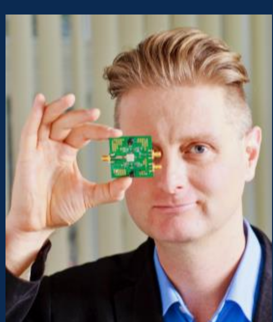
DAAB-Tx

On-Chip Integrated **D**istributed **A**mplifier and **A**ntenna Systems in SiGe BiCMOS for Ultra-Large-**B**andwidth **T**ransmitters

Prof. Dirk Plettemeier

TU Dresden

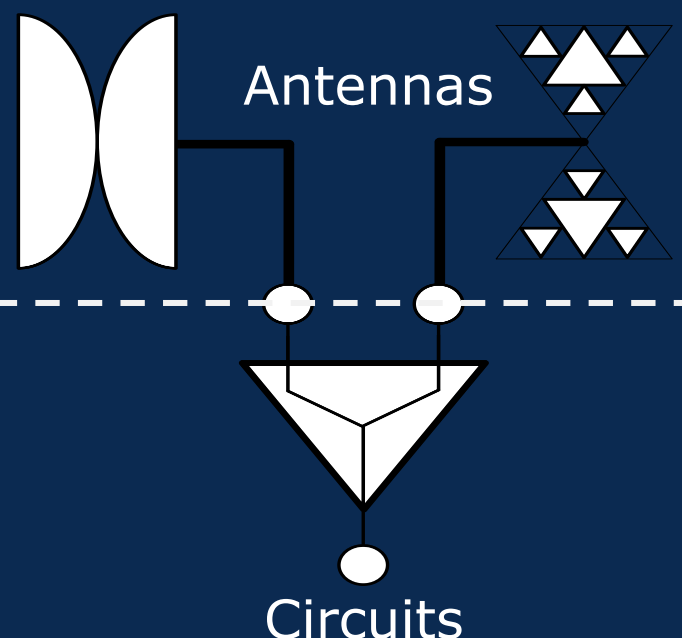
Chair for RF Engineering



Prof. Frank Ellinger

TU Dresden

Chair for Circuit Design & Network Theory

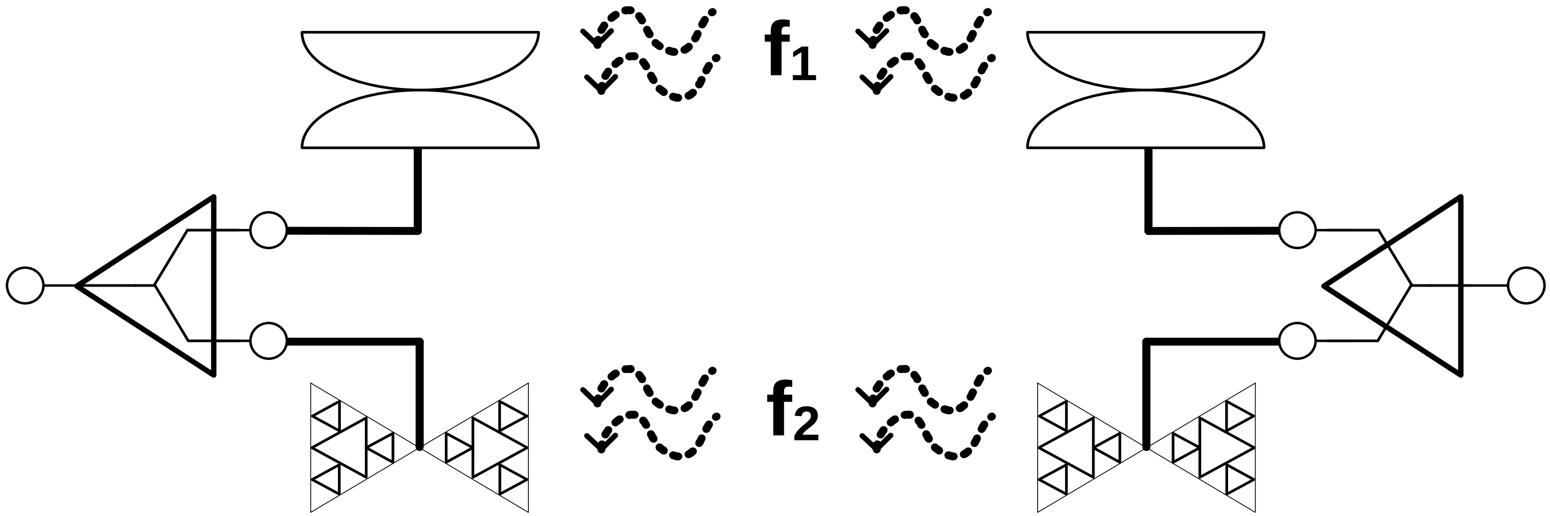


Major Goal

Integrated Antenna & Amplifier

Transceiver Frontend in SiGe

with 100 GHz BW to enable 100 Gb/s & beyond



Compared to SoA: **BW** improved by factor **5**

Traveling Wave Impedance Matching Approach to Achieve Maximum Bandwidth

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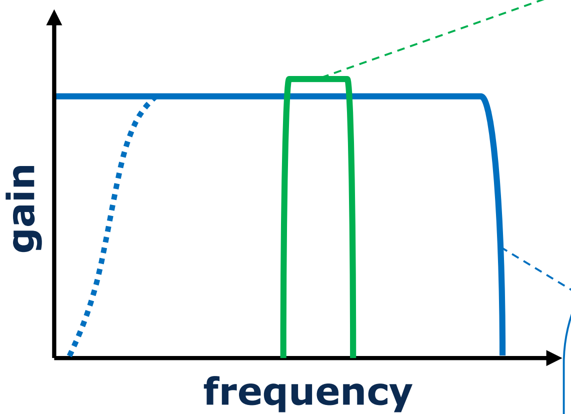
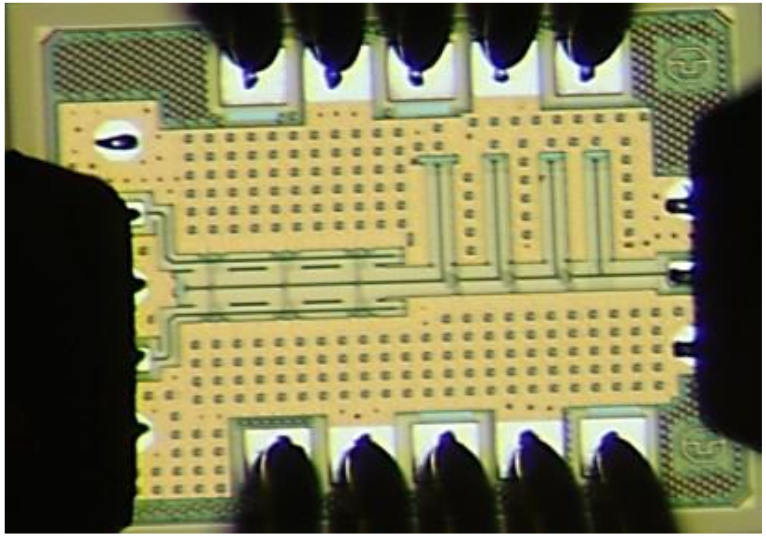


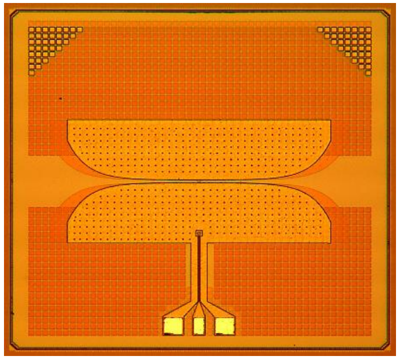
Conventional approach

Resonate capacitances with inductors

⇒ Low bandwidth



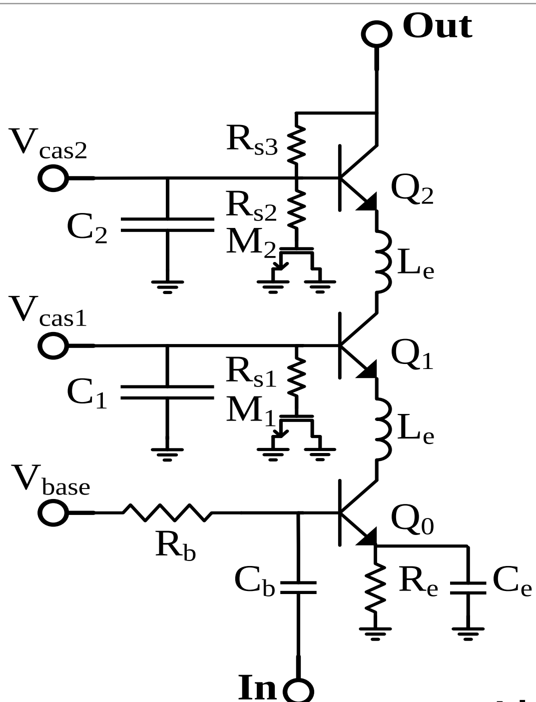
P. Testa, „220 GHz Wideband Distributed Active Power Combiner“

