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Visions for On-Chip Integrated Distributed Amplifier & Antenna Systems in SiGe BiCMOS for Ultra Large Bandwidth

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*I f**ee**l the n**ee**d the n**ee**d for sp**ee**d*

Tom Mitchel (Tom Cruise),

Movie Top Gun

Outline

How can we get in SiGe BiCMOS technology:

- Ultra high operation frequencies
- Ultra high bandwidths
- High gain
- High output power

Operation at ultra-high frequencies

- Very fast and scaled transistors

$\Rightarrow$ Low V_{dc} & signal power

- High air-channel losses

$\Rightarrow$ Optimization of PAs challenging but very important

$$P_{PA} \sim V_{dc}^2 / Z_L$$

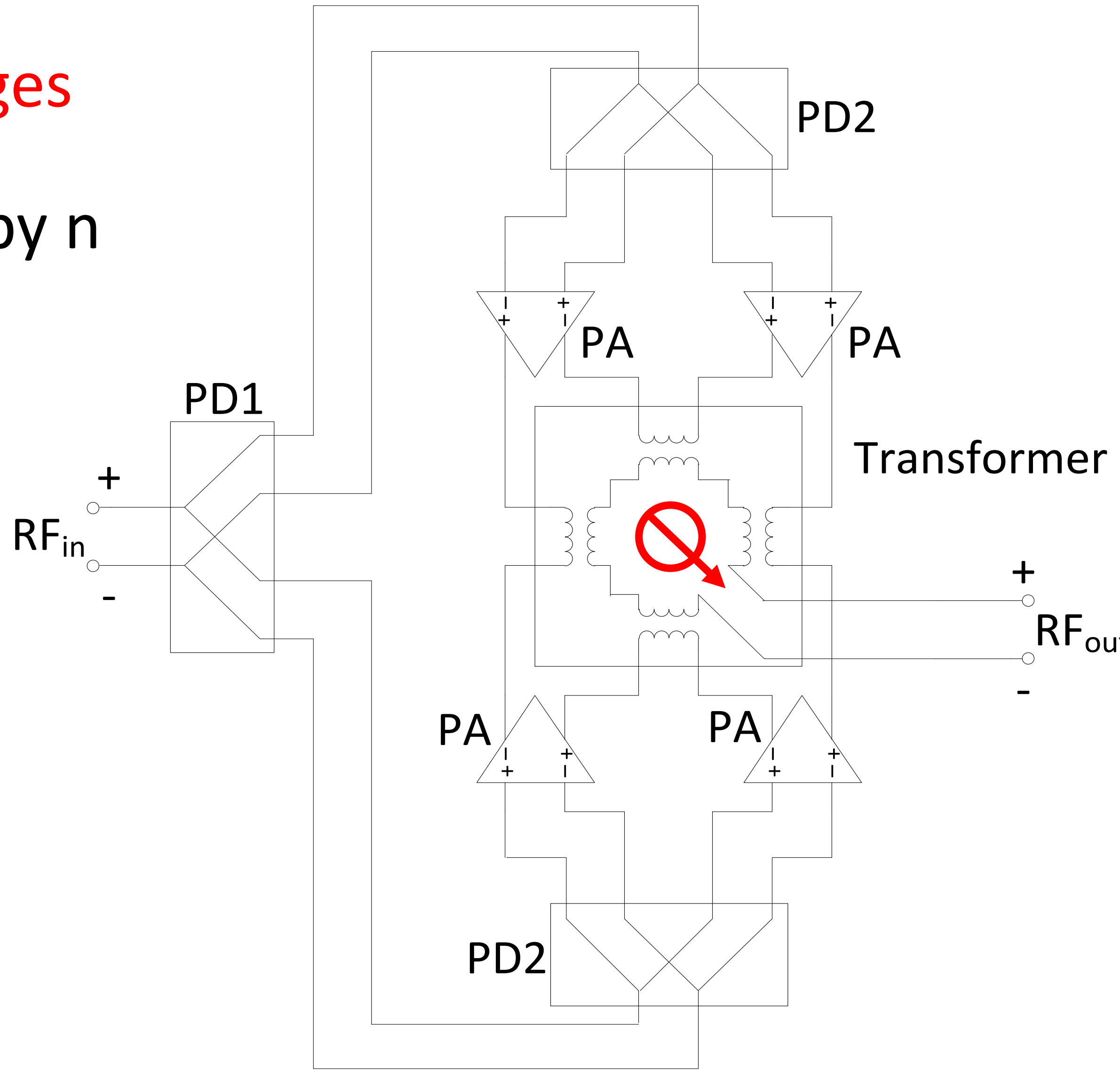
$\Rightarrow$ Very low Z_L for high TX power

