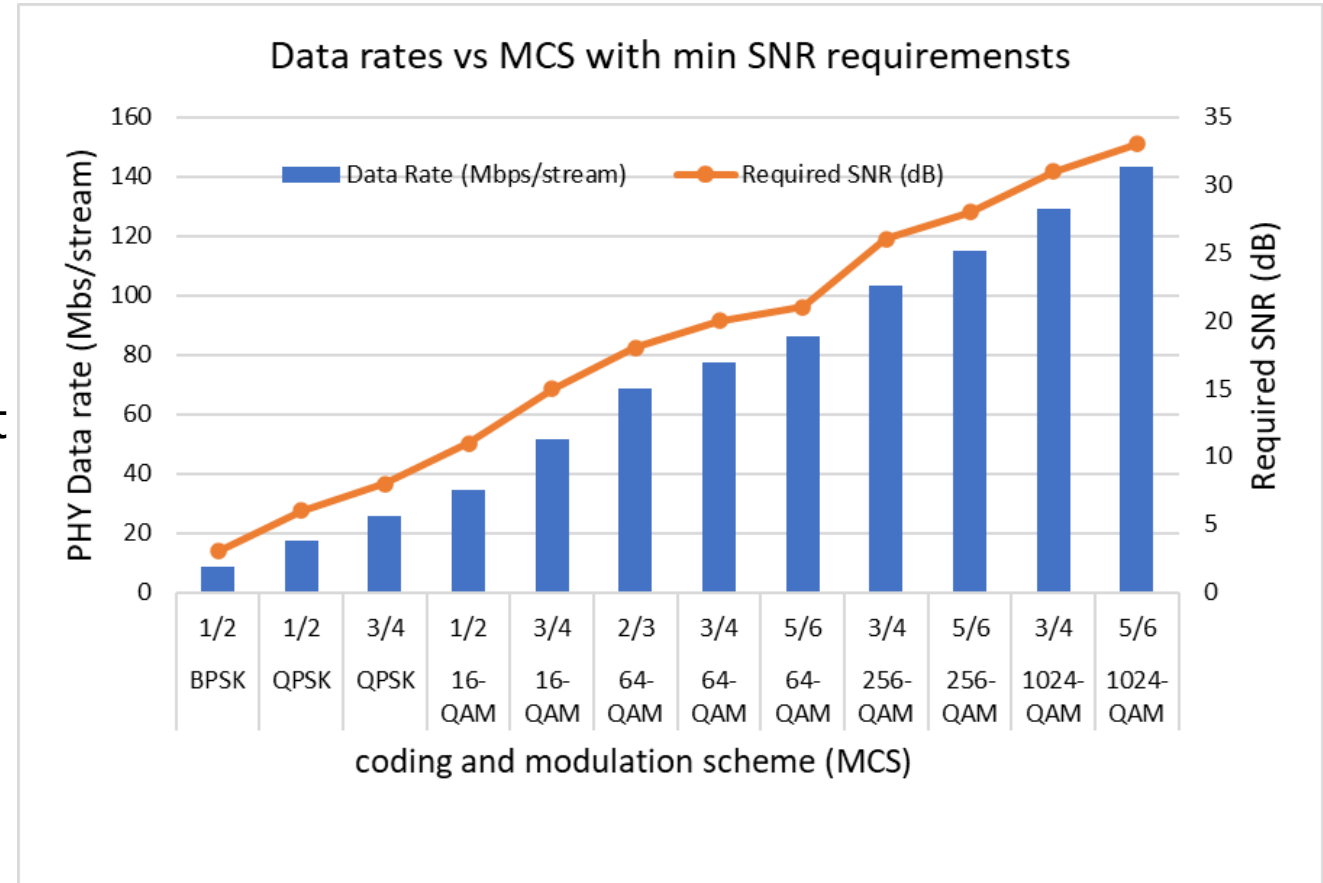


Opportunities for innovation in integrated device technologies

Solutioning thirst for more data

- Identified pathways to increasing data rates
 - Higher order modulation schemes
 - Significantly larger bandwidth
- Technology challenge is the SNR requirement
 - Must improve receiver sensitivity
 - Must improve transmit power and efficiency

