

Tu3E-5

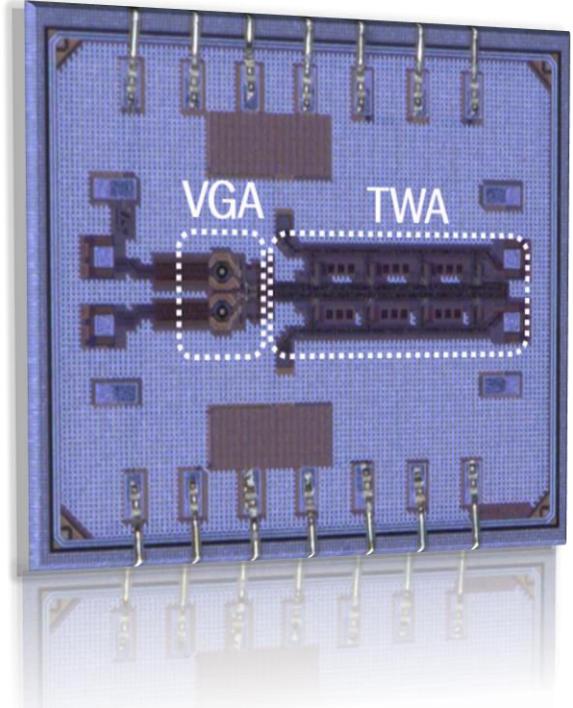
# 120 GBd 2.8 V<sub>pp,diff</sub> low-power differential driver for InP Mach-Zehnder modulator using 55 nm SiGe HBTs

Jung Han Choi, Nisarg Nijanandi

Fraunhofer Heinrich-Hertz Institute, Berlin, Germany

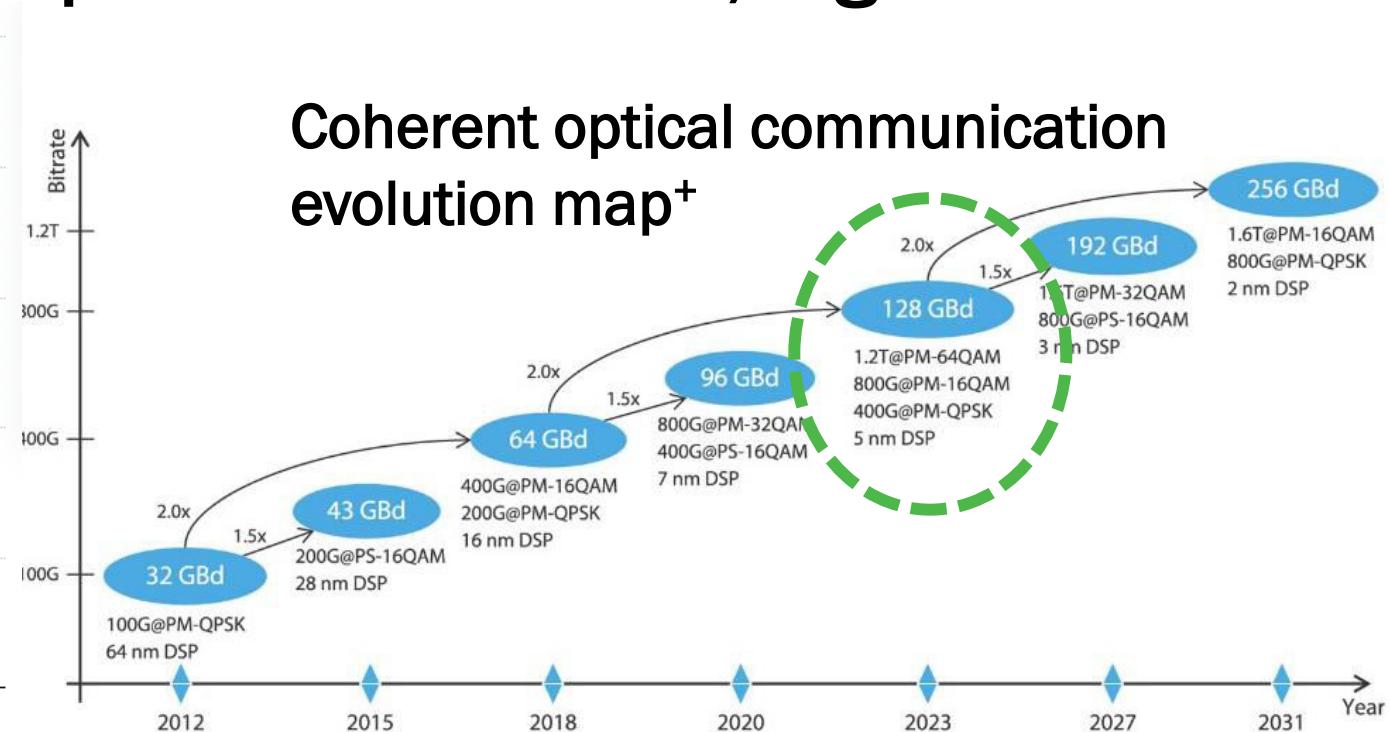
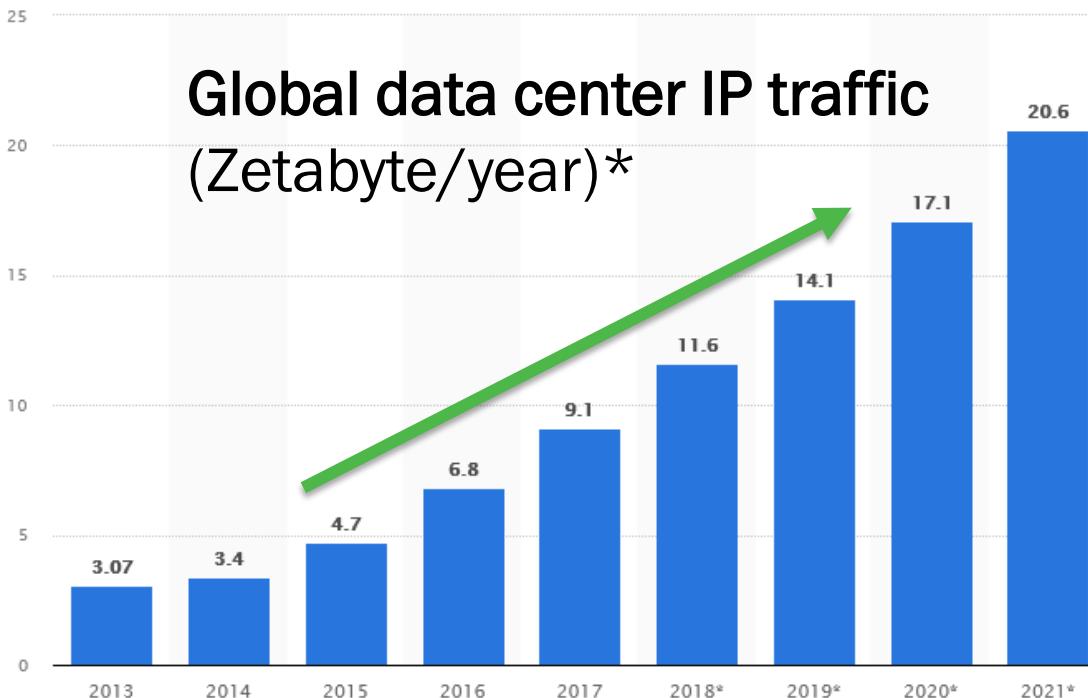
# Outline

- Introduction
- Motivation & Challenges
- Architecture
- Design
- Measurements
- Conclusion



# Introduction

- Data traffic in data center explodes very fast
- Demand for higher speed optical interconnect, e.g. > 100 GBd