$\Rightarrow$ Large impedance transformation

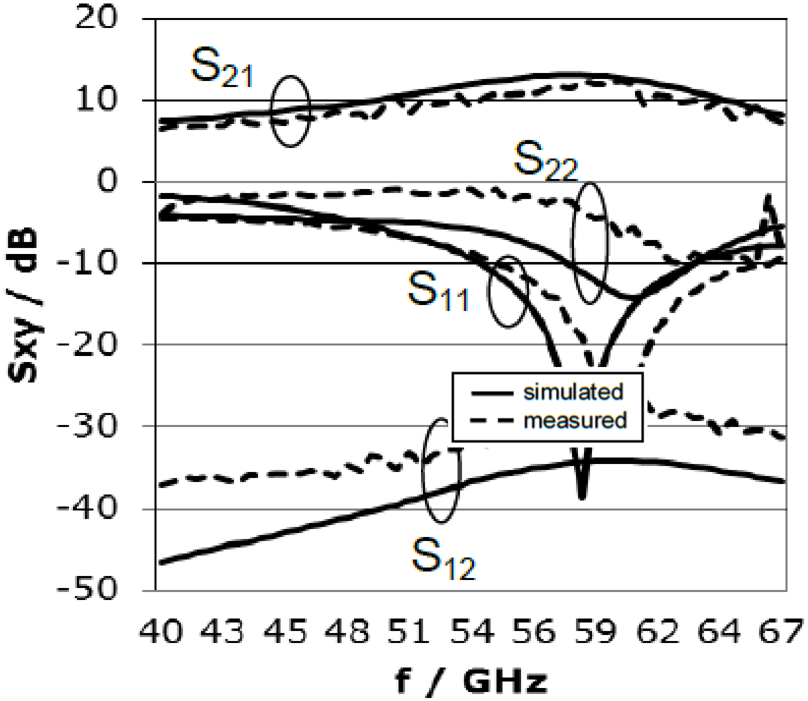
$\Rightarrow$ High losses

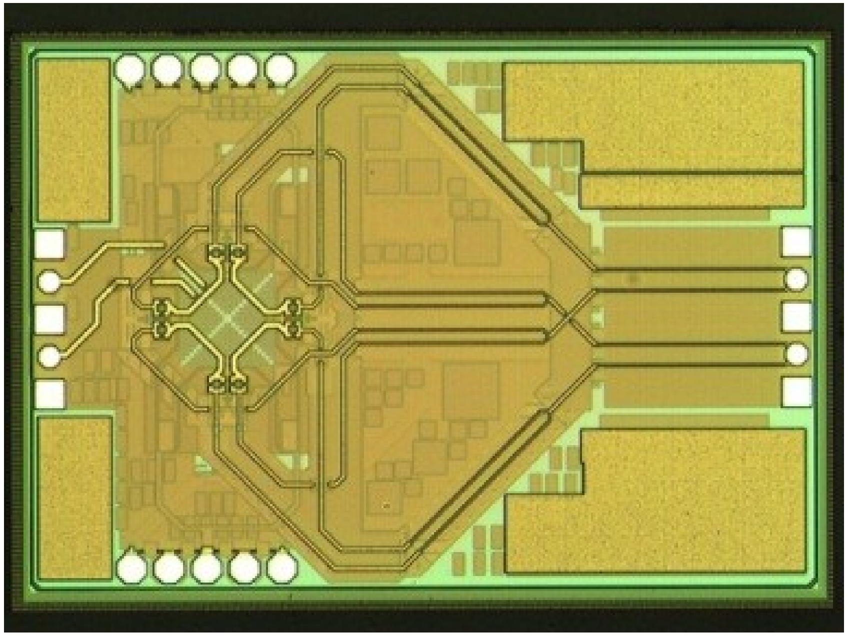
Transformer Based Power Adding

- Adding of n ac voltages
- TX power increases by n
- Required Z_L ↑ by n
- Z-trafo smaller
- Higher efficiency
- Larger BW



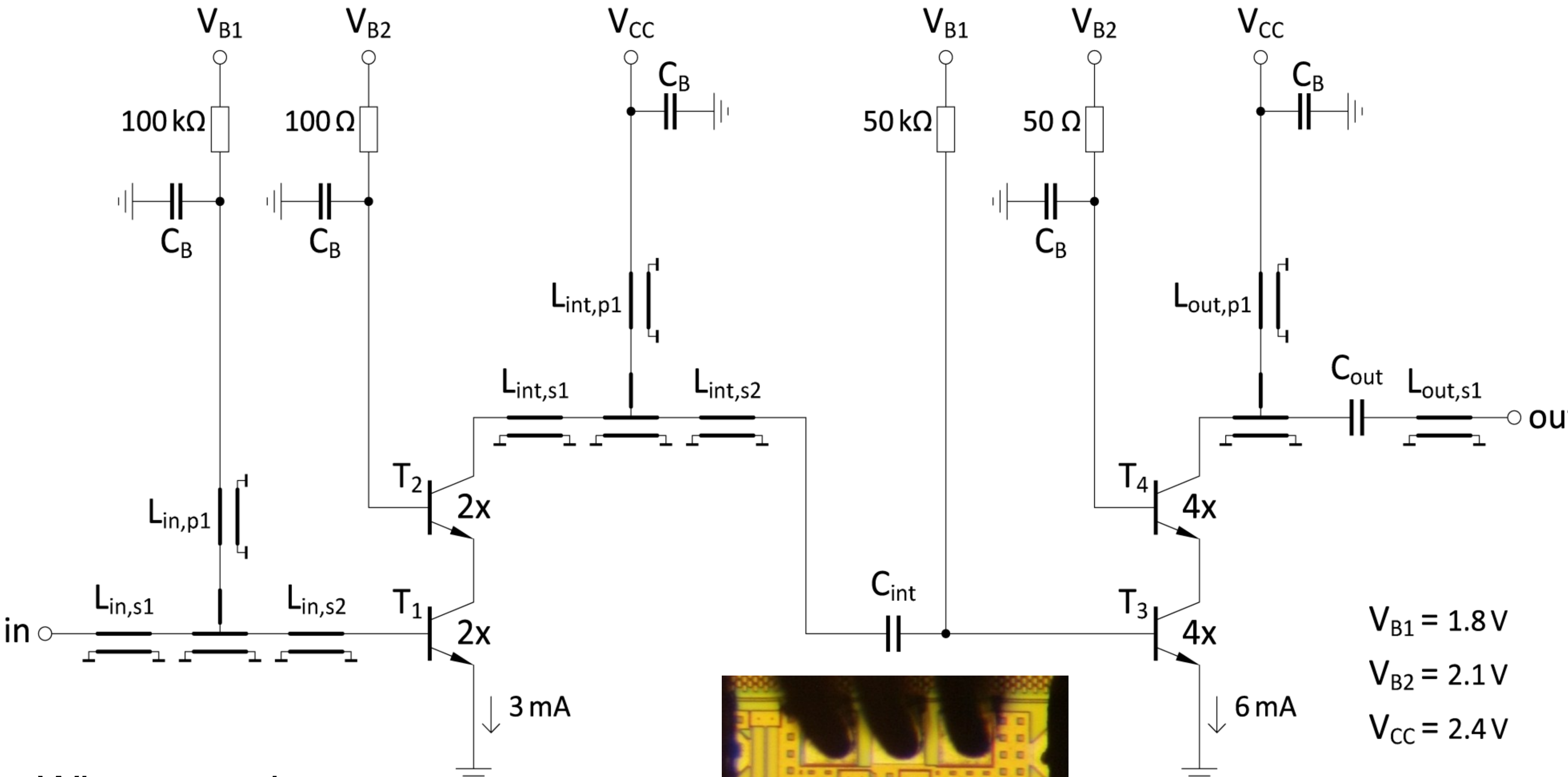
Combining PA at 60 GHz in SiGe

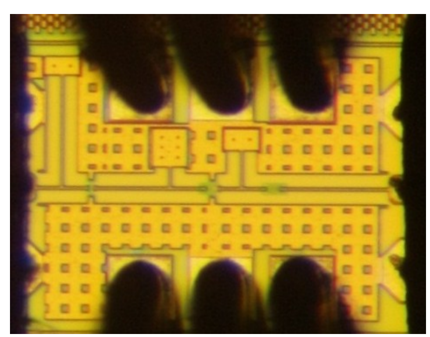




Ref.	f/BW [GHz]	P_{1dB} [dBm]	PAE [%] @P_{1dB}/peak	V_{dc} [V]	Technology
TUD	60/12	23.5	> 13	3.3	0.25 µm SiGe
[Pfe07]	62	21	n.a./6.3	4	0.13 µm SiGe
[Wan12]	79	16.4	13/19.2	1	65 nm CMOS
[Dea08]	270	7.7	4/n.a.	1.7	35 nm InP HEMT