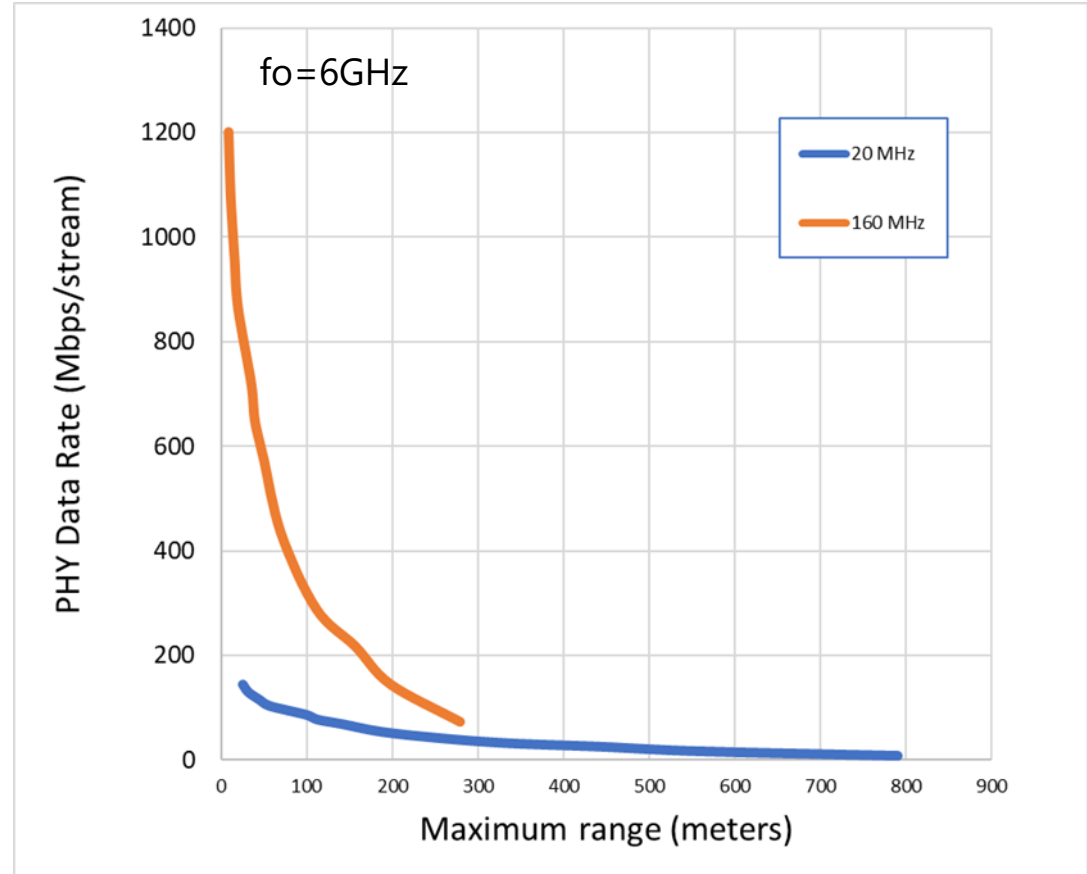


Scenario: WiFi6 (802.11ax), 20MHz Bandwidth, and a 400ns Guard Interval

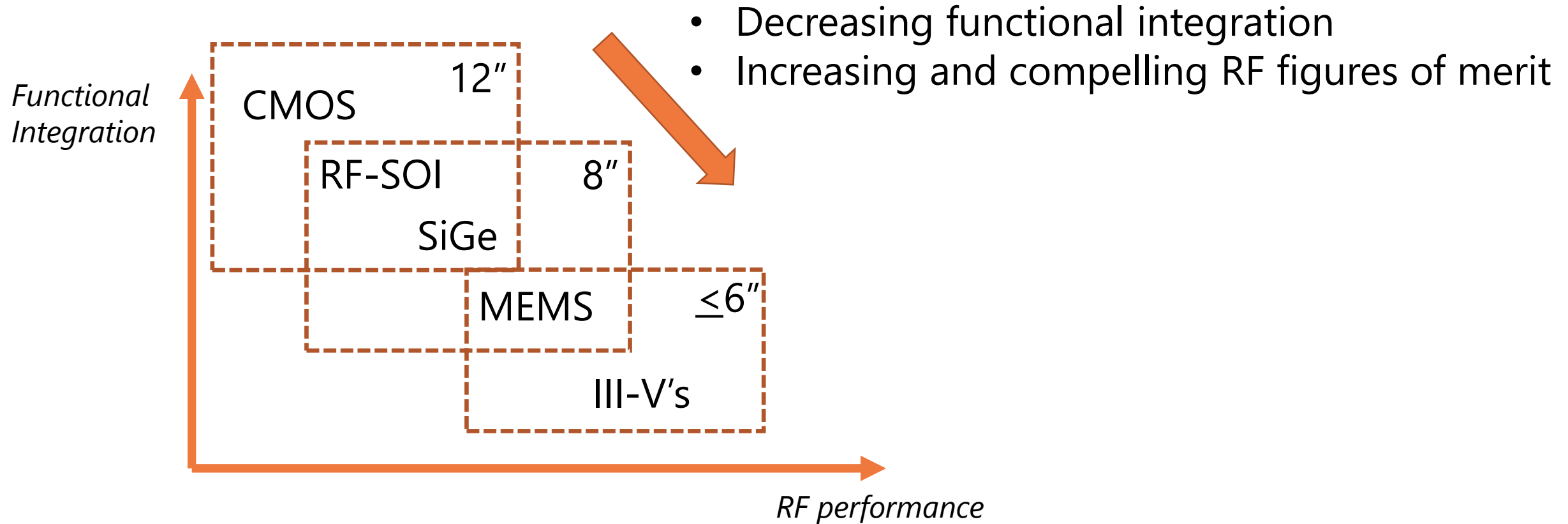
Challenge and opportunity

- Need for better performance
 - Individual components – linearity, noise, gain
 - Functional integration – cost, convenience, performance
- Need for also scale and cost
 - Short ranges will require network densification
 - Densification will require higher quantities and likely exacerbated with mMIMO
 - Acceptable supply risks for deployment

Sample calculation of maximum LOS range for typical mobile device (SISO)