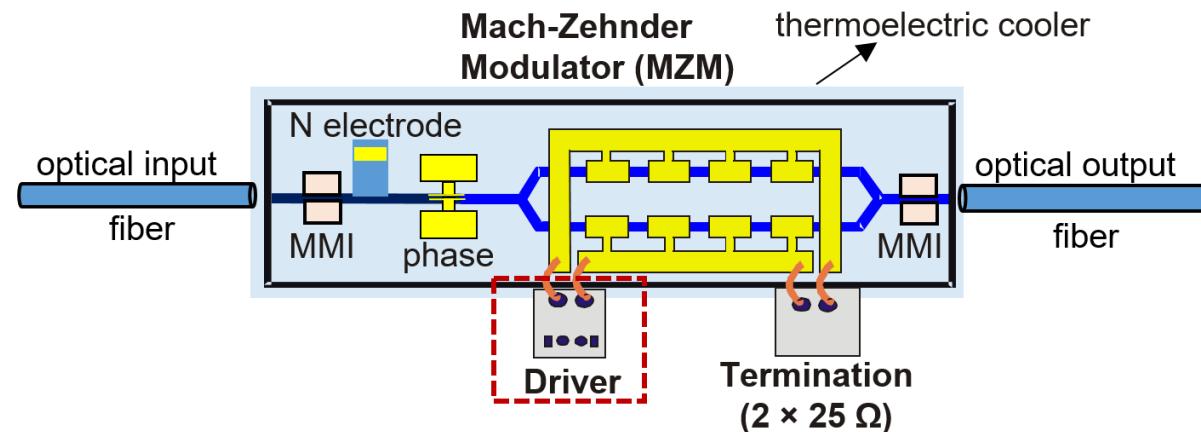


\* source: <https://www.statista.com/statistics/227246/global-data-center-ip-traffic-development-forecast/>

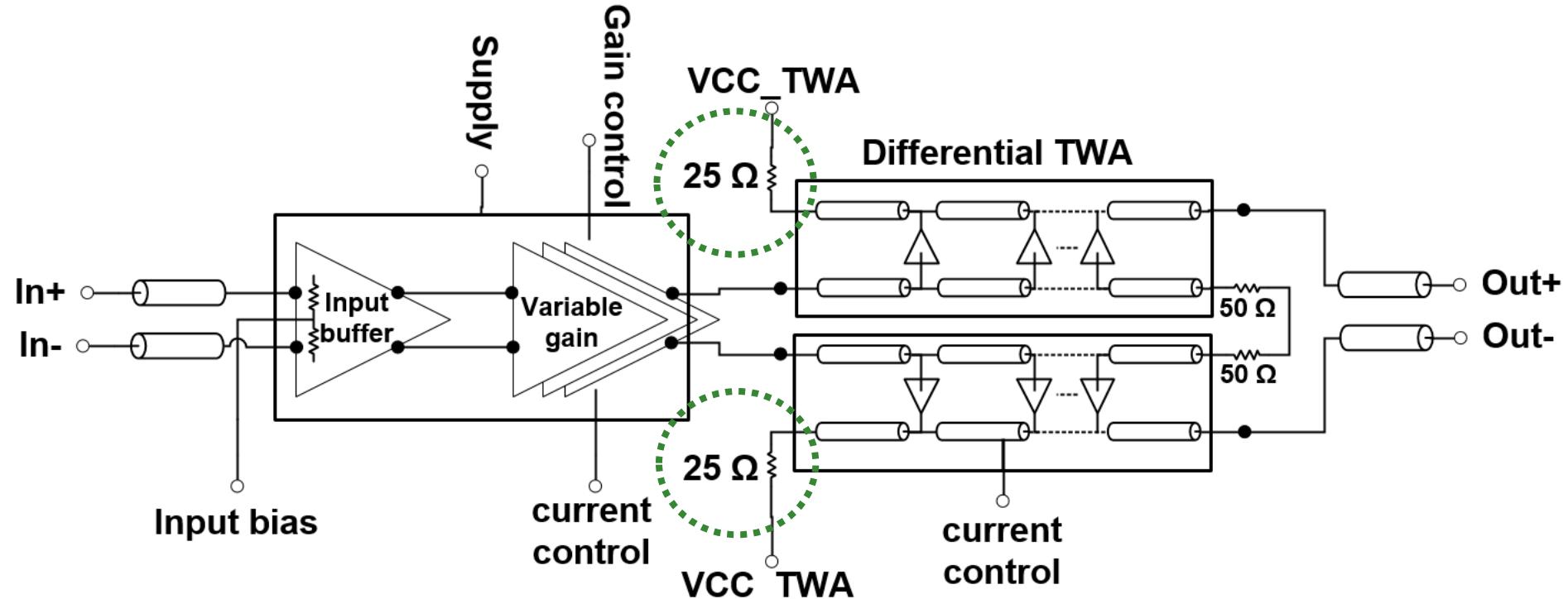
+ source: <https://www.zte.com.cn/global/about/magazine/zte-technologies/2022/6-en/special-topic--intelligent-e-otn/2.html>

- Optical Interconnect Forum (OIF)
  - 128 GBd Implementation Agreement (IA) available since 2021
- Optical modulator for > 100 GBd
  - InP Mach-Zehnder Modulator (MZM), LiNbO<sub>3</sub>, SiPh modulator, etc.
- Electronics for low-power & high-baud rate
  - > 60 GHz electro-optical bandwidth required
  - InP or SiGe HBT mostly used to support high voltage swing
  - Low power driver is of great significance

- Challenges for 120 GBd driver
  - High-voltage swing output:  $3.0 \text{ V}_{\text{pp, diff}}$
  - Non-conventional output (load) impedance:  $2 \times 25 \Omega$
  - Bandwidth:  $> 60 \text{ GHz}$
  - Low-power: no (small) thermal influence to optical device