160-210 GHz SiGe LNA

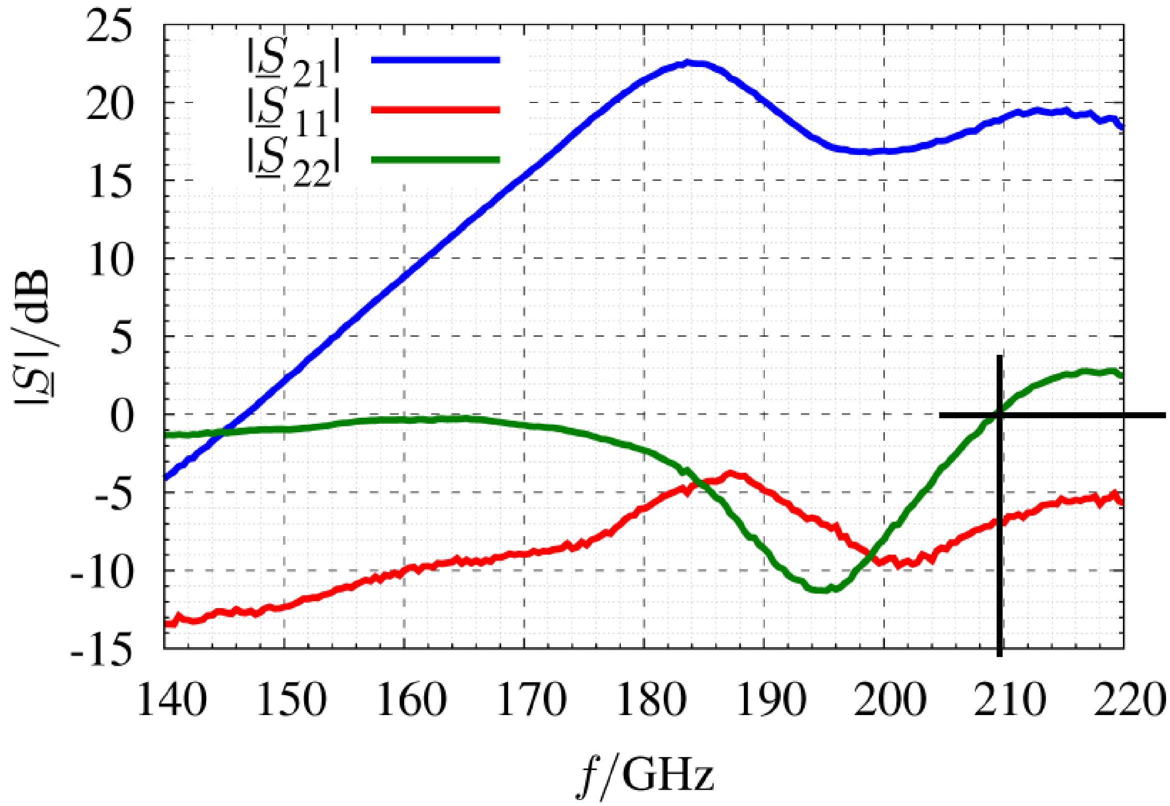




Why cascode:

- High Rout → high gain
- Low Miller effect → high f

Measurements

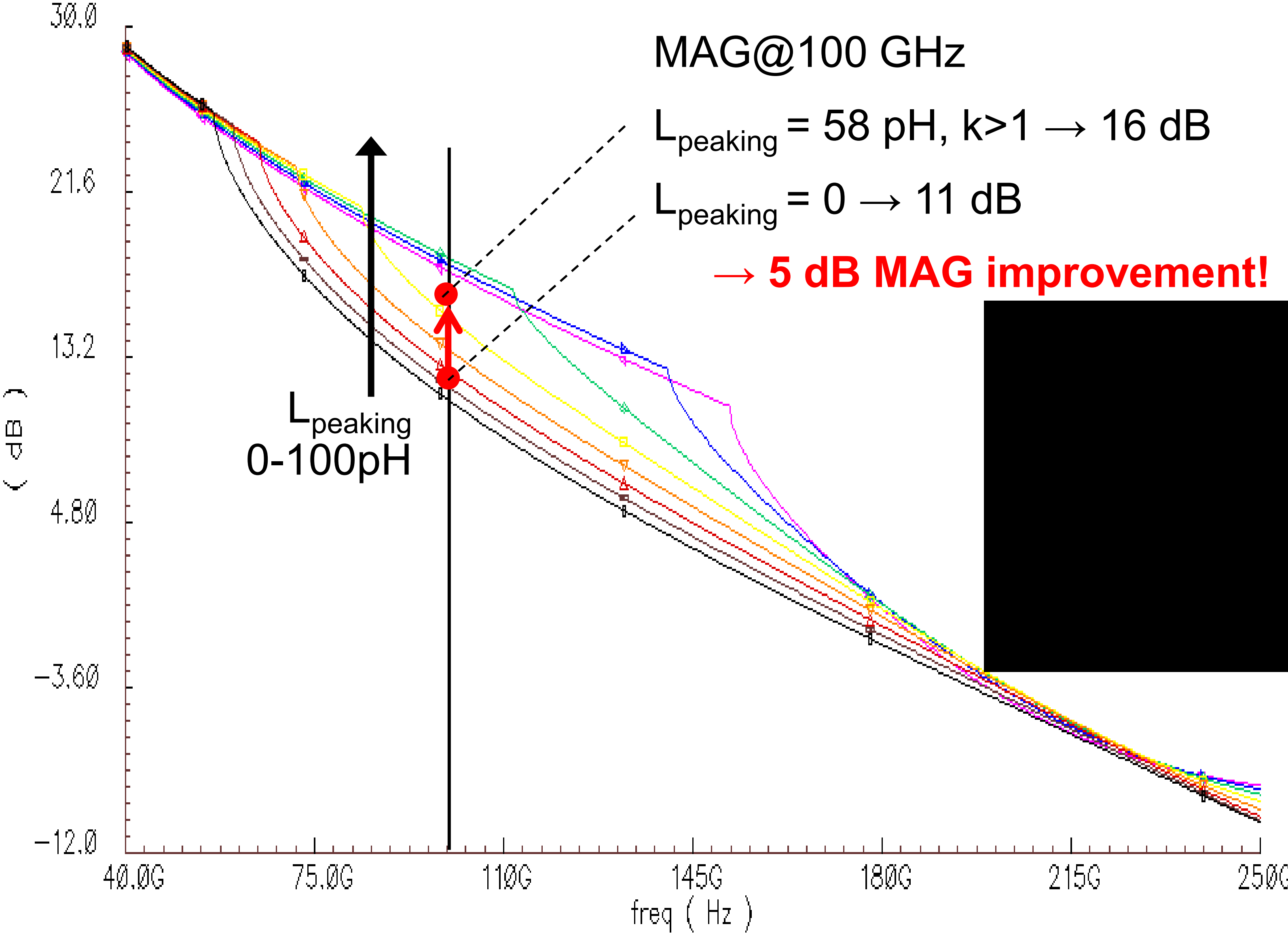


S_{22} > 0 dB at f > 210 GHz

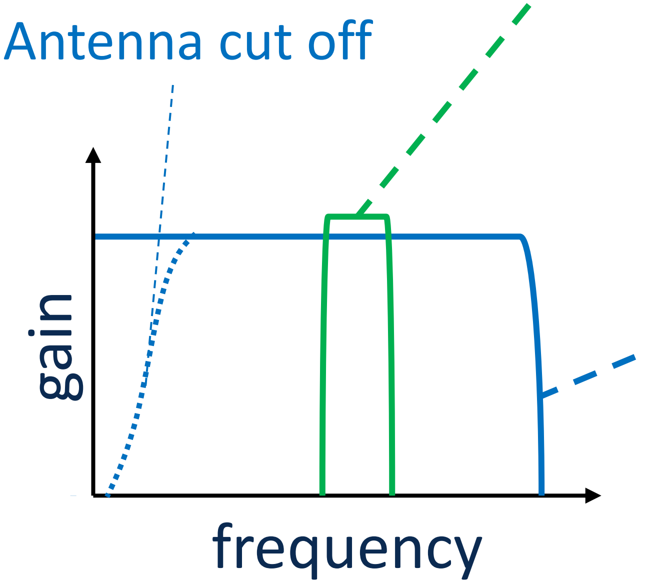
Redesign with S_{22} < 0 in fabrication

Ref.	Technology	f/GHz	BW/GHz	G/dB	P_{DC}/mW	A/mm^2
TUD	**130 nm SiGe HBT**	**205**	**> 30 (50)**	**17**	**22**	**0.24**
[Tess09]	50 nm GaAs mHEMT	200	40	16	24	**1.0**
[Sch12]	130 nm SiGe HBT	245	10	18	**303**	0.15

Higher Cascode MAG by $L_{peaking}$



BW Limited by Parasitic Capacitances Generating Lowpass Filter



Method 1:

Resonate capacitances with inductors

⇒ Narrowband impedance matching

⇒ Low bandwidth

Method 2:

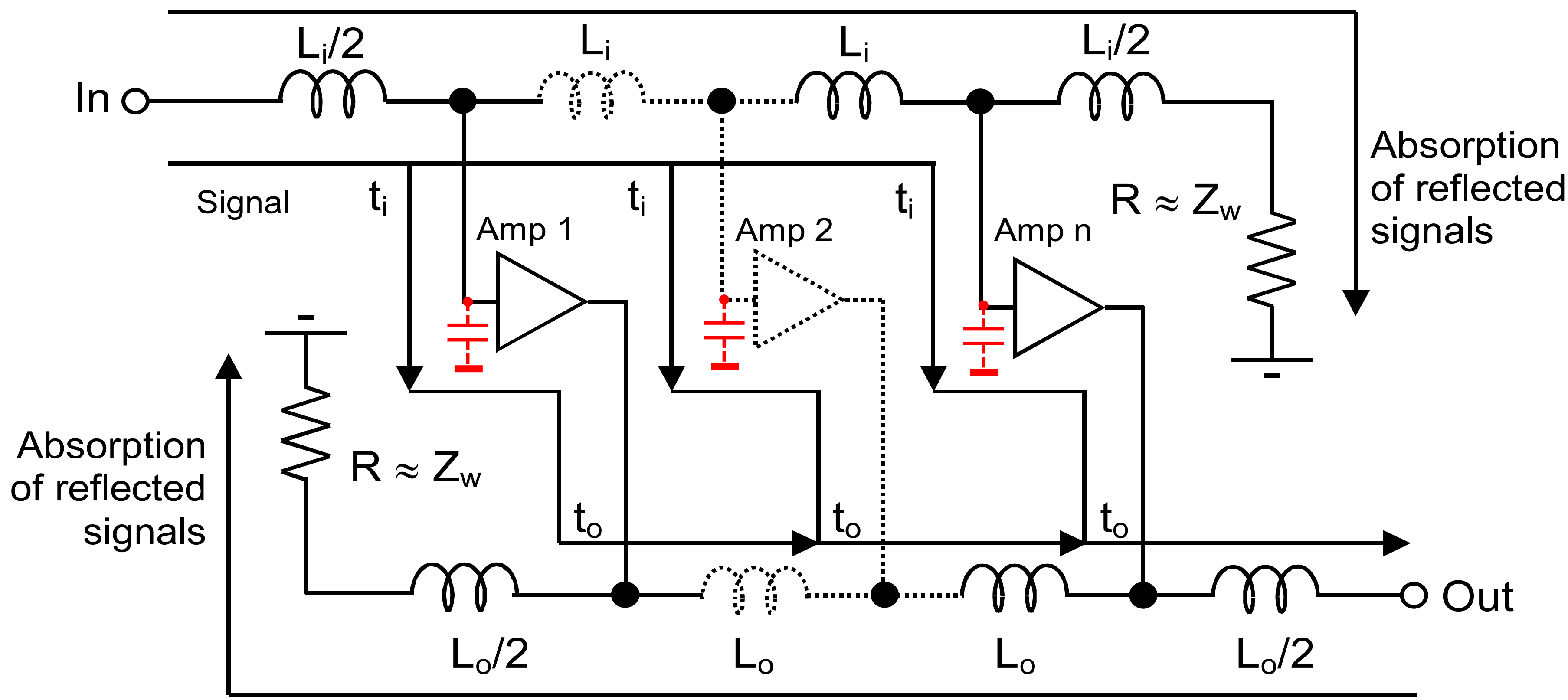
Incorporate capacitances into active equivalent transmission lines