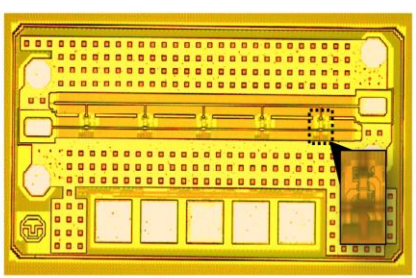


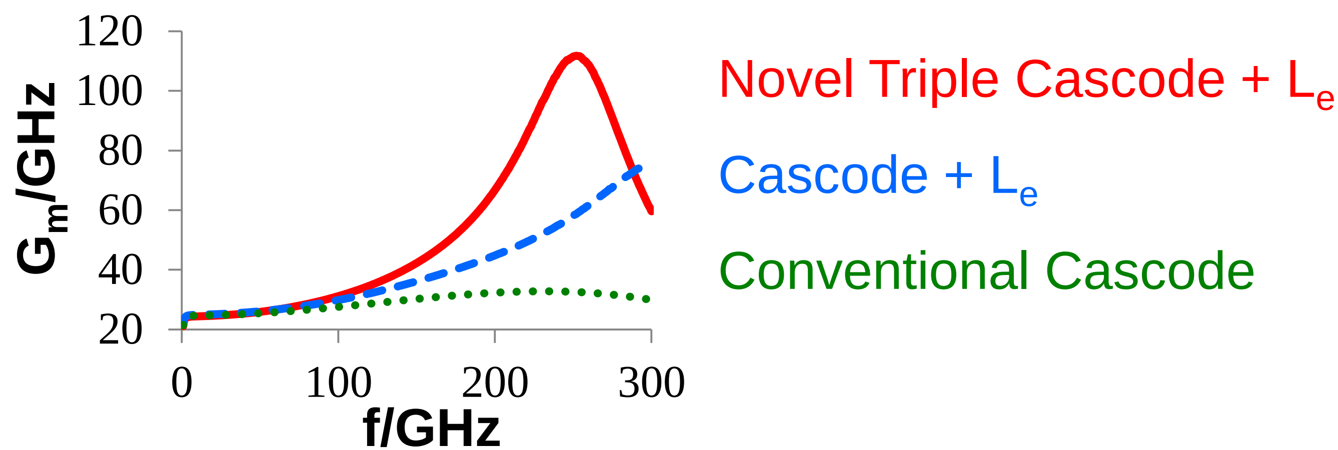
R. Hahnel, „Integrated stacked Vivaldi-shaped on-chip antenna for 180 GHz“

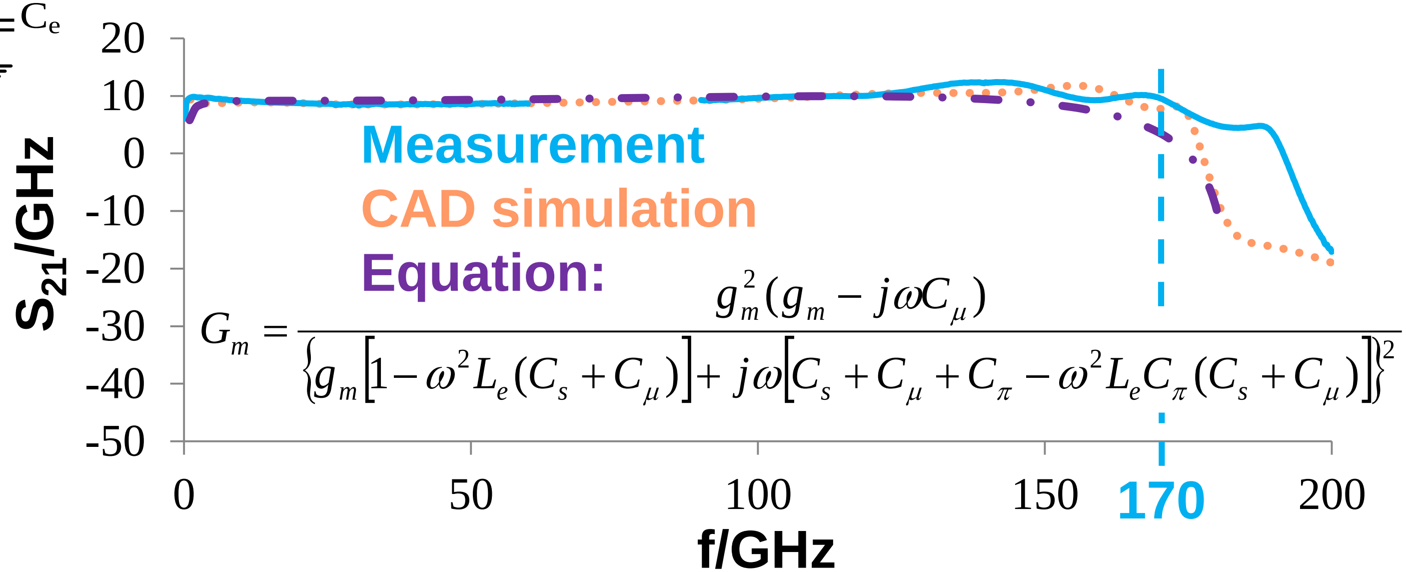
Amplifier concepts

Novel Triple Cascode Amplifier Cells for DC - 170 GHz TWA







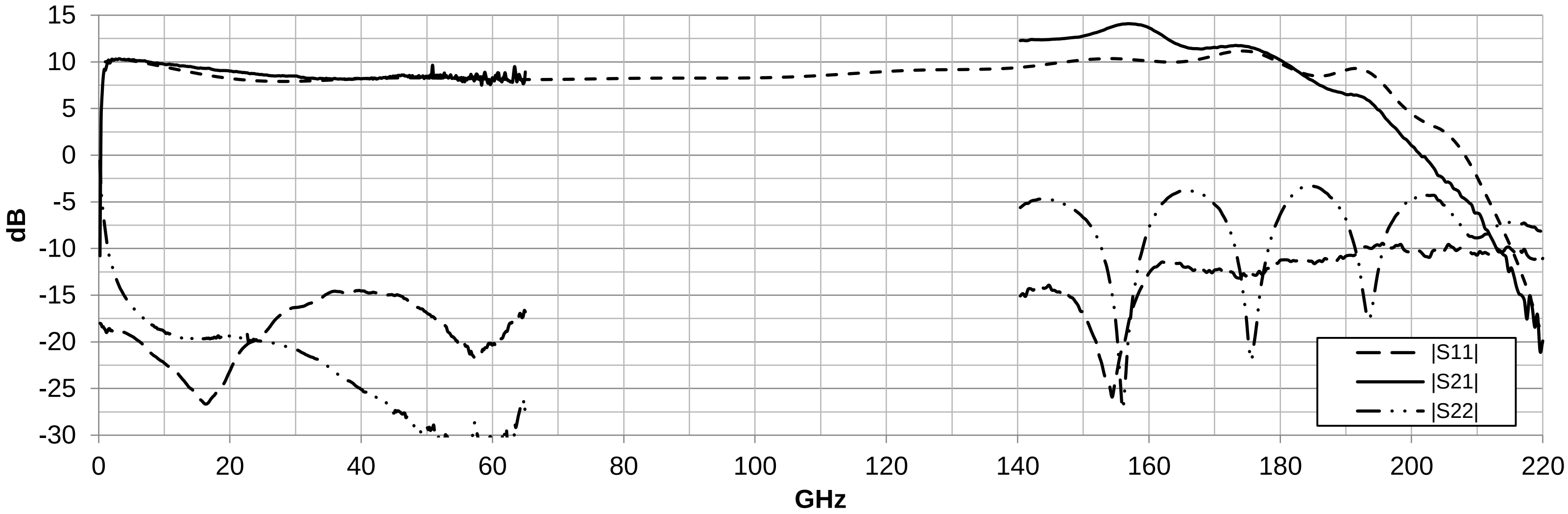


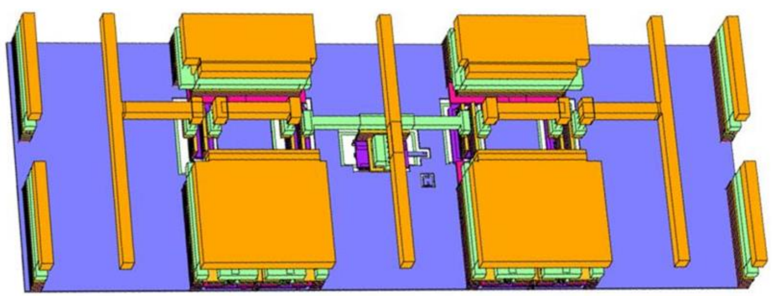
$$G_m = \frac{g_m^2(g_m - j\omega C_\mu)}{\left\{g_m\left[1-\omega^2 L_e(C_s + C_\mu)\right] + j\omega\left[C_s + C_\mu + C_\pi - \omega^2 L_e C_\pi (C_s + C_\mu)\right]\right\}^2}$$

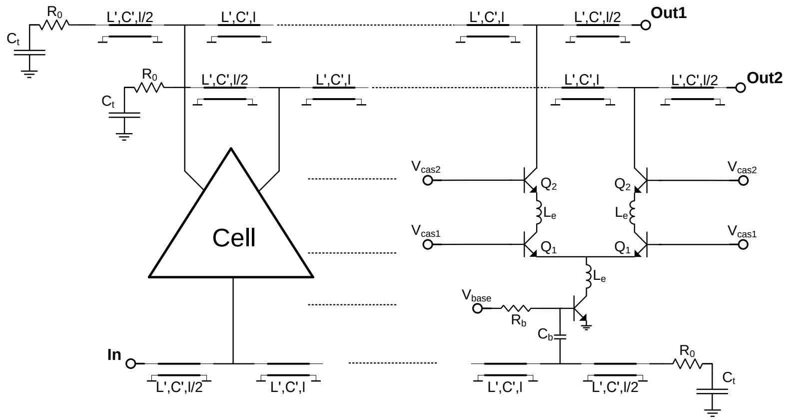
Testa, …Ellinger, 170 GHz SiGe Loss-Compensated Distributed Amplifier, **IEEE JSSC**, Oct. 2015

Novel triple cascode

Triple cascode to boost Gm and compensate the input line losses: 4 times faster than SOA