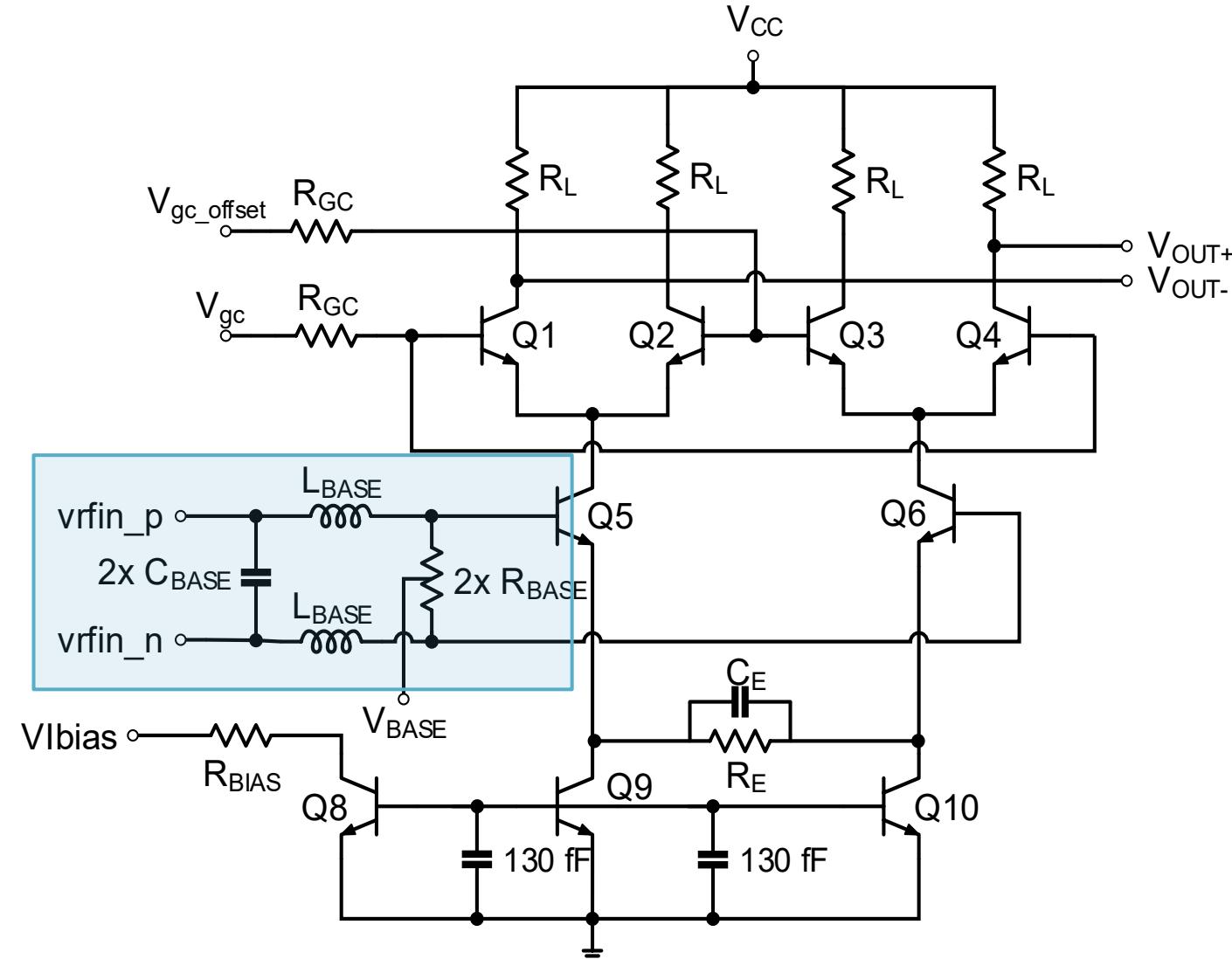
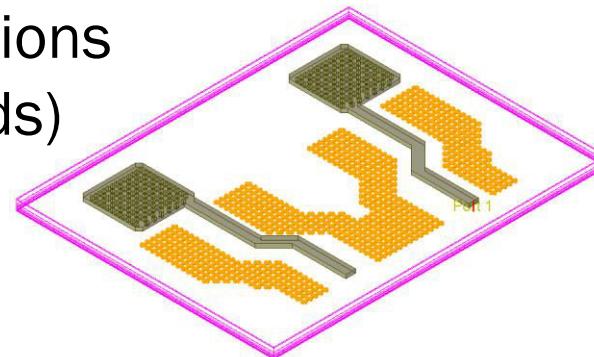
- Variable gain amplifier combines with travelling-wave amplifier
- Differential TWA configuration, Output impedance:  $2 \times 25 \Omega$



# Design

- Input matching 
  - $R_{BASE}$  combines with  $L_{BASE}$  and  $C_{BASE}$ .
- Pad impedance
  - Modeled as 30 fF

EM Simulations  
(input pads)