⇒ Distributed (traveling wave) LC structure

⇒ Wideband impedance matching

⇒ High bandwidth

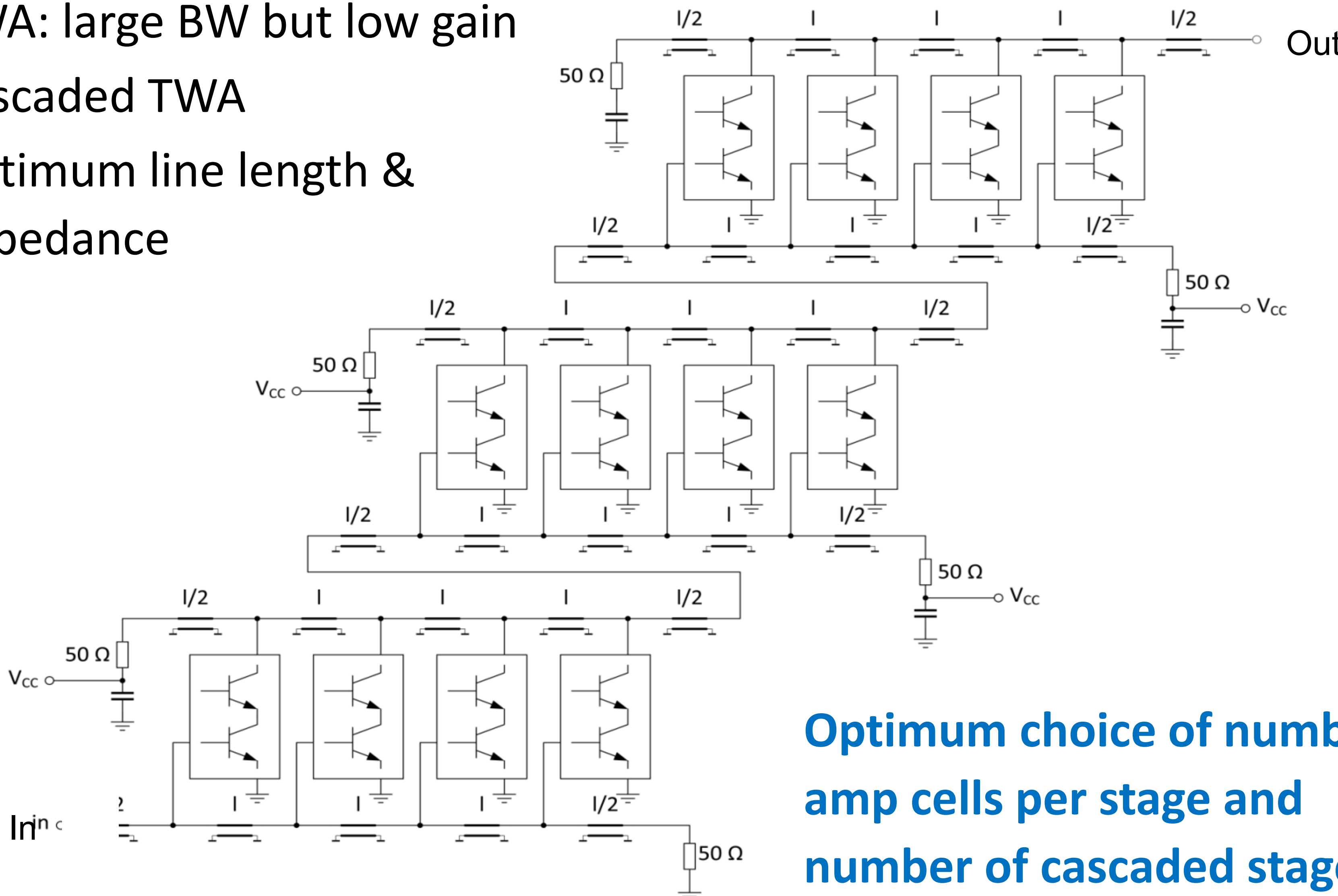
Traveling Wave Amplifier



F. Ellinger, 60 GHz SOI CMOS traveling wave amplifier with NF below 3.8 dB from 0.1-40 GHz, IEEE Journal of Solid-State Circuits, Feb. 2005

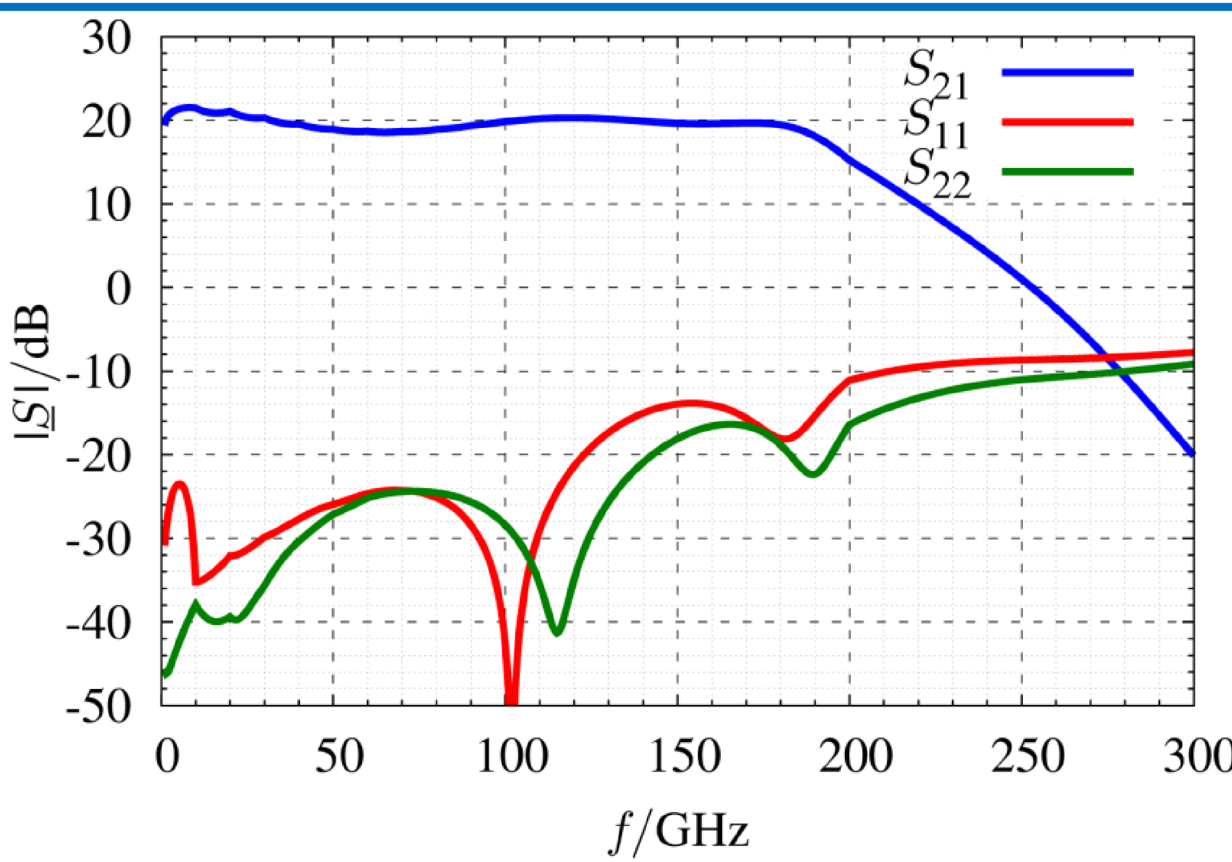
Cascaded TWA

- TWA: large BW but low gain
- Cascaded TWA
- Optimum line length & impedance



Optimum choice of number amp cells per stage and number of cascaded stages

Simulations Results, IC in FAB



Reference	Technology	Gain/dB	BW/GHz	P_{DC}/mW	A/mm^2
Group Ellinger, sim.	130 nm SiGe	20	**190**	**200**	0.6
Niknejad, RFIC12	130 nm SiGe	24	110	248	0.65
Zech, GeMiC12	50 nm GaAs HEMT	11	110	450	1.7