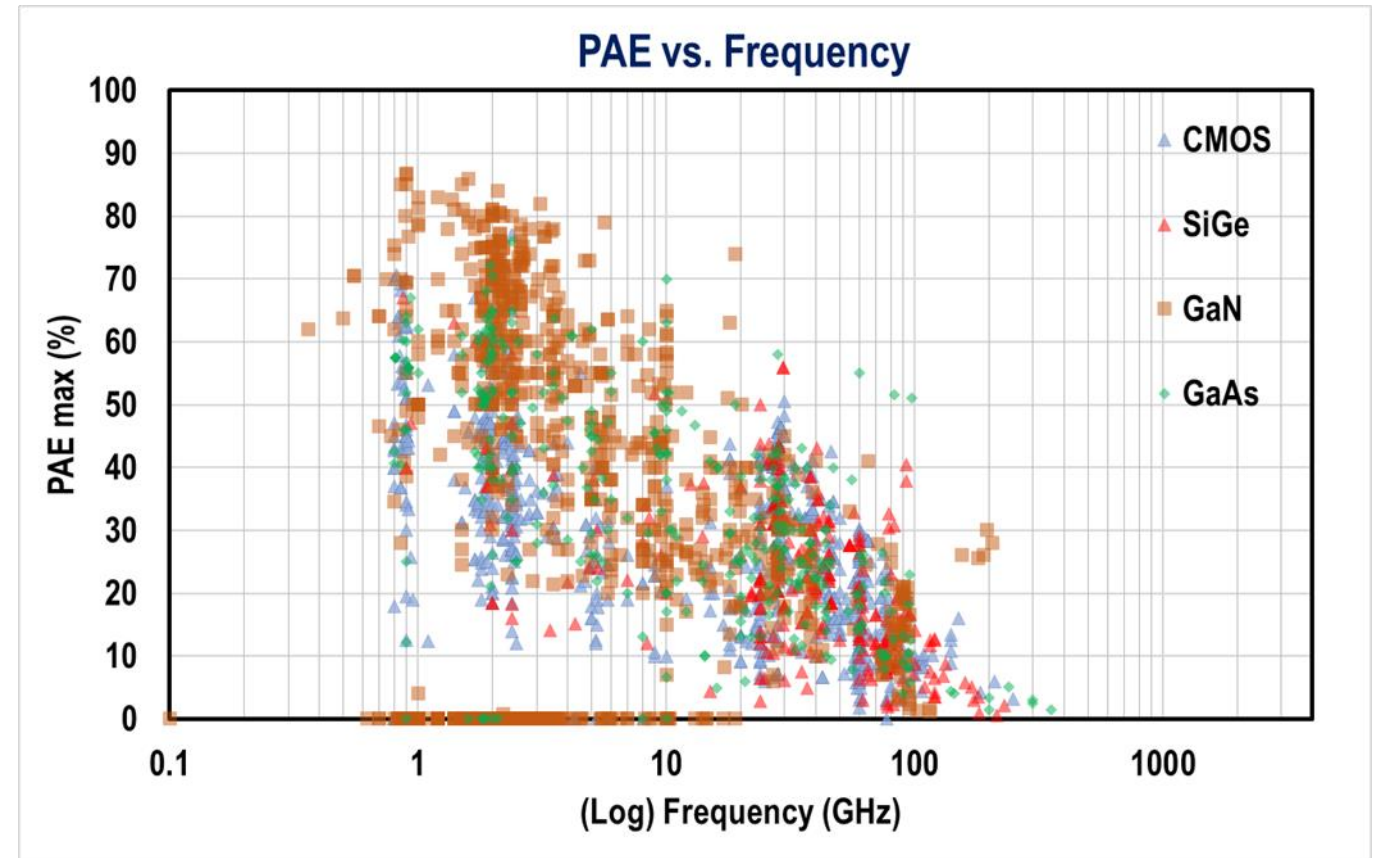


Inputs: 15dBm Tx radiated power, -10dBi Rx antenna gain, and a cascaded NF of 2.4dB



Technology – Tx perspective

- Incumbent 4G technologies have weaknesses for mmW
 - Efficiency
 - Output power
- Growing interest in alternatives
 - SiGe
 - GaN