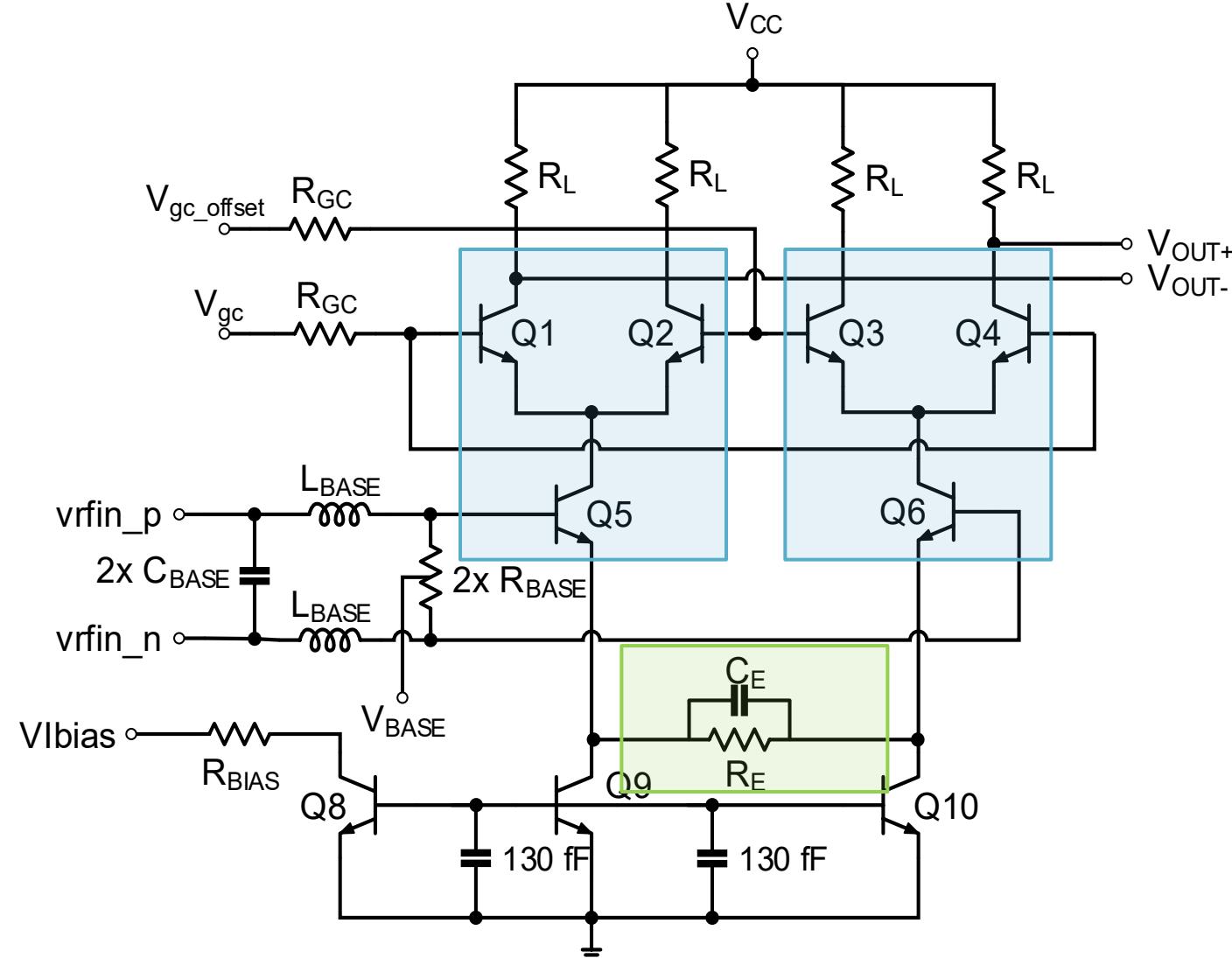
# Design

- Gilbert-Cell for VGA 
- Broadband degenerate emitter  $R_E \parallel C_E$  

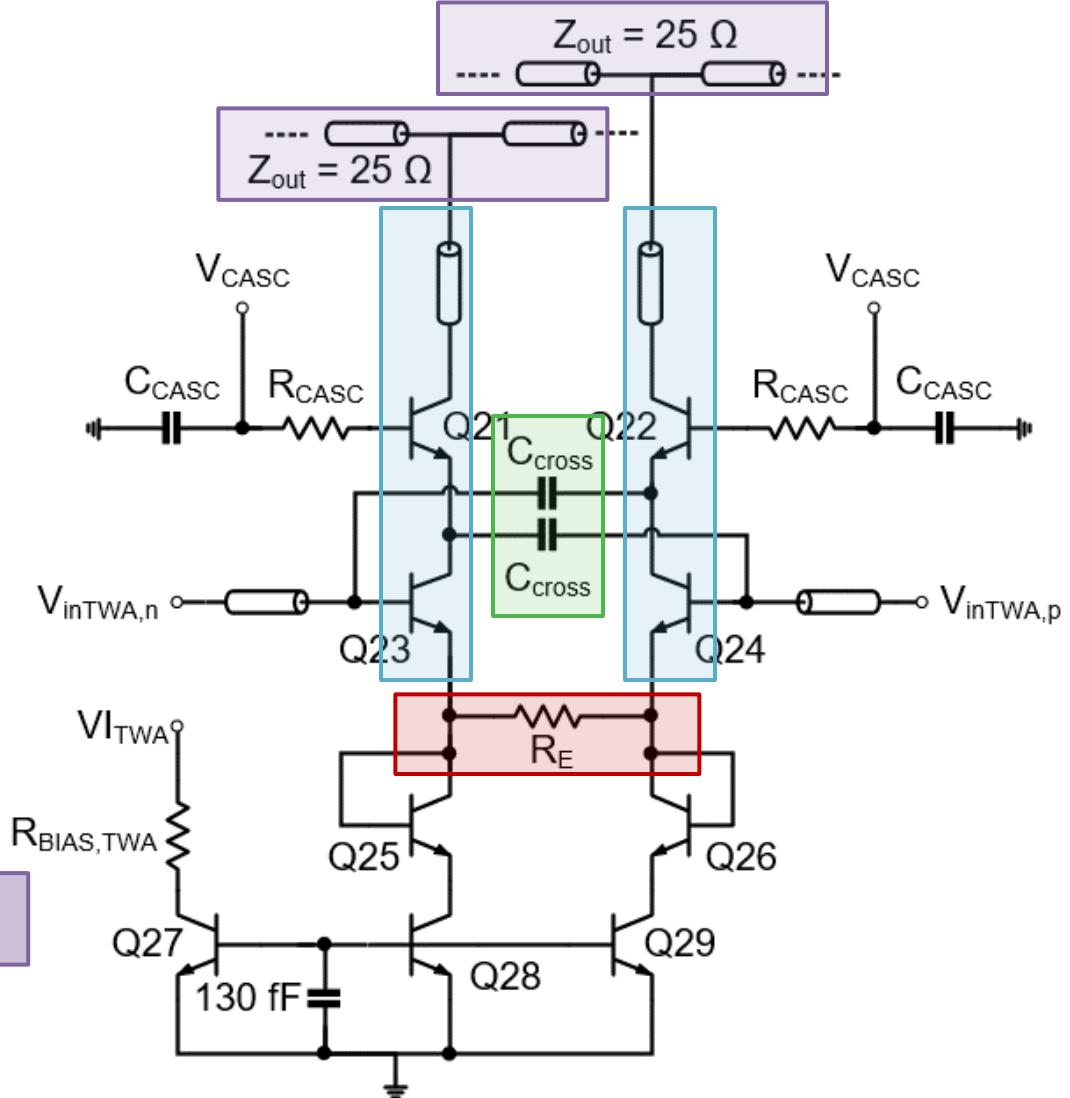
$$A_V = \frac{V_{out}}{V_{in}} = \frac{R_L}{Z_E} \tanh\left(\frac{V_{GC}}{2V_T}\right)$$

$$V_{in} = V_{rf_{in\_p}} - V_{rf_{in\_n}}$$

$$Z_E = R_L \parallel C_E, V_{GC} = V_{gc} - V_{gc\_offset}$$

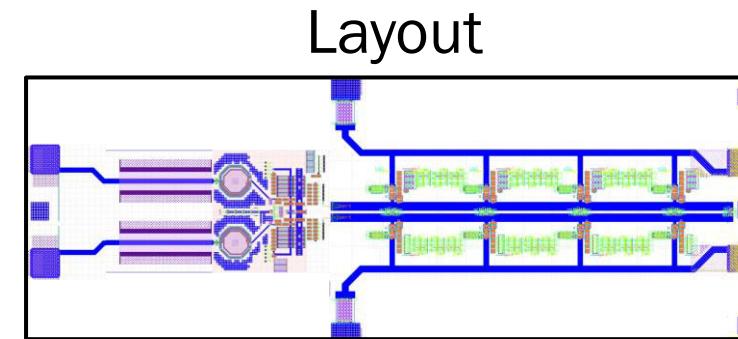
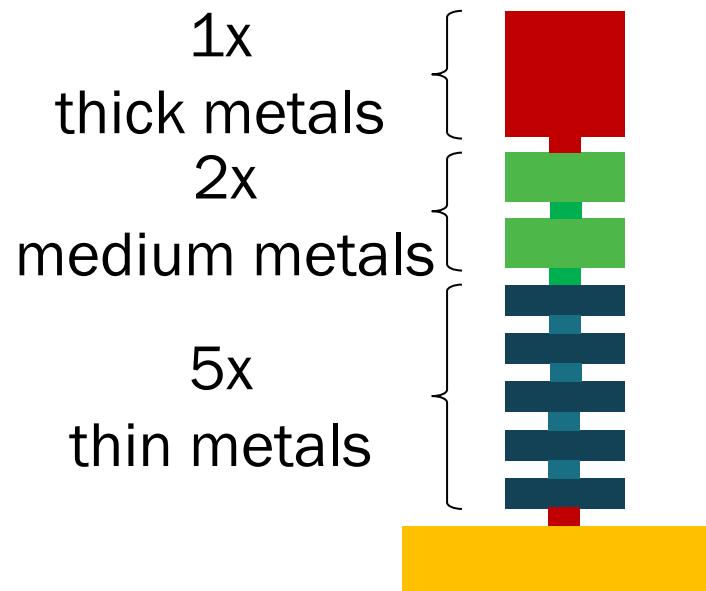


- Differential TWA
- Cascode configuration 
- High-output voltage swing
- Cross-coupled capacitor 
- $C_{\text{cross}}$ : 17 fF
- Emitter degenerate 
- $R_E$ : 35  $\Omega$
- Output transmission line: 25  $\Omega$  

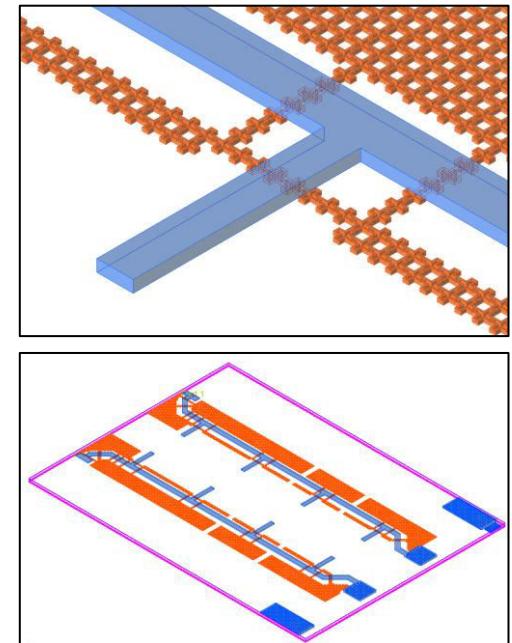


# Design

- 55nm SiGe HBT, 326 GHz  $f_T$  / 376 GHz  $f_{MAX}$ , 1.5V  $BV_{CEO}^*$
- 9 metals (incl. AP), high-Q passives (thick Cu layer)\*