Vision of DAAB Project: Subproject within DFG SPP 100 Gb/s & Beyond

- Integration of antennas and amplifiers on single chip

  → Lower connection losses, 50 Ω matching not needed, peaking

- State of the art for antenna & amplifier frontend on single chip:

  - GaAs HEMT: BW = 30 @ 220 GHz → 14 %, Gunnarson MWCL 08

  - SiGe HBT: BW = 15 @ 170 GHz → 9 %, Laskin RFIC 08

  Narrowband resonant matching

- Relative frontend BW of up to 50 % (e.g. 150-250 GHz)

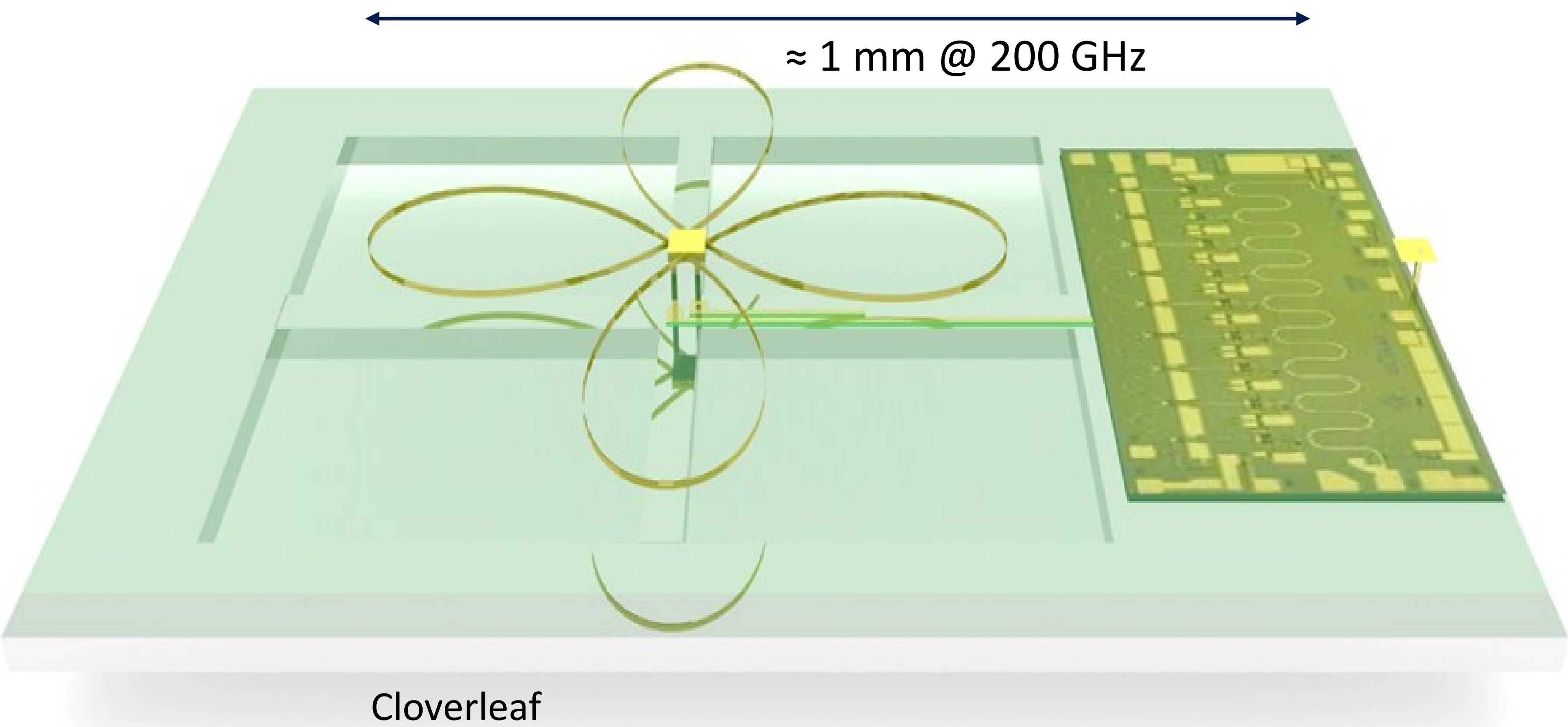
- Novel fully distributed antenna & amplifier systems