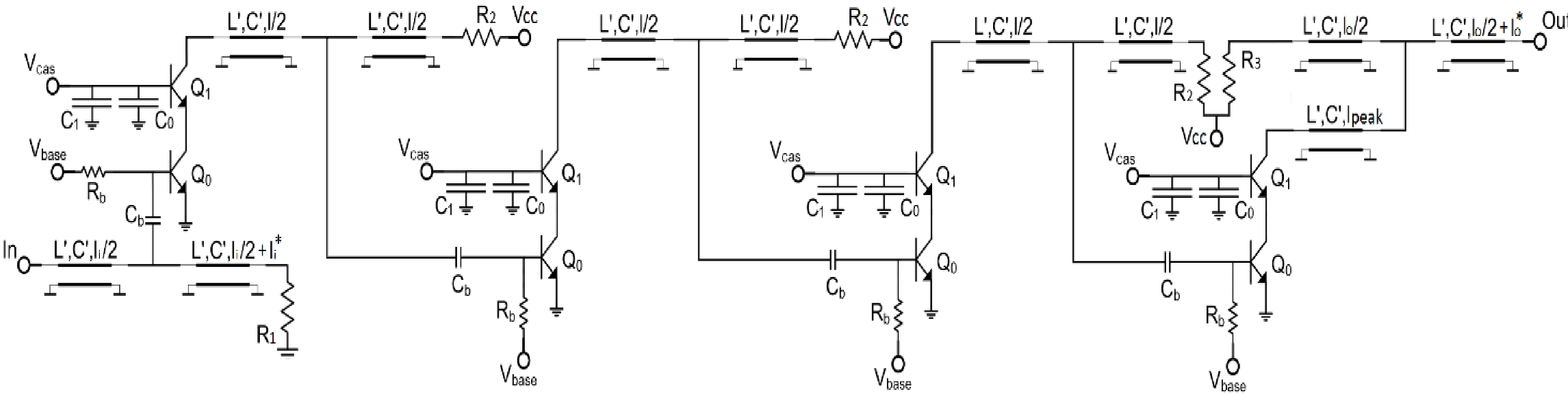


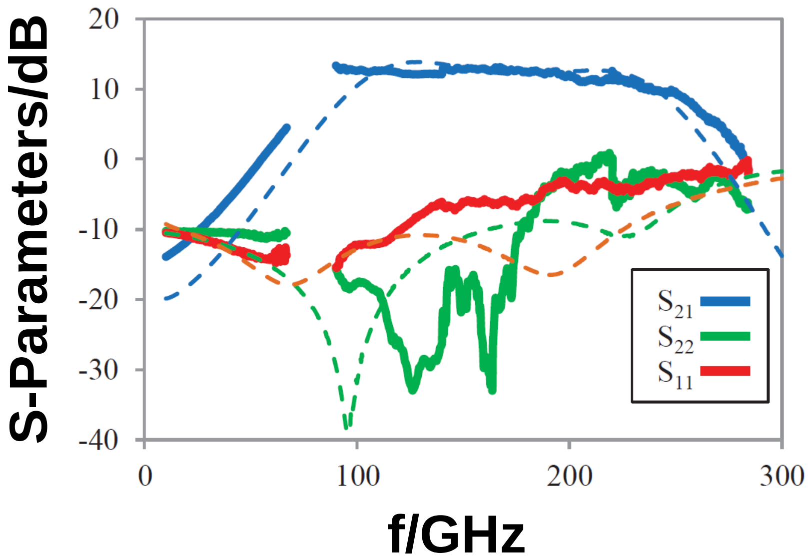


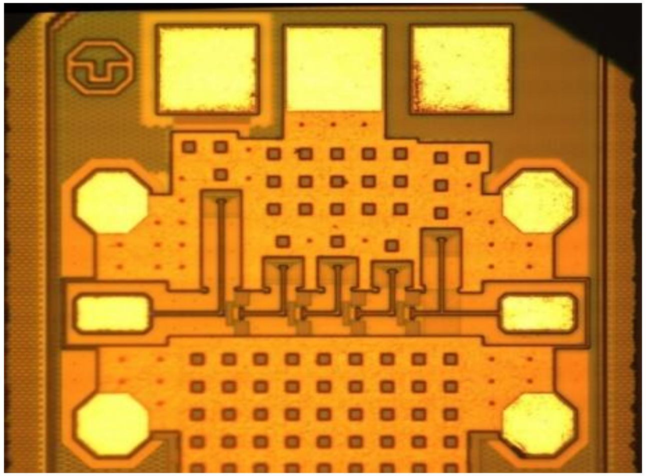


APMC ‘17

Cascaded Single-Stage TWA at 60 - 250 GHz in BiCMOS







Testa, …Ellinger, 250 GHz SiGe Cascaded Single Stage Distributed Amplifier, **IEEE CSICS**, 2015

Comparison with State of the Art Broadband Amplifiers in Silicon

FoM	3 dB BW/ GHz	Gain/ dB	GBP/ GHz	Area/ mm^2	P_{DC}/ mW	Tech	Ref.
3.6	0-70	13	312	1.7	120	90 nm CMOS	Chen EuMIC13
9.3	15-110	24	1500	0.7	247	0.13 µm SiGe	Niknejad RFIC12
13.8	**0-170**	**10**	**537**	**0.4**	**108**	**0.13 µm SiGe**	**DAAB**
46	**60-250**	**13**	**759**	**0.2**	**74**		

→ **5×** FoM = Gain × BW /(Area × P_{dc})

Layout for mmWave Common-Base Amplifiers

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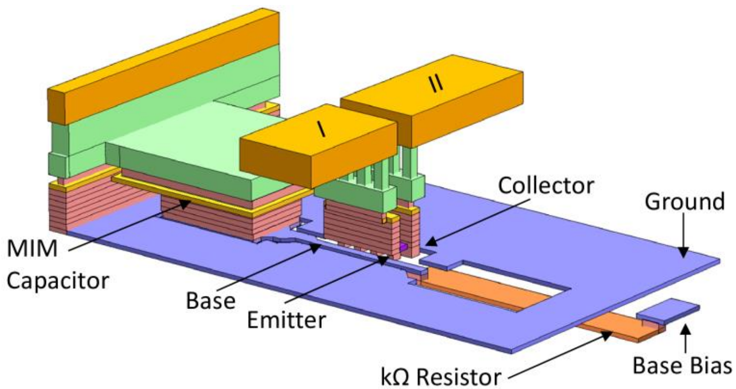