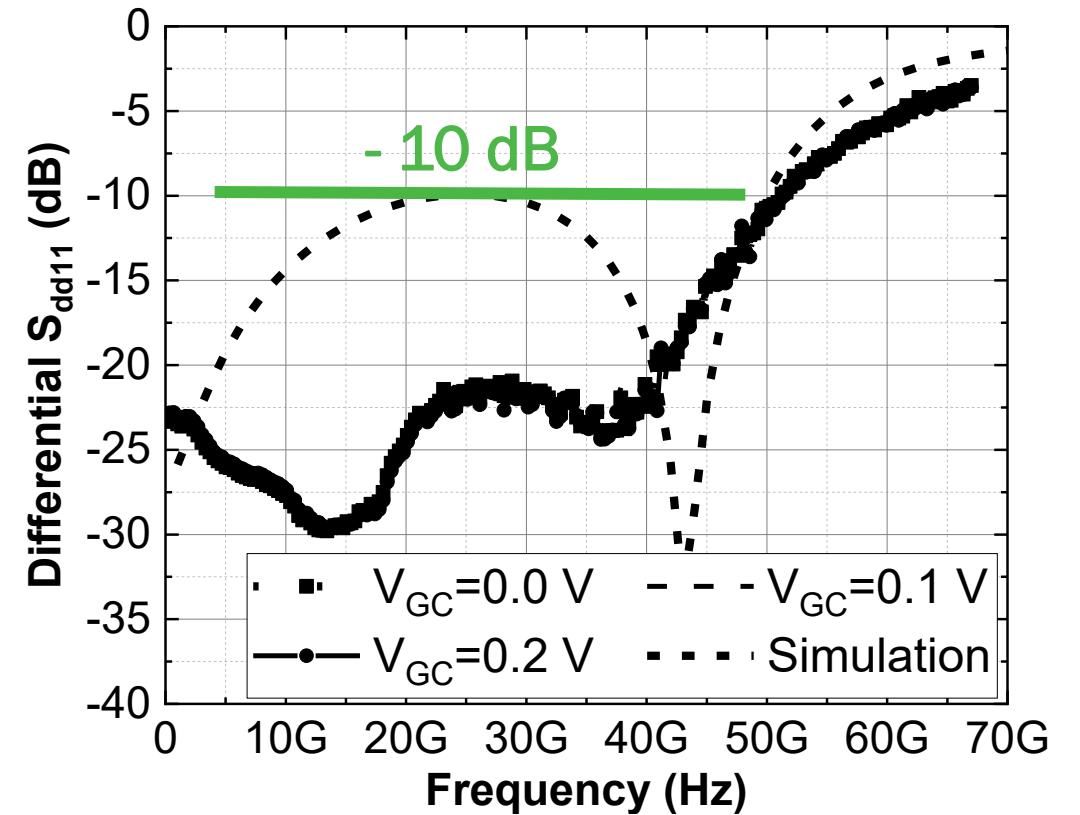
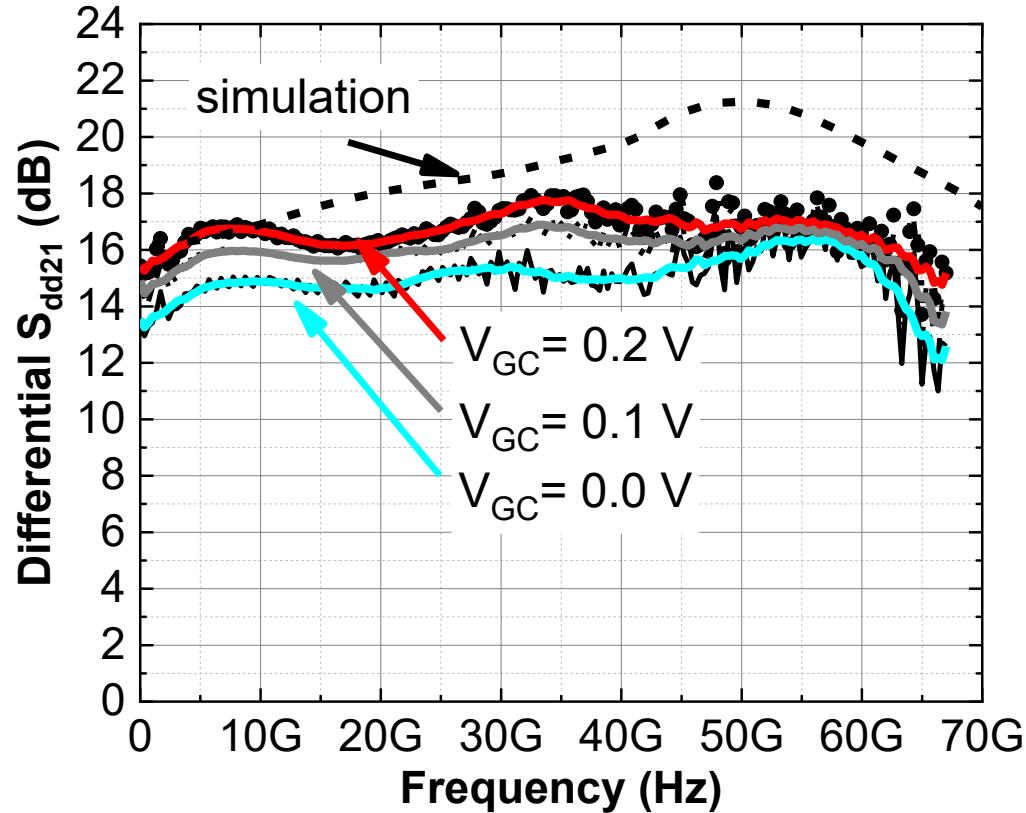