Approach 1: Wideband TWA & Antenna on Single Chip

⇒ Large BW

⇒ Relative low risk

⇒ Benchmark approach

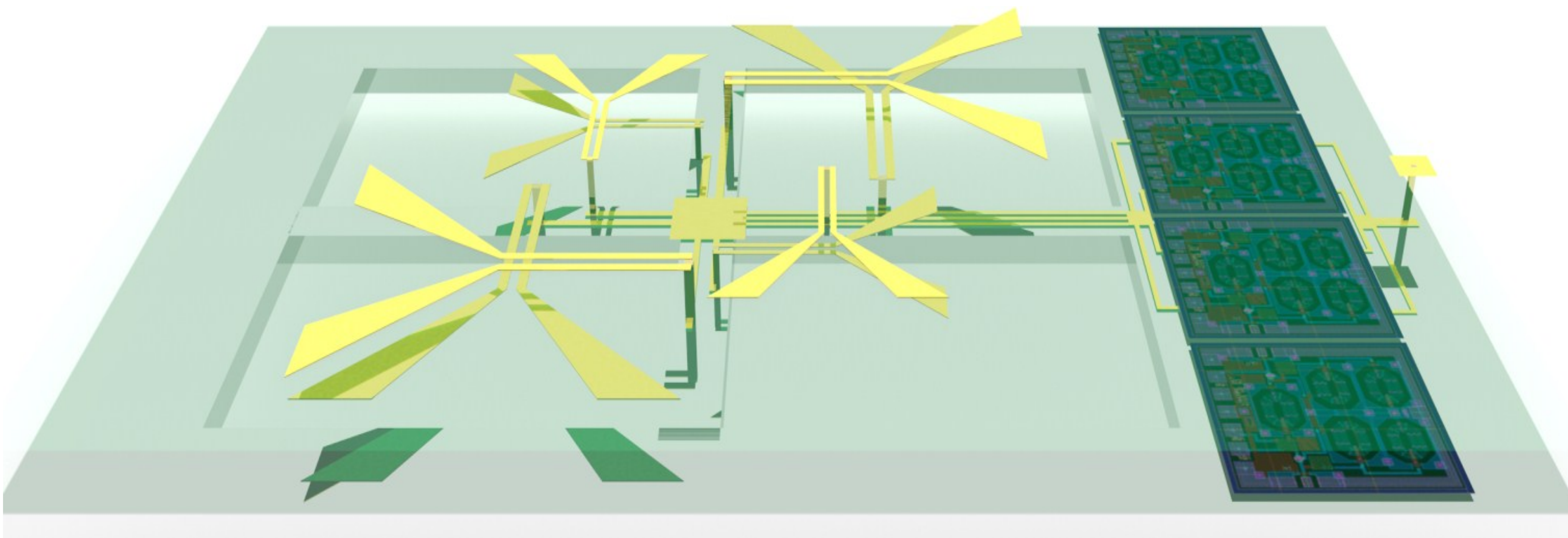


Approach 2: Antennas at Different Metal Levels & Locations and Multiple TWAs

Very large BW

⇒ More signal radiated upwards and lower substrate losses

Substrate etching lowers losses especially at lower metal levels



Linear tapered slot

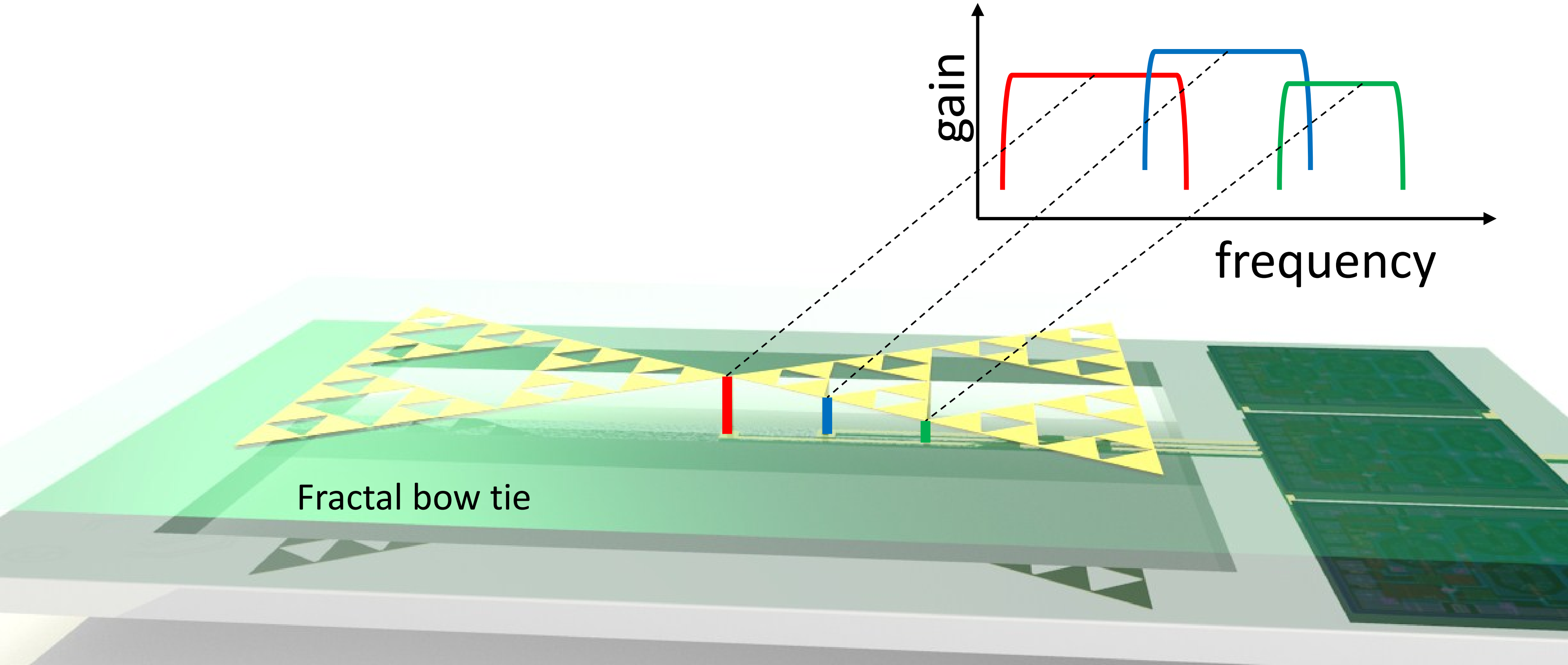
M. Jenning, D. Plettemeier, Multilayer & multi-directional linearly-tapered slot antenna for 300 GHz applications, EuCAP, April 2010