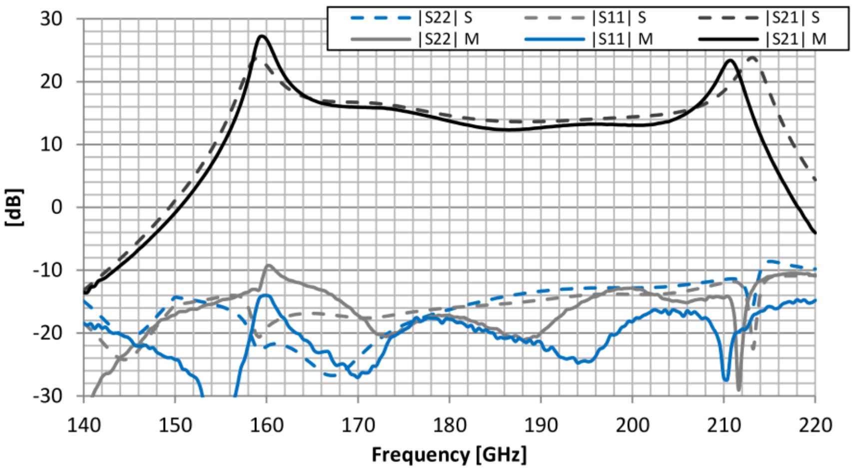

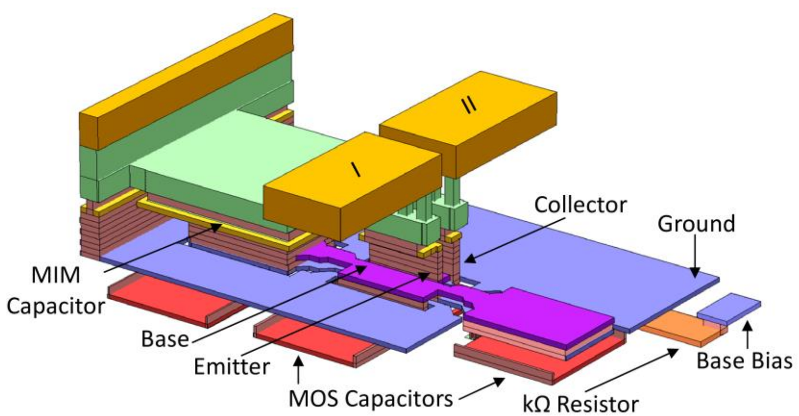

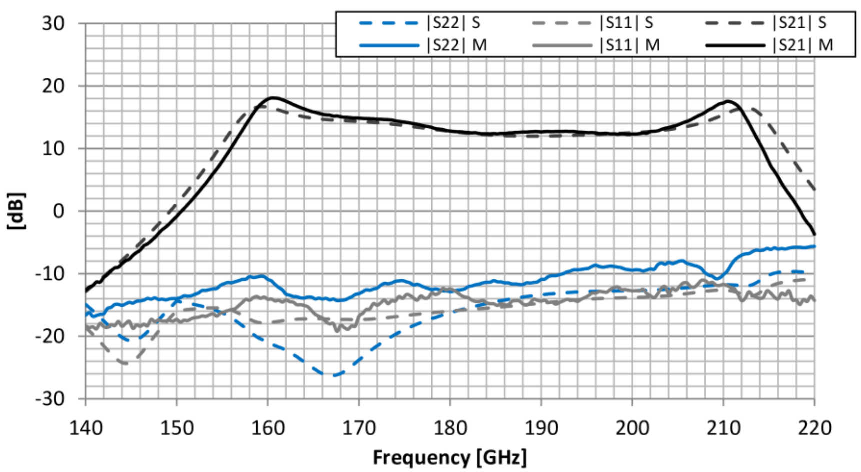

PRIME ‘17

Distributed Power Divider

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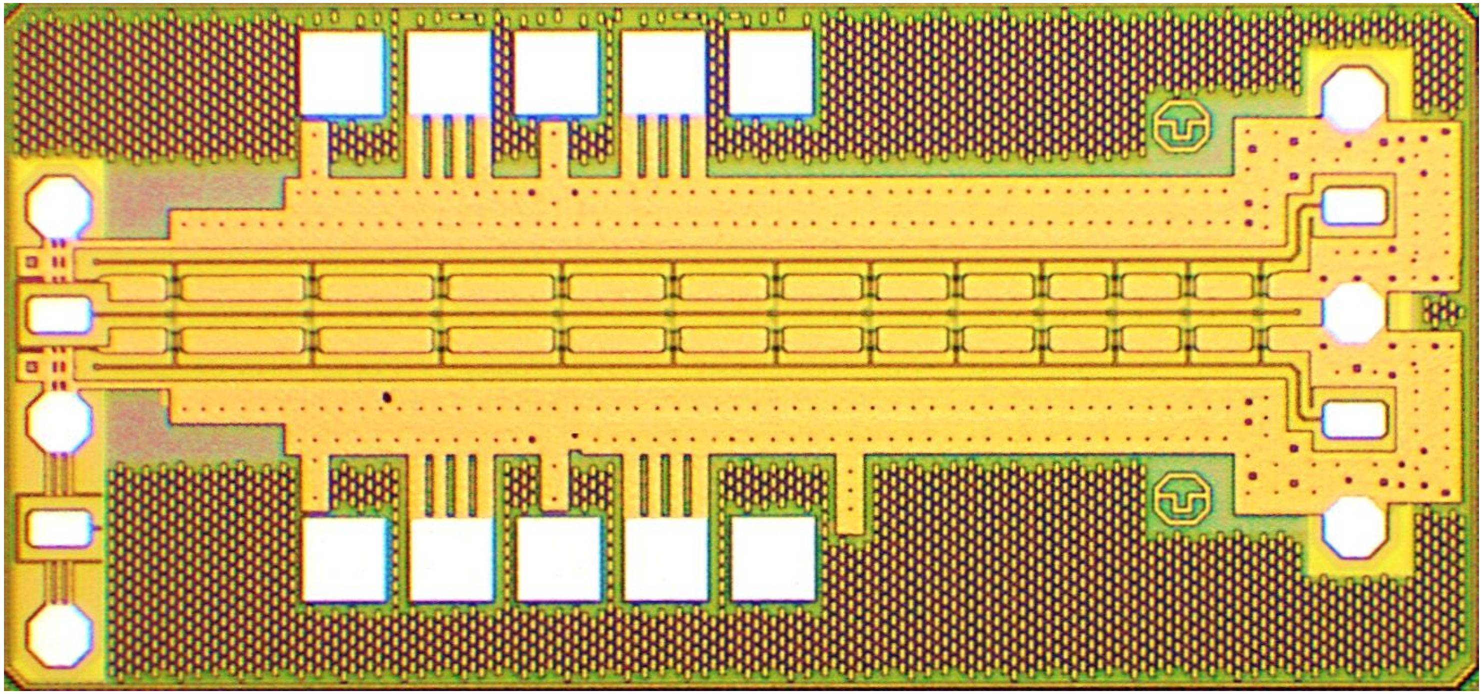
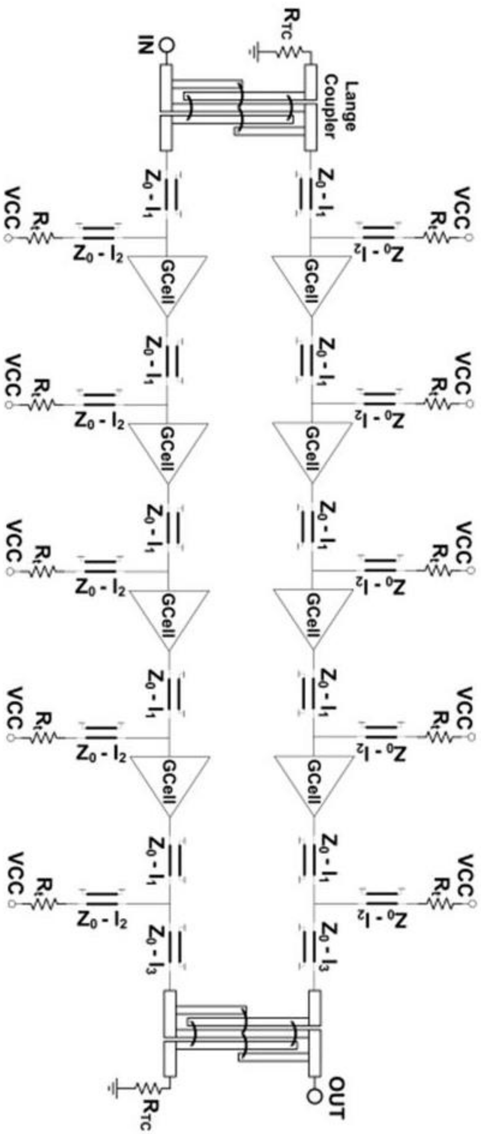
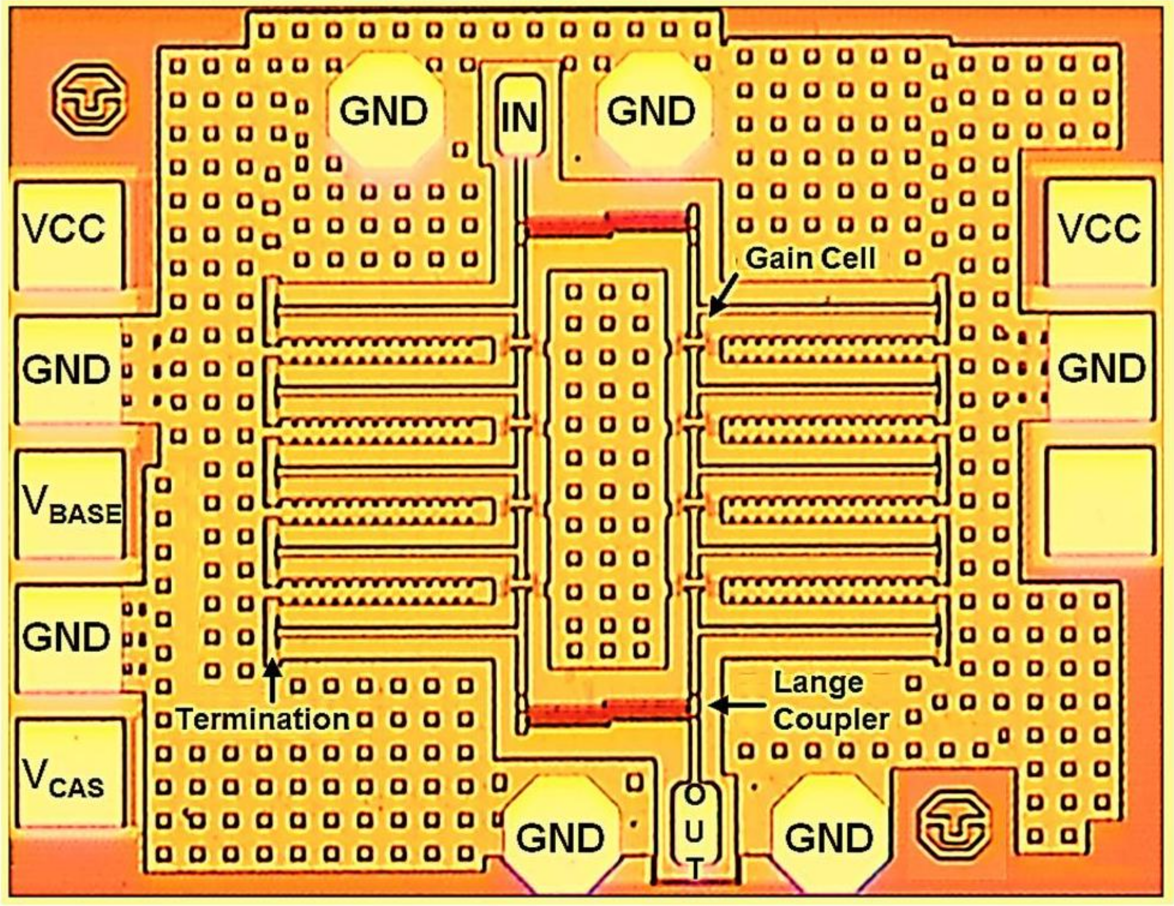


Balanced CSSDA





Never Tested Before

Balanced CSSDA

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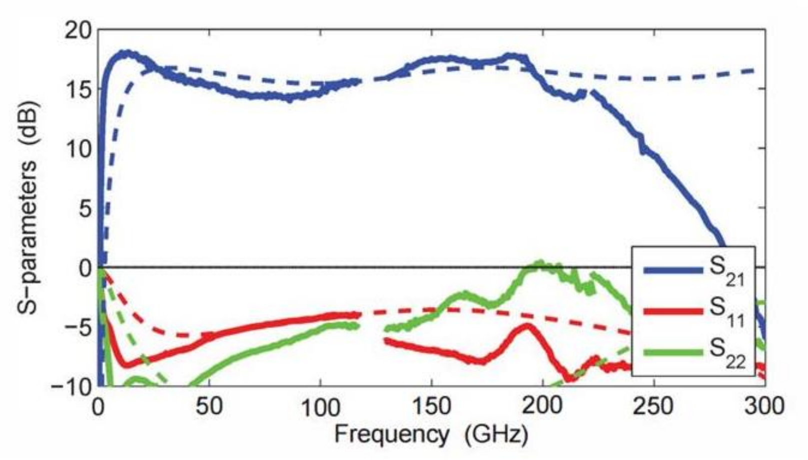
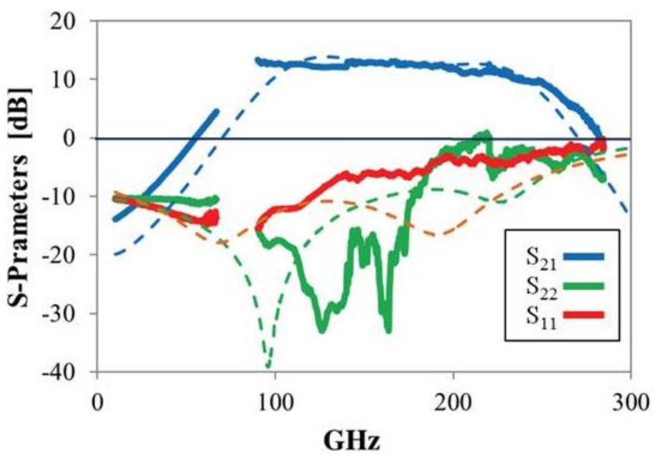
TABLE I COMPARISON OF PUBLISHED CSSDA

	This work	[3]	[4]	[5]	[6]	[7]
Gain [dB]	16	16	13	13	15	16
Area [mm^2]	0.38	0.54	0.22	0.72	0.31	1.36
f_{UP} [GHz]	220	235	250	70	80	65
BW [GHz]	180	235	170	70	80	40
f_{max} [GHz]	370	650	450	160	n/a	n/a
Pout* [dBm]	4	n/a	-6	3	n/a	n/a
P_{DC} [mW]	363	117	74	85	90	333

Improved in-out matching - Improved linearity



[3] InP DHBT Wideband Amplifiers with up to 235 GHz Bandwidth, K. Eriksson, L. Darwazeh, H. Zirath, IMS 2014.