EM Simulations

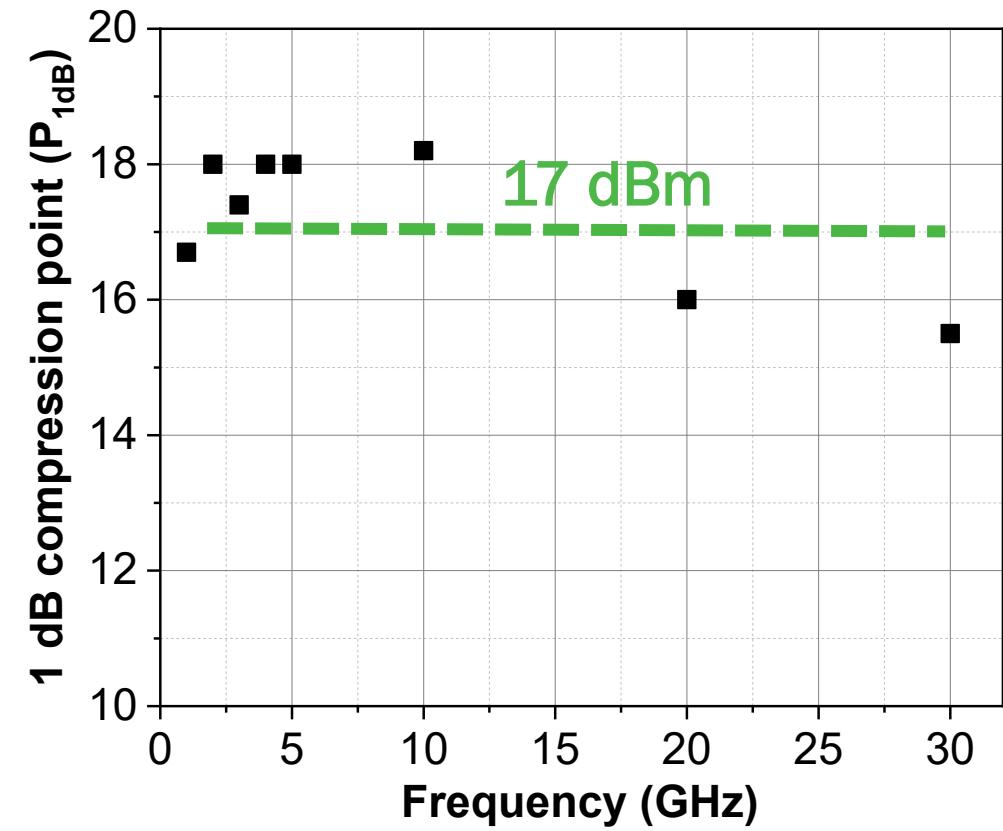
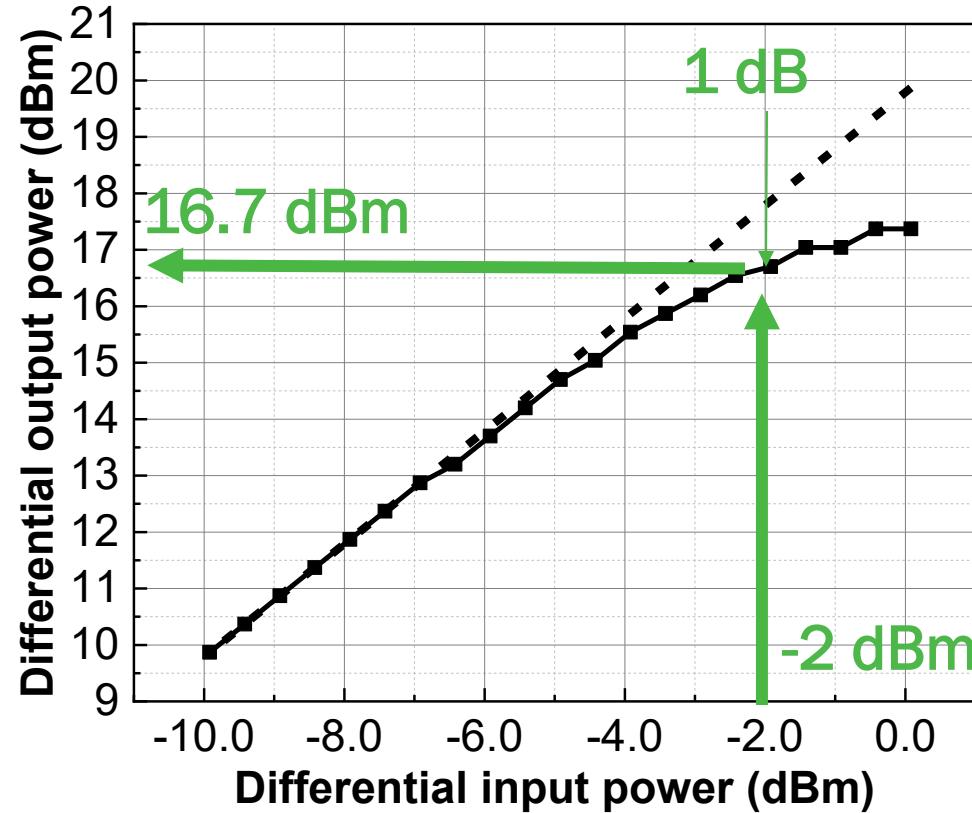


\* source: Pascal Chevalier, 55nm SiGeBiCMOS for Optical, Wireless and High-Performance Analog Applications, EuMC2015, WS12: EuMIC-SiGe for mm-Wave and THz

- Differential large-signal S-Parameters @ -3 dBm
  - Bandwidth: > 67 GHz, Reflection < -10 dB up to 50 GHz

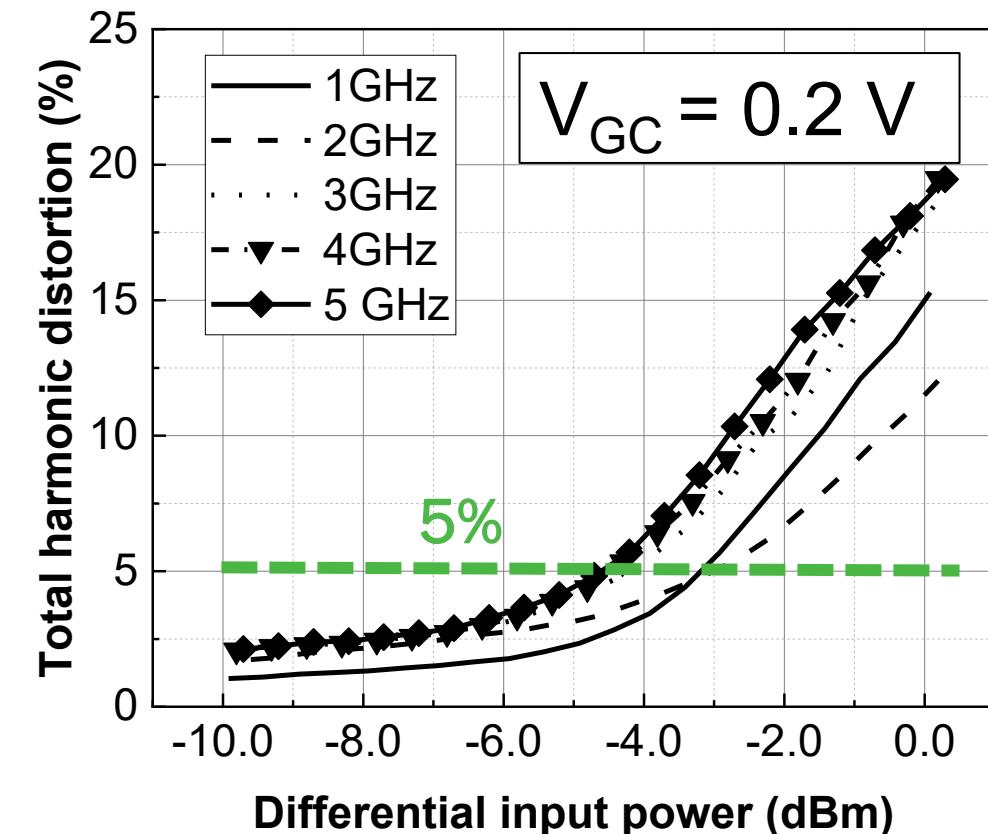
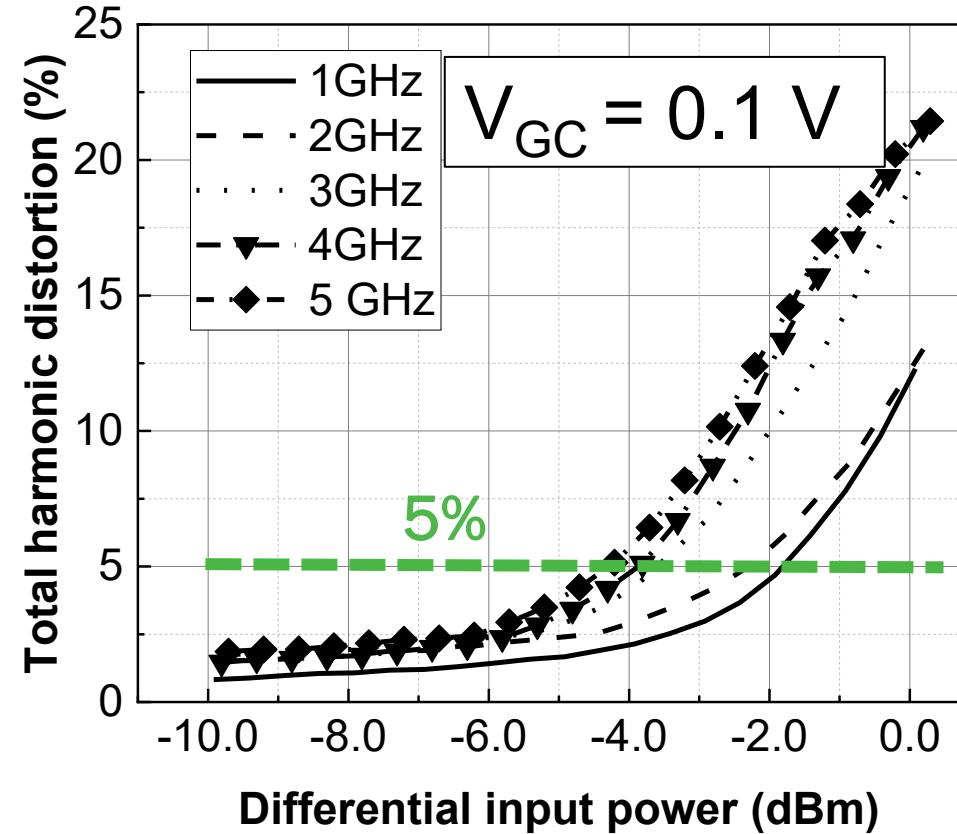