Approach 3: Multiple Antenna Contact Points and Multiple Frequency Scaled Amps

⇒ Different contact points have different optimum centre frequencies

⇒ Adding of multiple bands by frequency scaled amplifiers

⇒ Very large BW

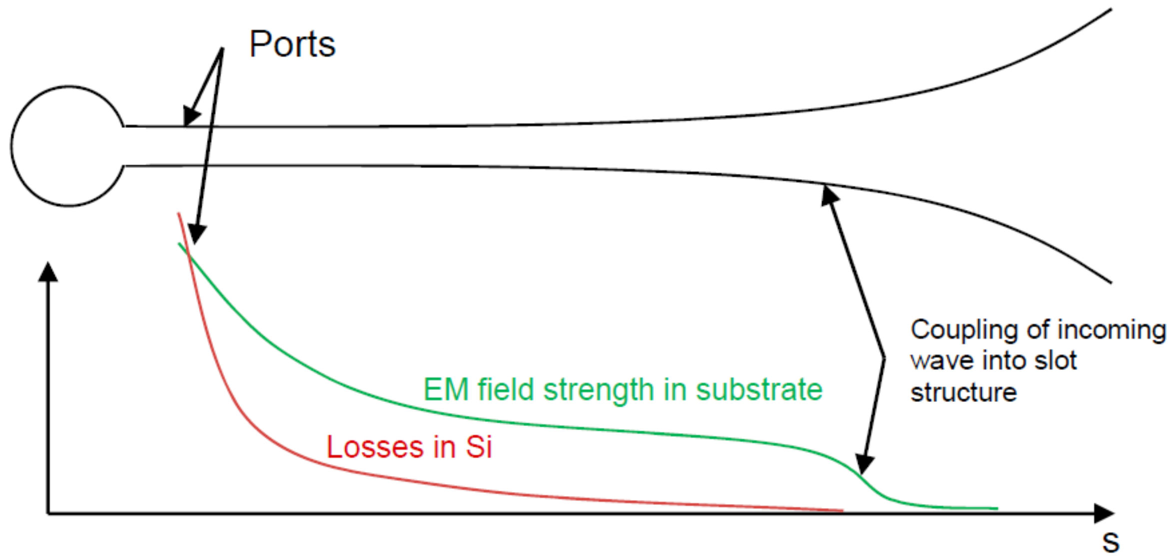


Antenna Losses in Dependency of Field and Port Position

Conventional: Whole energy via single point

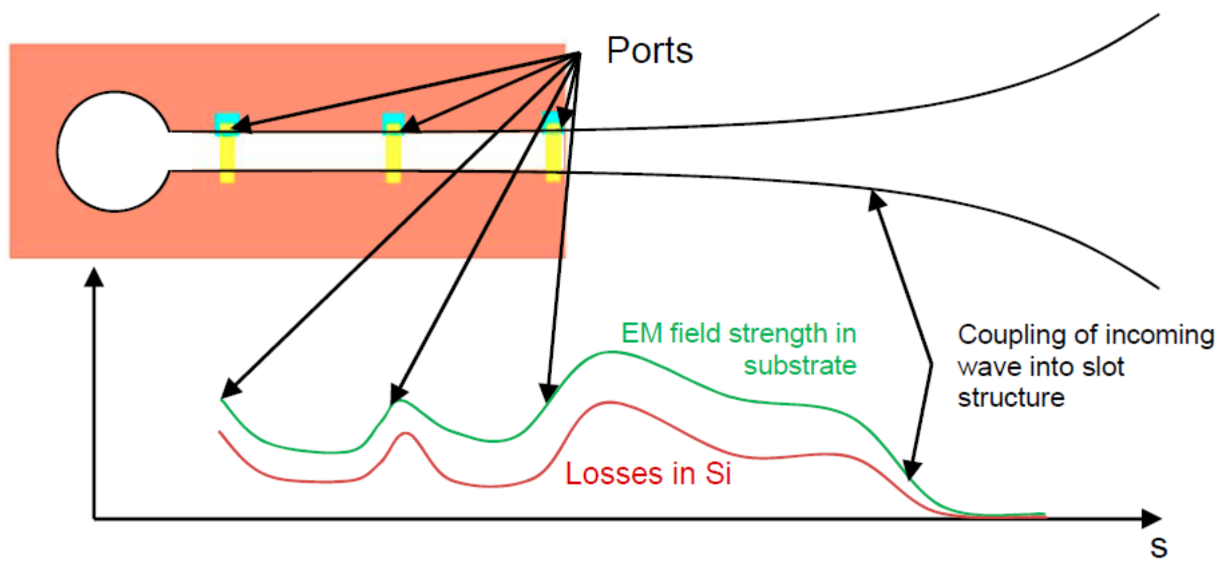
⇒ losses ~ amplitude²

⇒ large substrate losses



Distributed: energy fed via several points

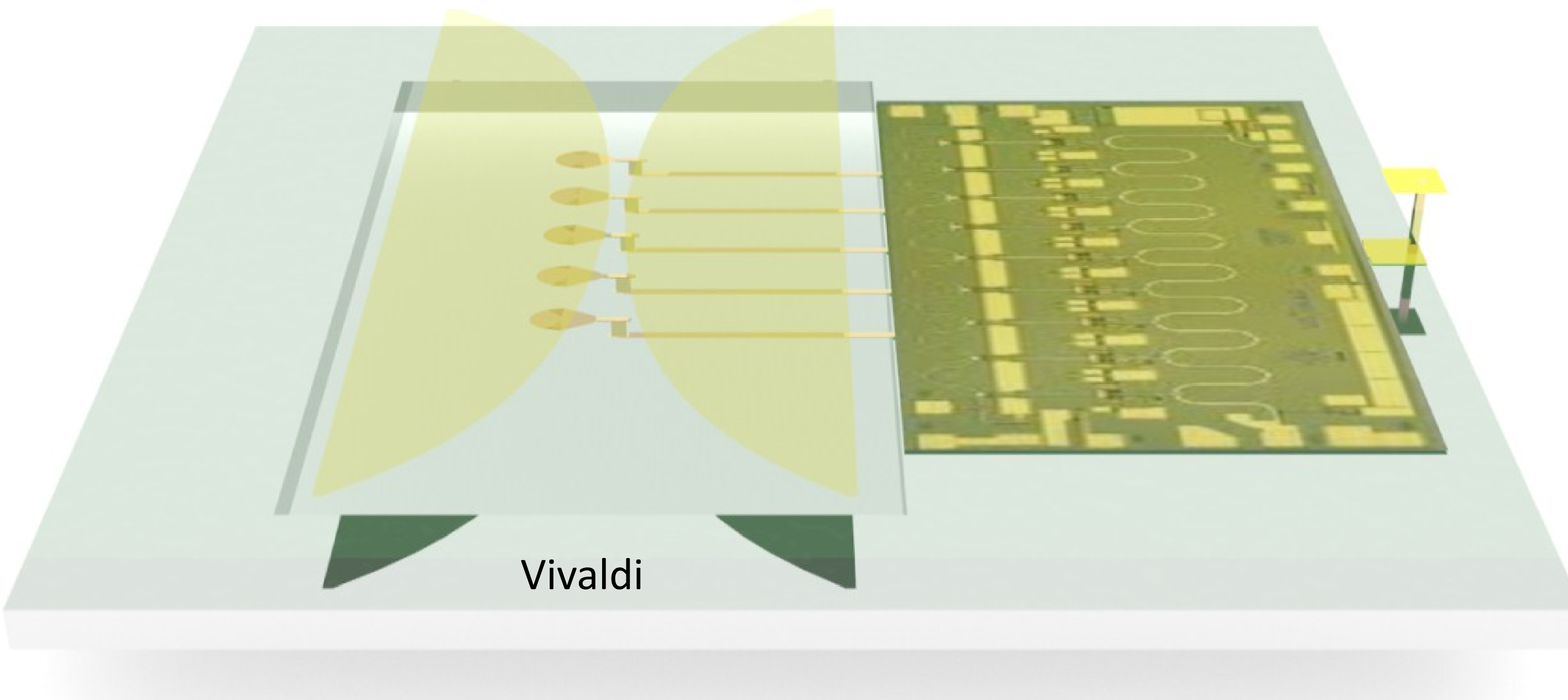
⇒ lower losses



Approach 4: Multiple Antenna Contact Points & Distributed Adding with one TWA

Antenna feeding points as transmission line elements for amplifier towards fully distributed system

⇒ Higher BW



R. Hahnel, D. Plettemeier et. al., Broadside Radiating Vivaldi Antenna for the 60 GHz Band, iWAT 2013

Summary

- **SiGe ICs**

  - 160-210 GHz 22 mW amplifier

  - TWA with 190 GHz BW

  - 60 GHz PA with 23.5 dBm Pout

- **Visions for broadband amp & antenna frontends at 150-250 GHz**

  - Several metal layers to minimize fields penetrating substrate

  - Combined antennas with different feeding points = center freq.

  - Fully distributed systems: antenna feeding points part of amp

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- DFG SPP 100 Gb/s and Beyond

Dresden University of Technology thanks you for your attention!

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