[4] 250 GHz SiGe-BiCMOS Cascaded Single Stage Distributed Amplifier, P. V. Testa, R. Paulo, C. Carta, F. Ellinger, CSICS 2015.

Analysis and Design of a 220 GHz Balanced Cascaded Single-Stage Distributed Amplifier, P.V. Testa, C. Carta, F. Ellinger, to be submitted.

Antenna concepts

Highly Accurate Antenna Measurement Setup up to 220 GHz

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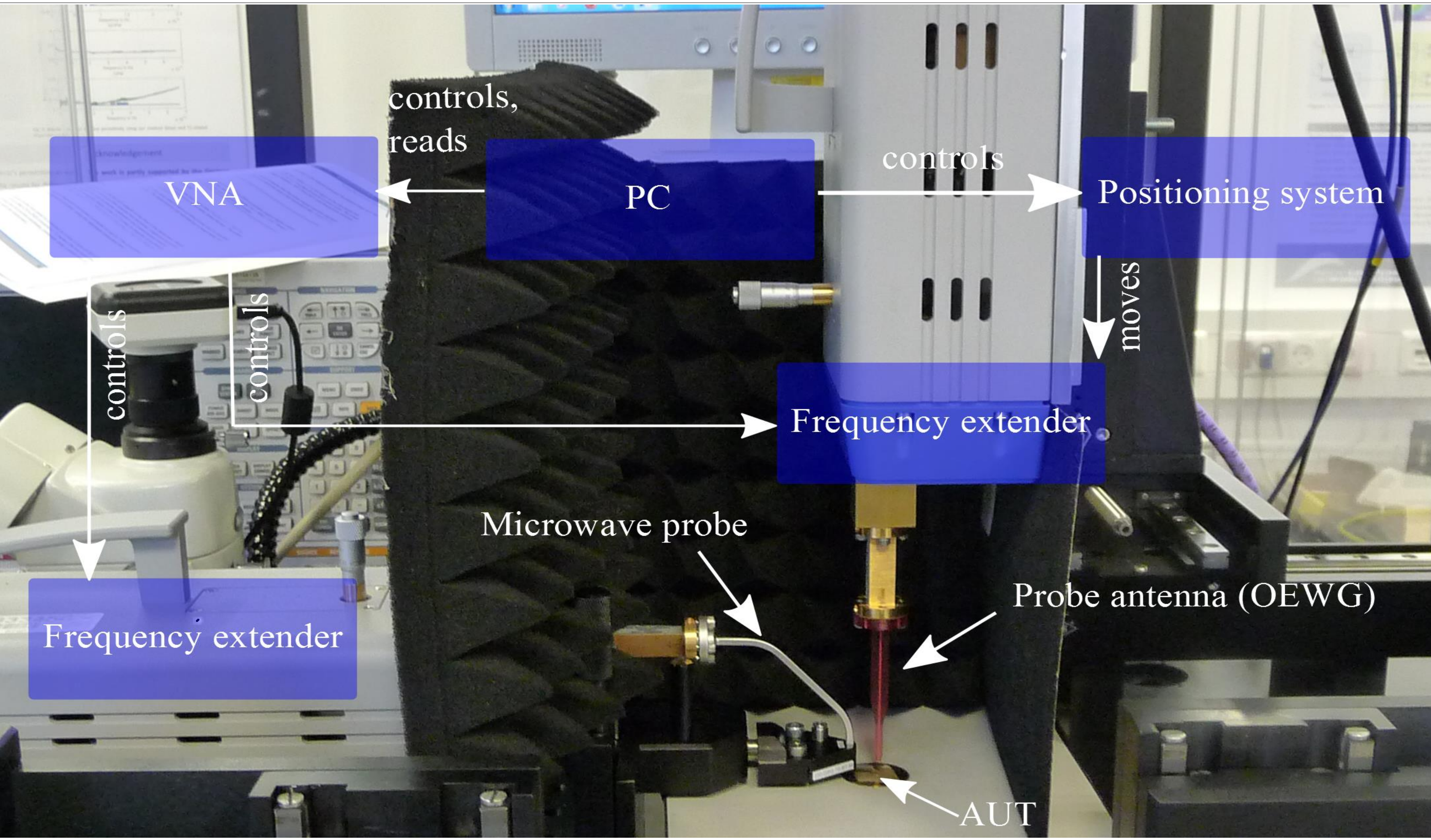
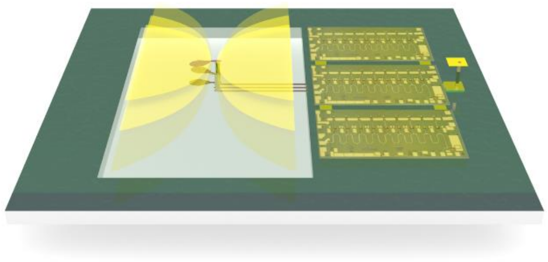


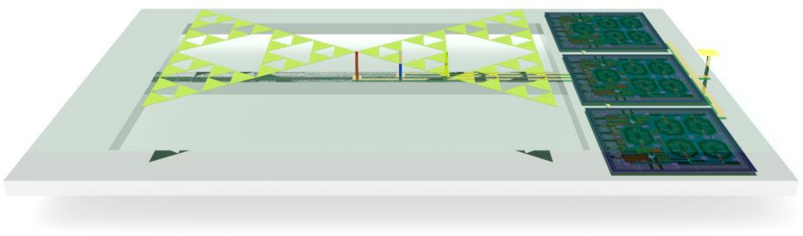
Klein, Hahnel, Seiler, Jenning, Plettemeier, On-Chip Antenna Pattern Measurement Setup for 140 GHz to 220 GHz," **IEEE ICUWB**, 2015

Advanced Antennas

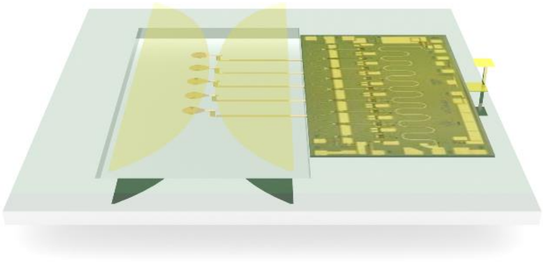
Antennas at Different Metal Levels & Locations and TWAs plus Adder