- Nonlinearity measurements @ 45°C, load impedance: 2x 25 Ω



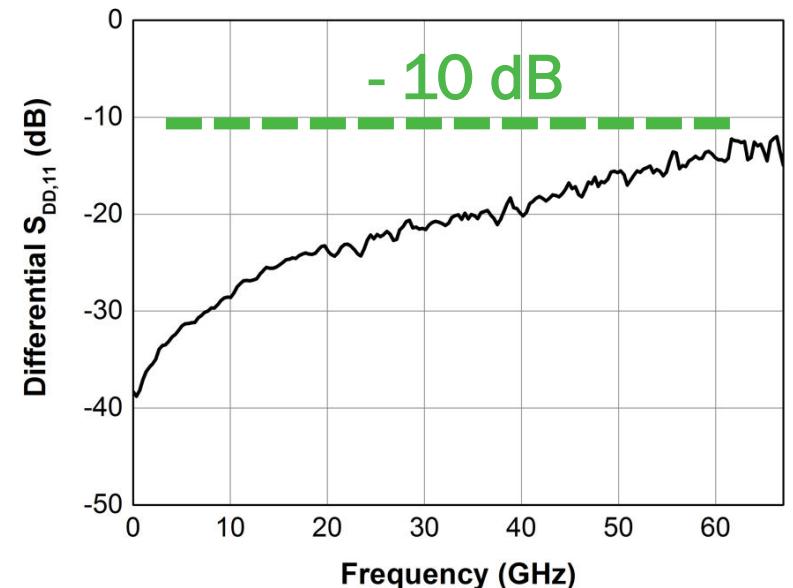
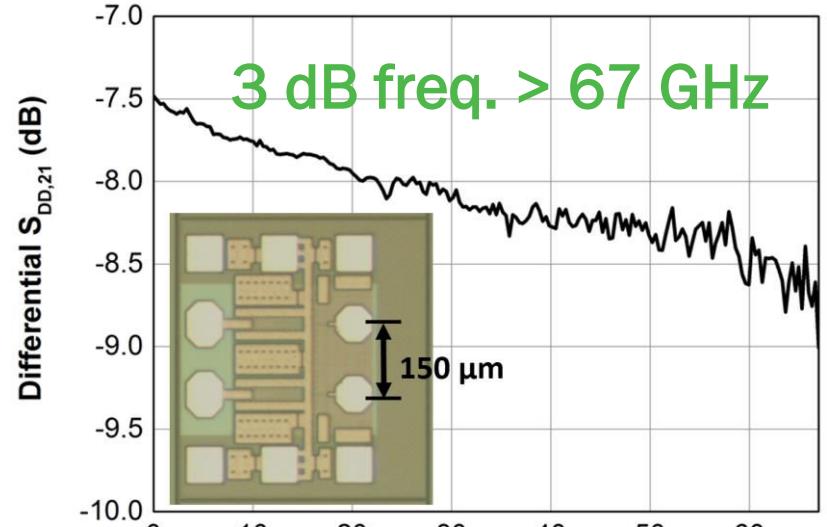
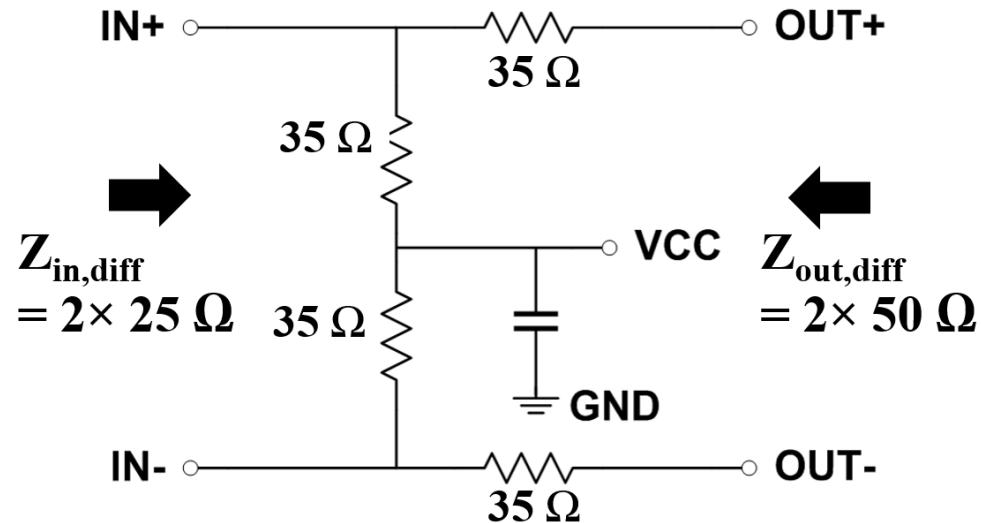
# Measurement

- Total-harmonic distortion: 45°C, load imp.:  $2 \times 25 \Omega$ , -5 dBm
  - 2.5 % @ 1 GHz, < 5% up to 5 GHz



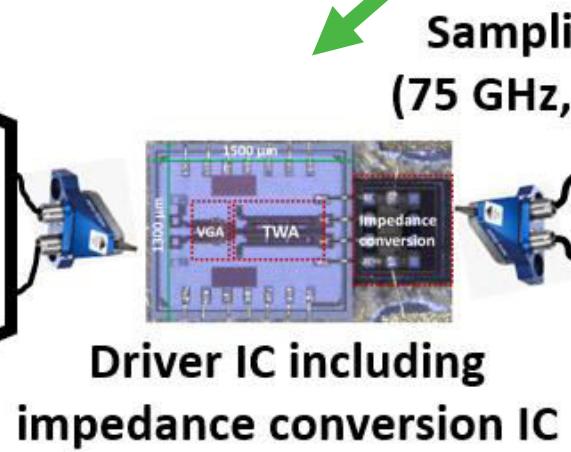
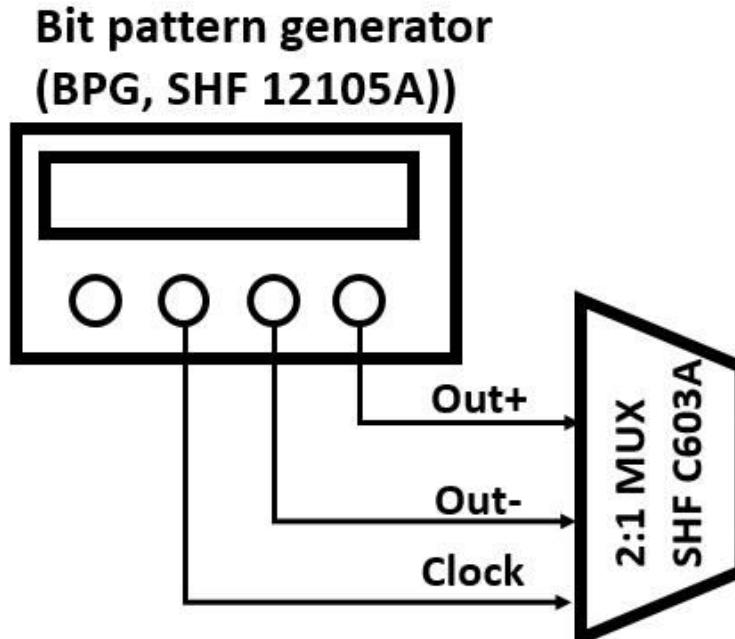
# Measurement