Multiple Antenna Contact Points and Frequency Scaled LNAs plus Adder

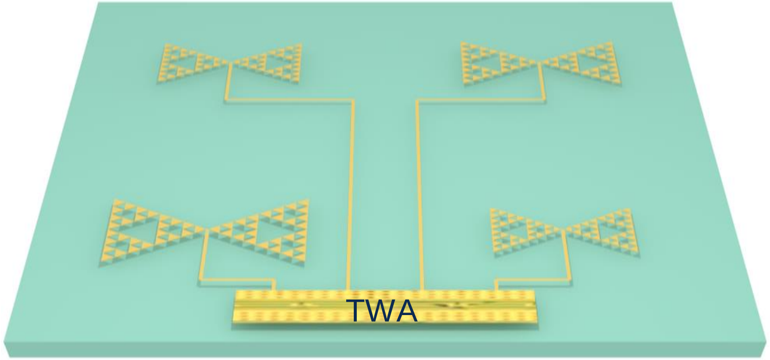


Multiple Antenna Contact Points and Distributed Adding with one TWA



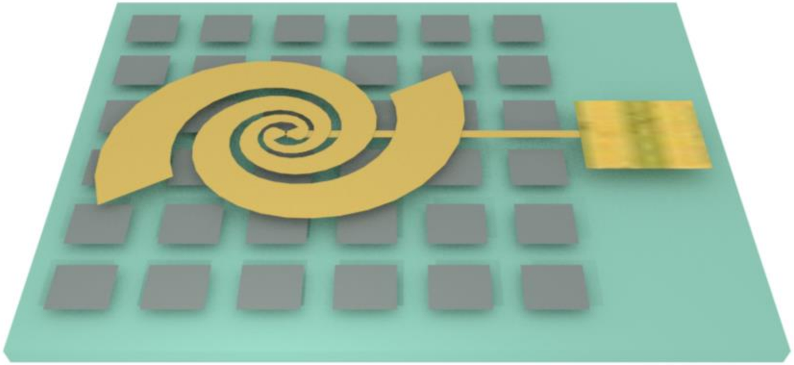
Advanced Antennas

Multiple adjacent frequencies



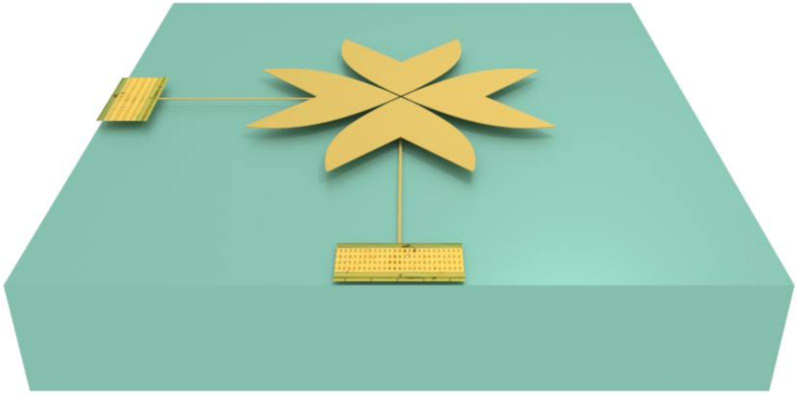
Minimize mutual coupling

Ultra-broadband



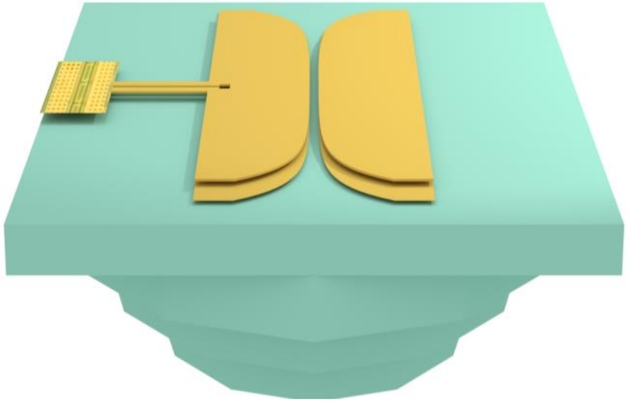
E.g. spiral antennas

Dual-polarization



BW × 2 & less coupling

Quasi-lens



Better polarization & gain

Fully Integrated Pyramid-Stacked Slot Antennas with Vivaldi-shaped Taper

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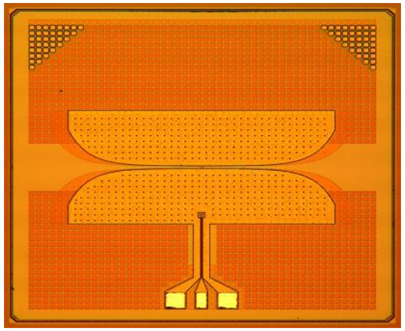
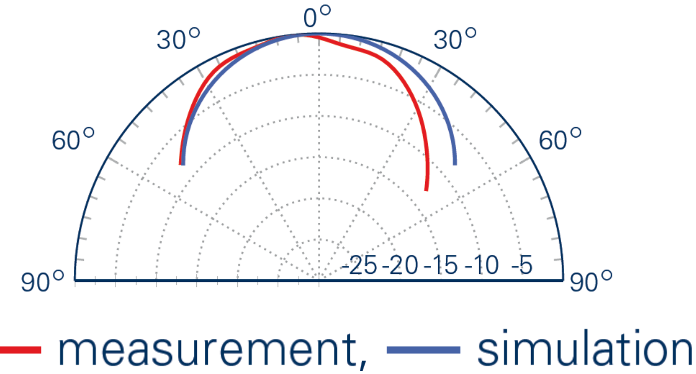
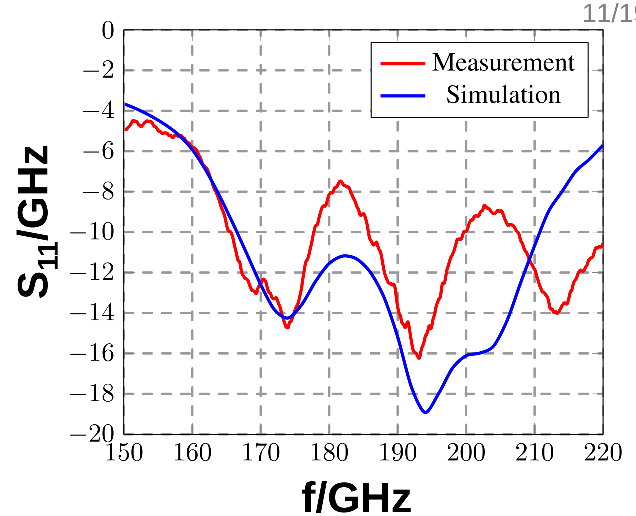
2 stacked metals

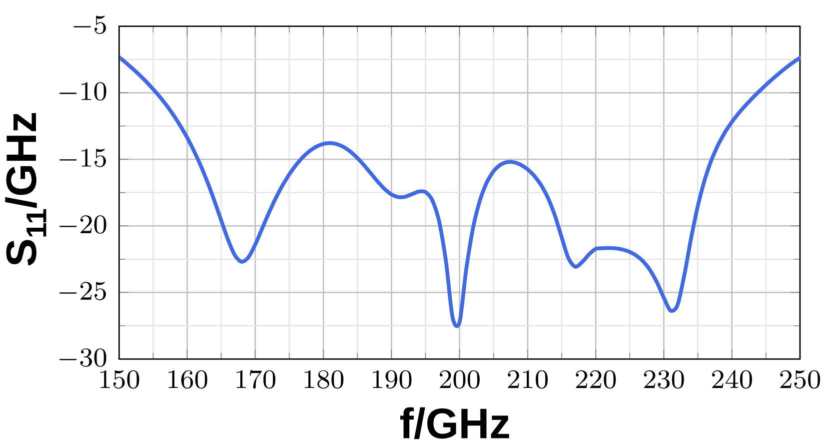






Hahnel, Klein, Plettemeier, Integrated stacked Vivaldi-shaped on-chip antenna for 180 GHz, **IEEE APS**, 2015

3 stacked metals, simulations



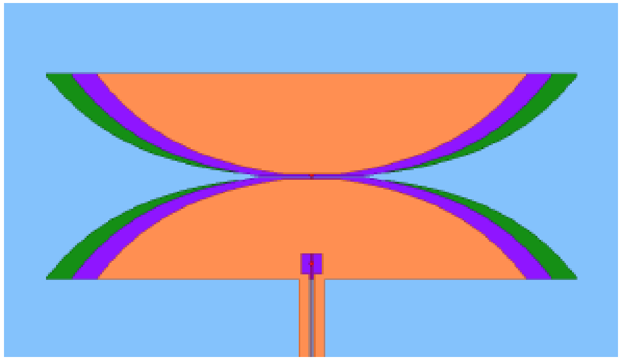
Hahnel, .. Plettemeier, .. Ellinger, Distributed On-Chip Ant. to Increase System BW at 180 GHz“, **GeMIC**, 2016

BW	f_{center}	Gain	Ref
Planar & integrated in silicon			
n.a.	140 GHz	8 dBi	IMS14
5 GHz	140 GHz	-2 dBi	APL11(1)
45 GHz	**187 GHz**	**1 dBi**	**DAAB**
89 GHz	**194 GHz**	**3 dBi**	**DAAB(1,2)**
External high quality substrate			
20 GHz	160 GHz	9 dBi	JSSC14
37 GHz	230 GHz	6 dBi	APMC14

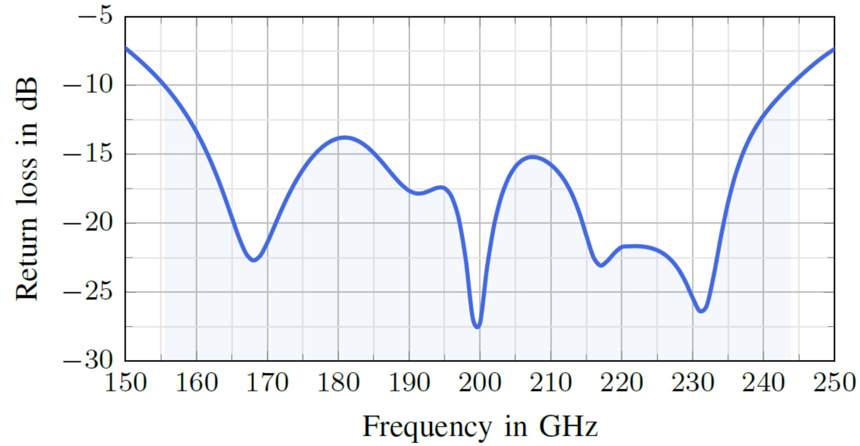
(1) Simulated (2) taped out Aug. 2015

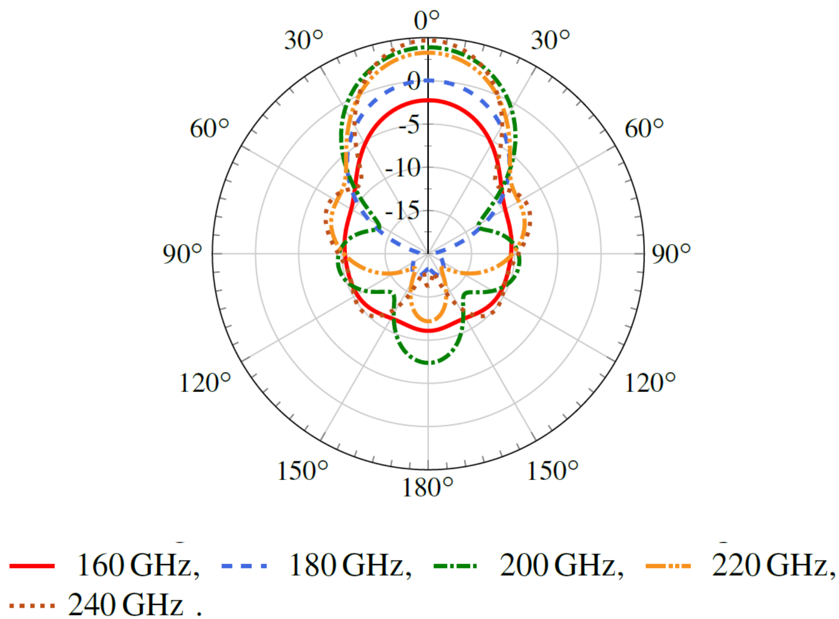
→ **45 + 89 GHz BW Record**

Novel three stacked vivaldi-shaped open slot antenna



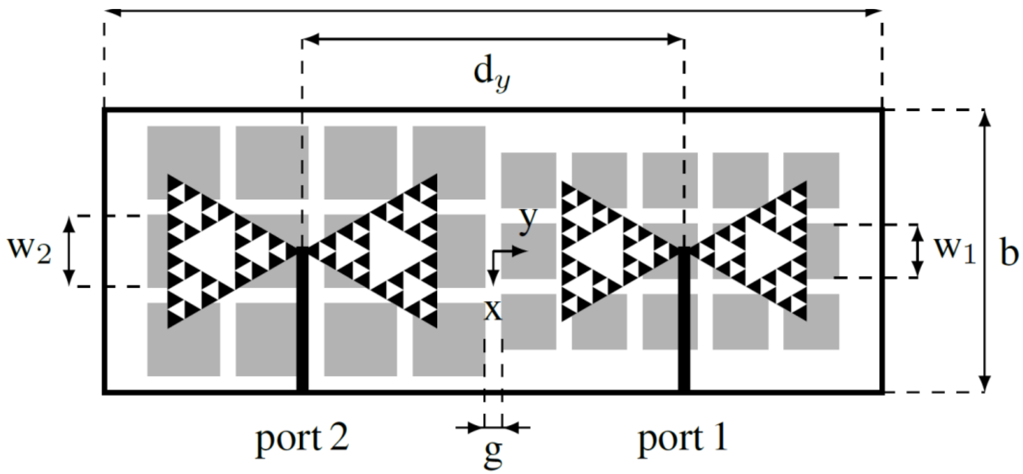
Simplified EM-Simulation model of three stacked vivaldi-shaped open slot antenna

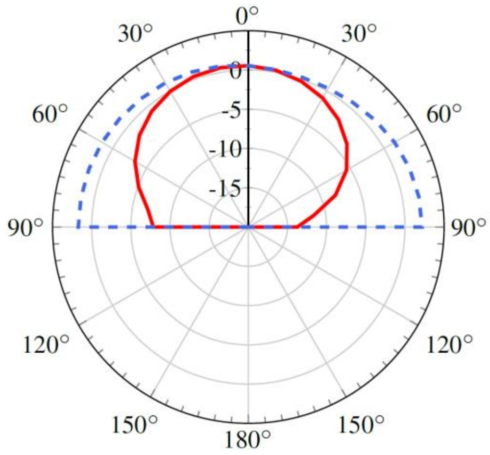




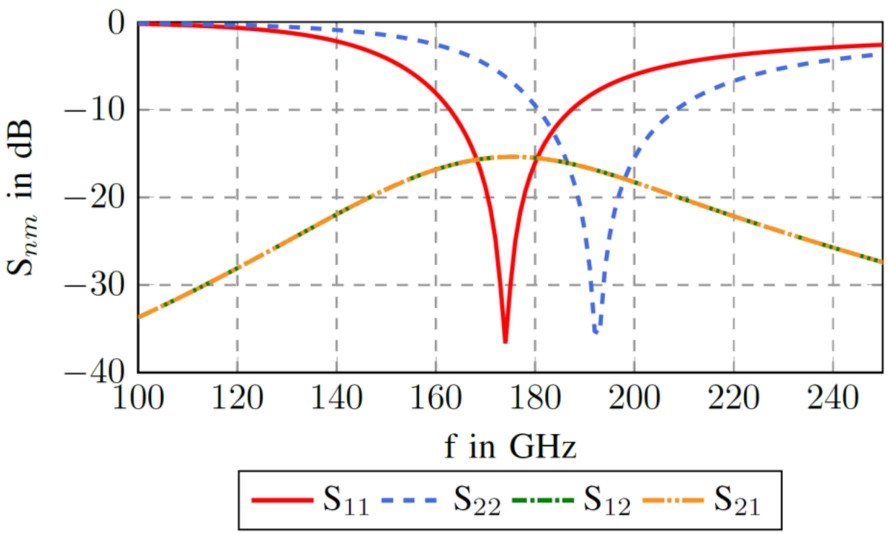
Hahnel, Klein, Hammerschmidt, Plettemeier, Testa, Carta, Ellinger, "Integrated Dual Polarized On-Chip Antenna for mm-Wave Applications", **GEMIC**, 2016

Multiple adjacent frequencies





Port 1 active, f = 175 GHz, phi = 0 deg, phi = 90 deg



Hahnel, Klein, Hammerschmidt, Plettemeier, Testa, Carta, Ellinger, "Integrated Dual Polarized On-Chip Antenna for mm-Wave Applications", **GEMIC**, 2016

Novel dual polarized on-chip antenna for mm-Wave applications

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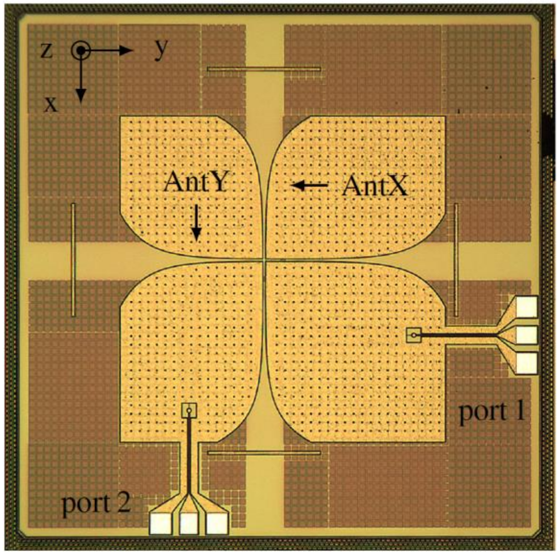
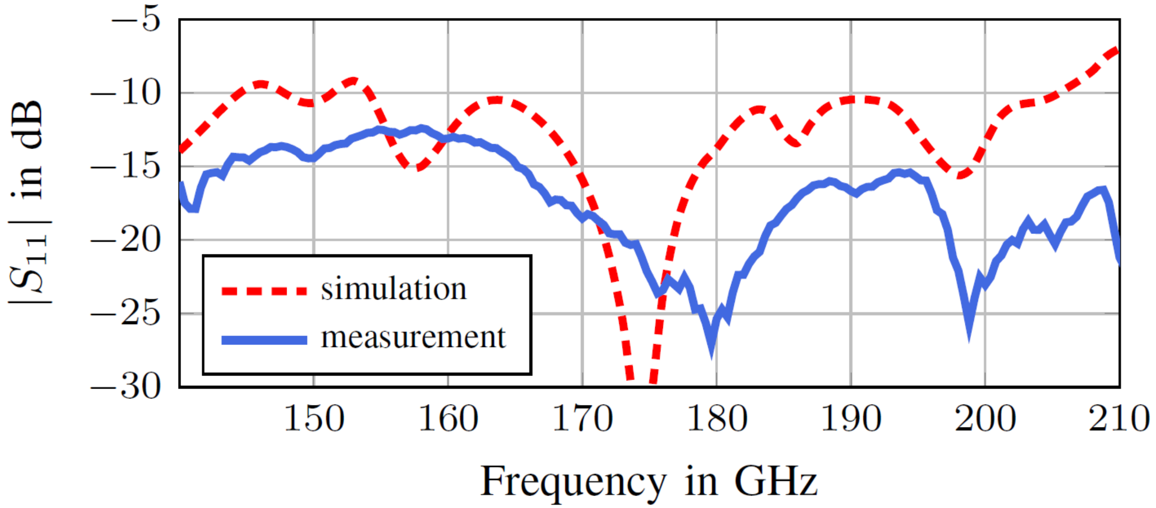




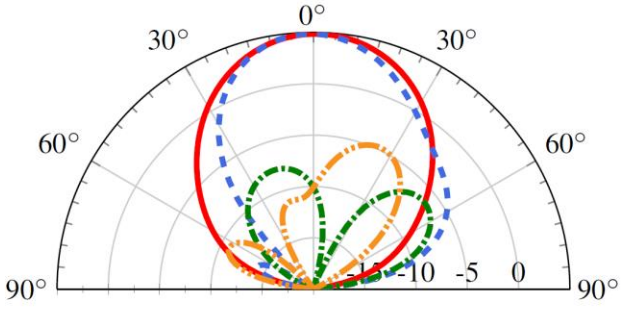
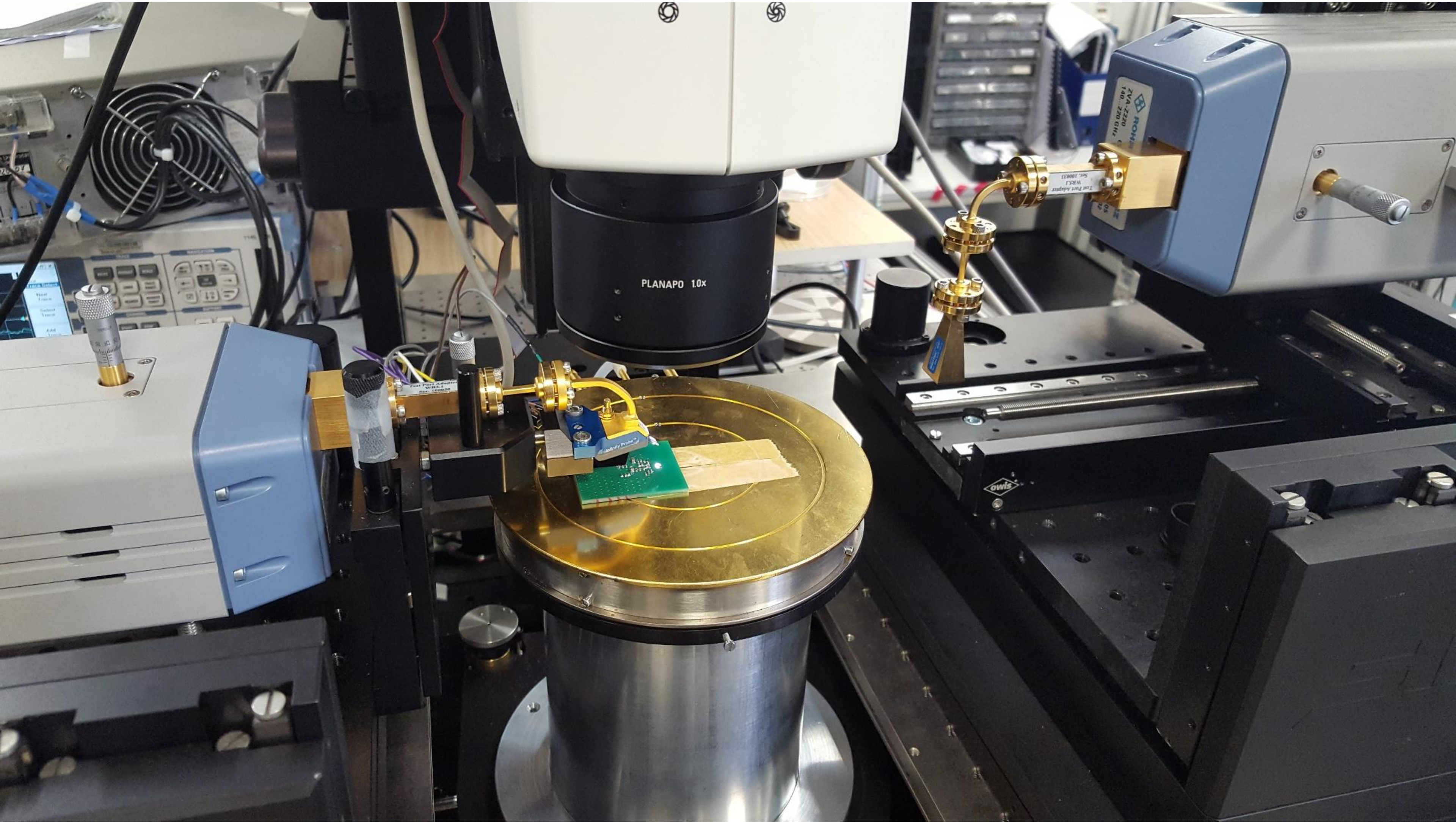