- Time-domain measurement
  - Impedance conversion IC
    - $2 \times 25 \Omega \rightarrow 2 \times 50 \Omega$

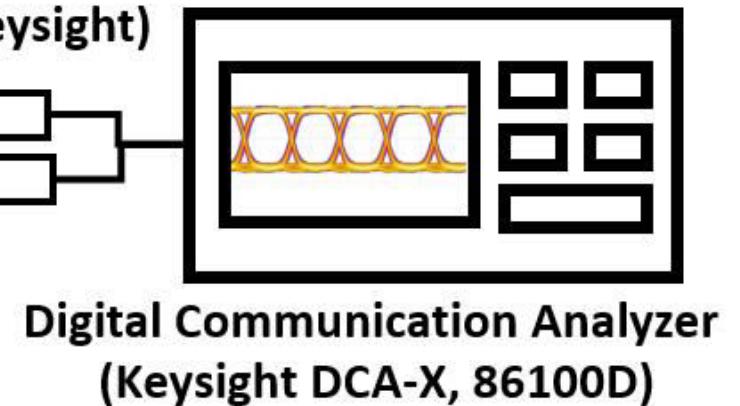


# Measurement

- Time-domain measurement

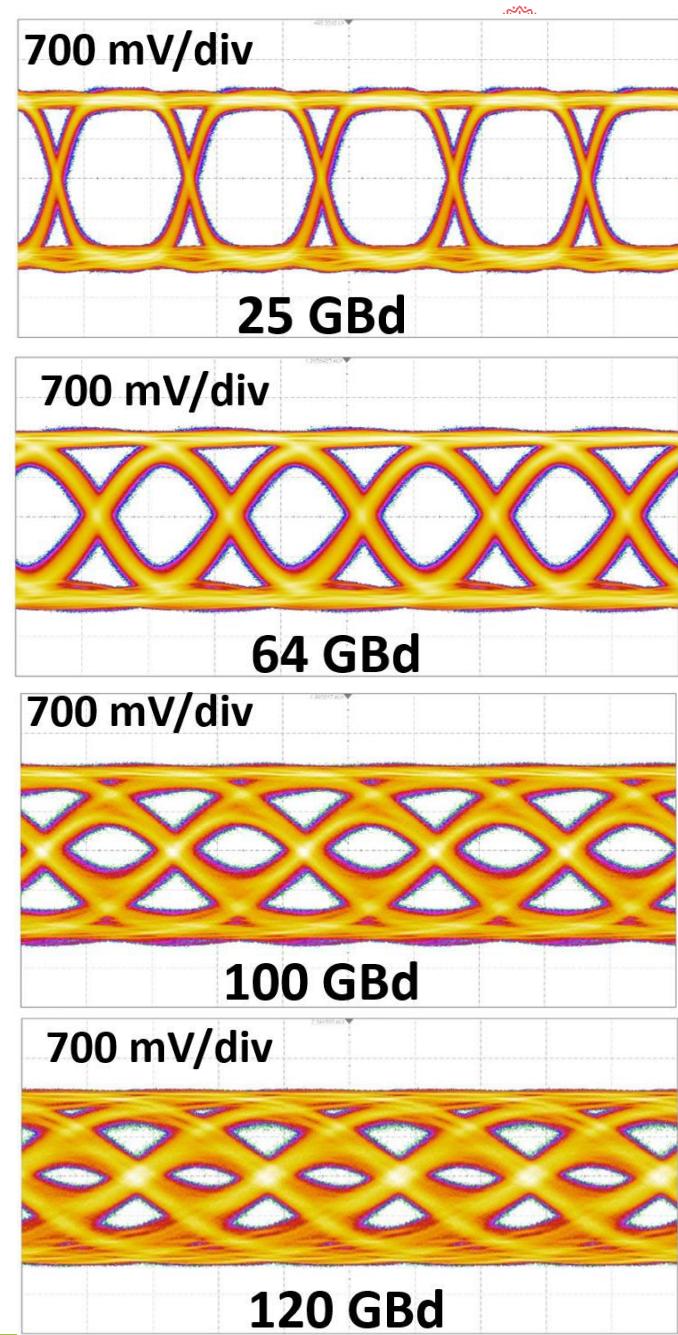


**Sampling head (75 GHz, Keysight)**



# Measurement

- Time-domain measurement
  - De-embedding
    - Impedance conversion IC, probes, etc.
    - Software: Keysight Pathwave ADS
  - $2.8 \text{ V}_{\text{pp, diff}}$  rail-to-rail up to 120 GBd for  $2 \times 25 \Omega$
  - Power: 960 mW

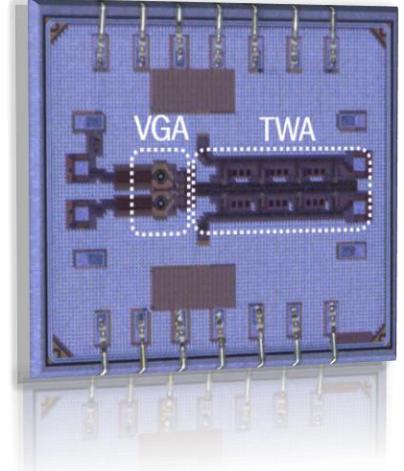


# State-of-the-Art

Ref.	Bandwidth (GHz)	Data rate (GBd)	Technology	Output (V <sub>pp</sub> )	Load impedance	Output (differential)	Driver type	Optical component (load)	Power (W)
[6]	-	140	SiGe HBT 150nm	2	capacitive load	diff.	Multiplexer	Plasmonic organic hybrid MZM	7.15
[7]		222	InP DHBT	0.24/0.73	capacitive load	diff.	2:1 multiplexing selector	Plasmonic organic hybrid MZM	0.5 / 0.8
[8]		100	SiGe HBT 180 nm	-	-	-	-	InP MZM	-
[9][10]	> 67	128 (176)	InP DHBT	1.5	<b>2x 25 Ohm</b>	diff.	lumped + distributed	InP MZM	0.84
[11]	> 70	56	SiGe HBT 55nm	4.8	2x 50 Ohm	diff.	distributed	-	1.1
[12]	90	120	SiGe HBT 130 nm	4	2x 50 Ohm	diff.	distributed	-	0.55
[13]	57.5	56	SiGe HBT 55nm	3.8	2x 50 Ohm	diff.	lumped	Silicon Photonic MZM	0.82
<b>This work</b>	<b>&gt; 67</b>	<b>120</b>	<b>SiGe HBT 55nm</b>	<b>2.8</b>	<b>2x 25 Ohm</b>	<b>diff.</b>	<b>lumped + distributed</b>	<b>InP MZM</b>	<b>0.96</b>

# Conclusion

- 120 GBd driver for InP MZM modulator
  - 55 nm SiGe HBT
  - Variable gain amplifier integrated with TWA
  - $2.8 \text{ V}_{\text{pp, diff}}$  rail-to-rail up to 120 GBd for  $2 \times 25 \Omega$
  - Total harmonic distortion: 2.5 % @ 1 GHz, < 5% up to 5 GHz
  - Power consumption: 960 mW
- State-of-the-art performance
  - Highest output voltage swing for  $2 \times 25 \Omega$  load
  - Next: electro-optical submount measurement



# References

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