Fig. 4: Pattern in dBi at 180 GHz, port 1 with AntY excited: realized gain, x-component: $\varphi = 0°$, $\varphi = 90°$, realized gain, y-component: $\varphi = 90°$, $\varphi = 90°$.

Hahnel, Becker, Klein, Plettemeier, “Integrated Dual Polarized On-Chip Antenna for mm-Wave Applications”, **IEEE APS-URSI**, 2017

Integrated receiver

Measurement setup



Integrated receiver from 140 GHz to 220 GHz

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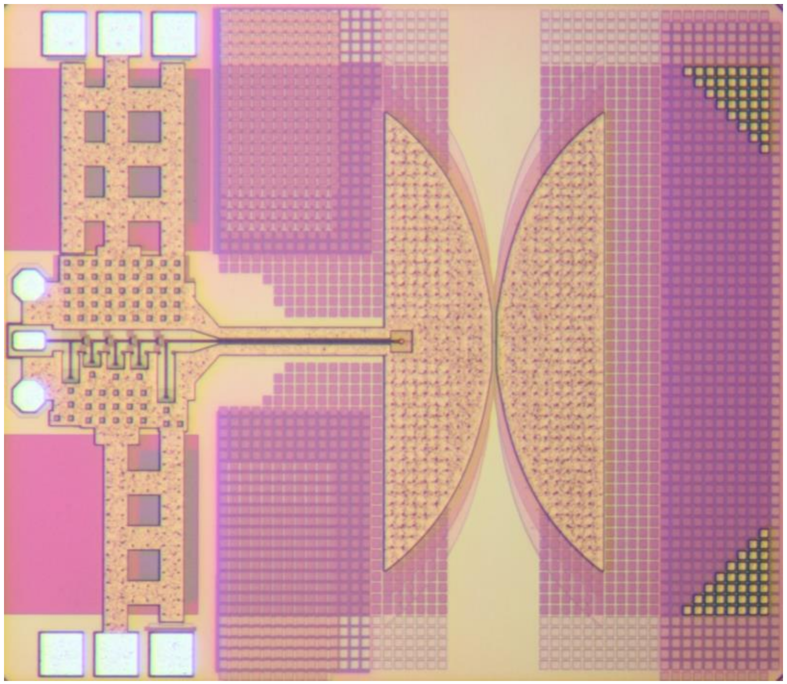

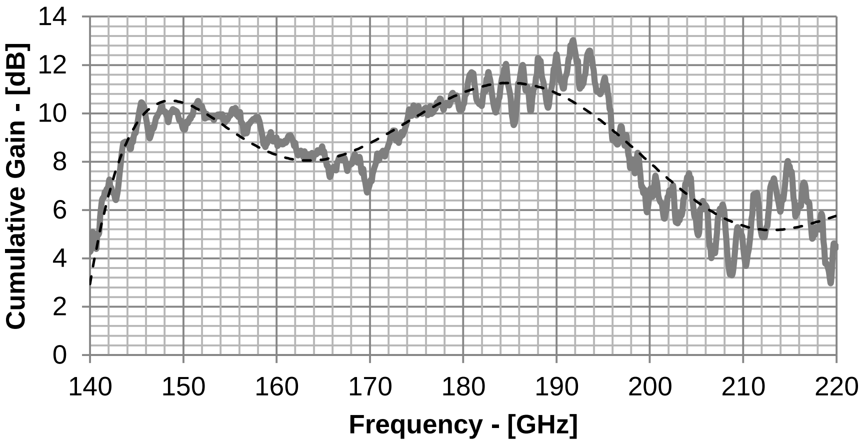

$$S_{\mathrm{REC},21} = \sqrt{G_{Ant_R}} S_{Amp_{21}} e^{-\gamma l} \frac{1 + \frac{S_{Amp_{22}}}{S_{Amp_{21}}} - \frac{S_{Amp_{11}} S_{Amp_{22}}}{S^2_{Amp_{21}}}}{e^{2\gamma l} - \Gamma_{Ant_R} S_{Amp_{11}}}$$

P.V. Testa, B. Klein, R. Hahnel, C. Carta, D. Plettemeier, F. Ellinger, "140-220 GHz Receiver Using On-Chip Antennas and Distributed Amplifiers in SiGe BiCMOS", to be submitted to *IEEE Microwave and Wireless Components Letters*.

Integrated receiver from 95 GHz to 200 GHz

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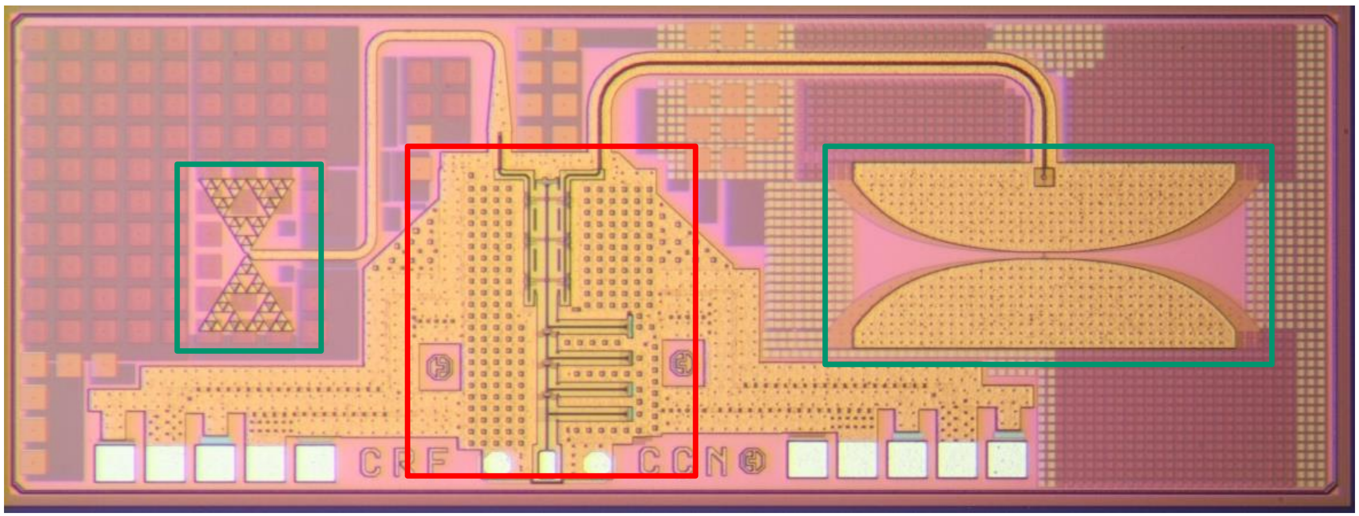
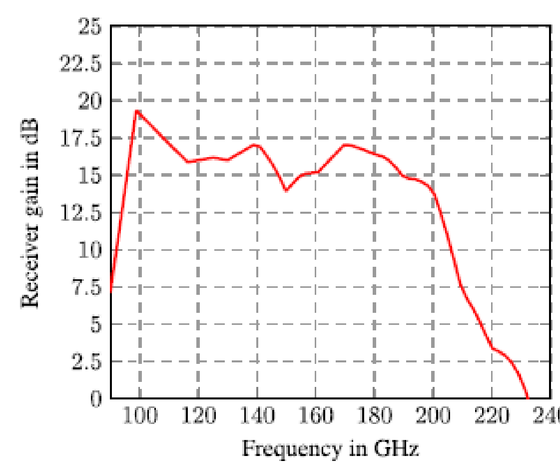
Fractal Bow-Tie

2-stacked vivaldi -shaped open slot antenna



Traveling wave amplifiers + Combiner



State of the Art for Integrated Amplifier /Antennas Frontends at > 120 GHz

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Cumulative BW	Center Frequency	Amp. Gain	Antenna Gain	Tech.	Ref.
Silicon					
12 GHz	120 GHz	n.a.	4 dBi	CMOS & wire	[Def14]
~10 GHz	170 GHz	15 dB	-8 dBi	SiGe	[Las08]
~20 GHz	240 GHz	5 dB	2 dBi[1]	SiGe	[Bre13]
105 GHz	**148 GHz**	**20 dB**	0-4 dBi	**SiGe**	**[DAAB]**[1,2]
III/V					
24 GHz	220 GHz	3.5dB	20dBi	GaAs HEMT	[Abb15]

(1) Simulated **(2) Circuit in fabrication**

→ Bandwidth improved by a factor of **5** (Si) & **4** (incl. III/V)

→ Matches well with project goal of 100 GHz BW

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Dresden University of Technology thanks you for your attention!

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