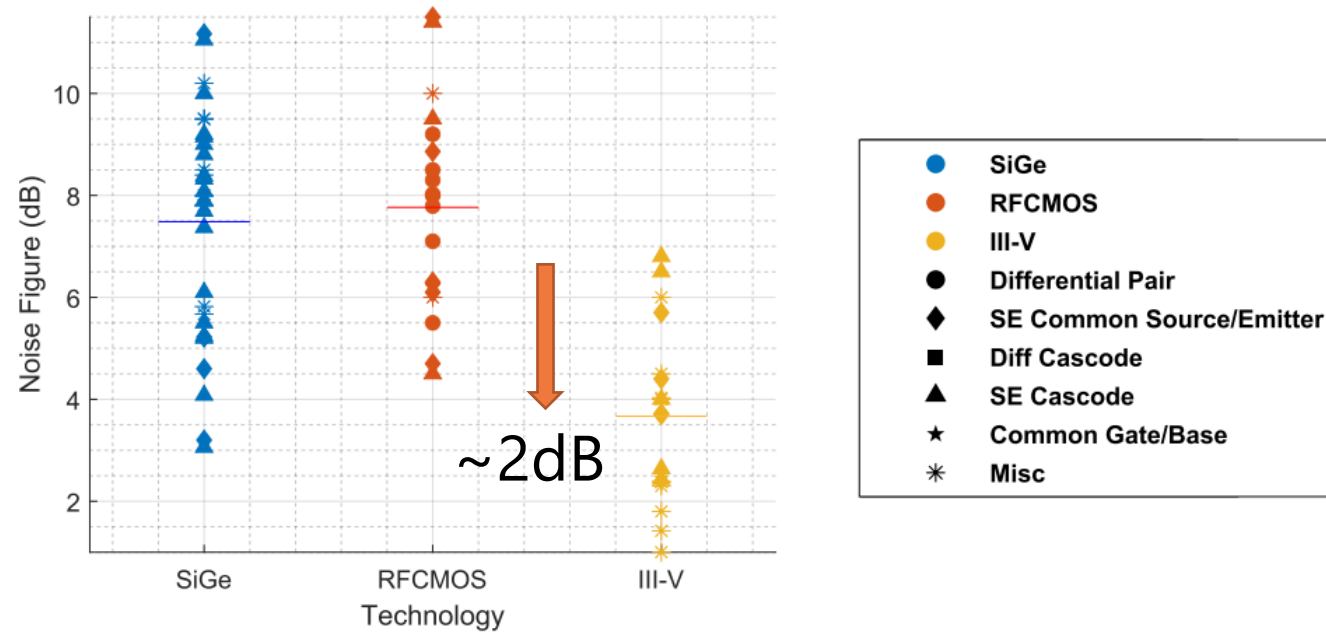


Reference: https://gems.ece.gatech.edu/PA_survey.html

Technology – Rx perspective

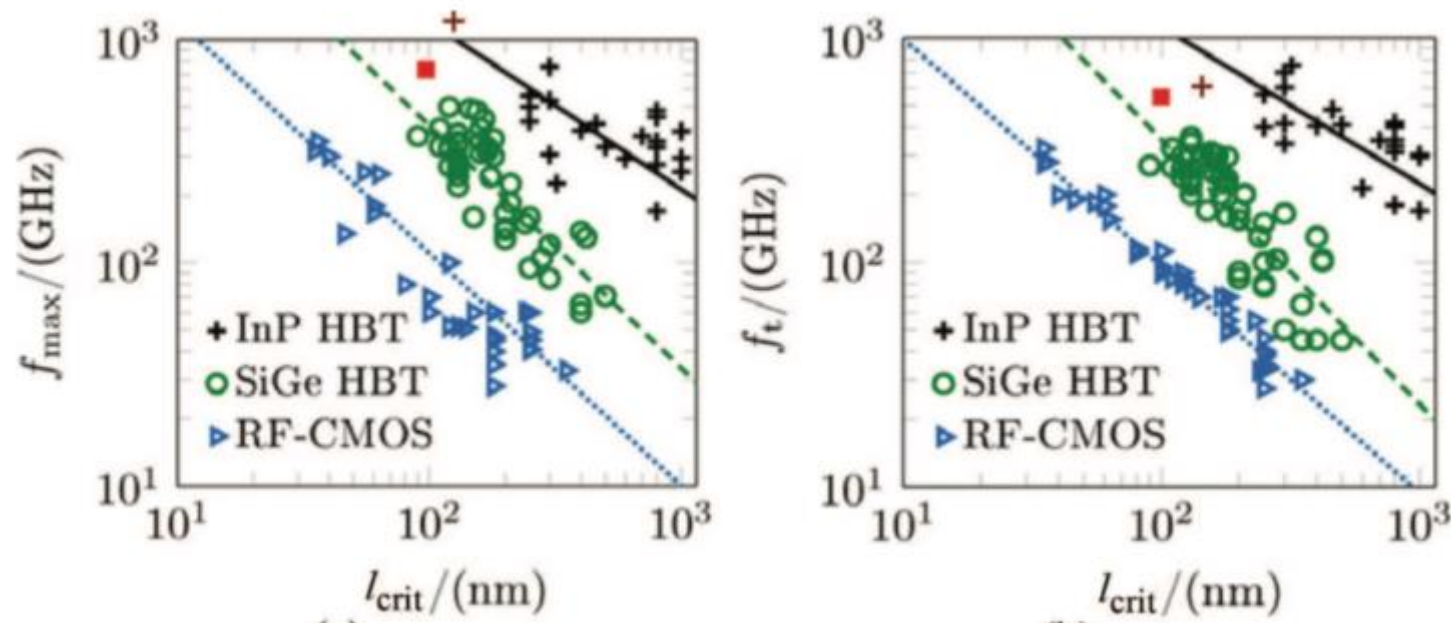
- III-V's have attractive noise figures and linearity with similar Pdc as RFSOI and SiGe
- GaN similarly attractive with higher CP1 but at the expense of Pdc (~10x)

Literature survey of LNA performance in F-, D-, and G-Bands (80–200 GHz)¹



¹Stadler, P.; Papurcu, H.; Welling, T.; Tejero Alfageme, S.; Pohl, N. An Overview of State-of-the-Art D-Band Radar System Components. *Chips* **2022**, *1*, 121-149. <https://doi.org/10.3390/chips1030009>

Technology figures of merit comparison: RF-CMOS, SiGe, & InP

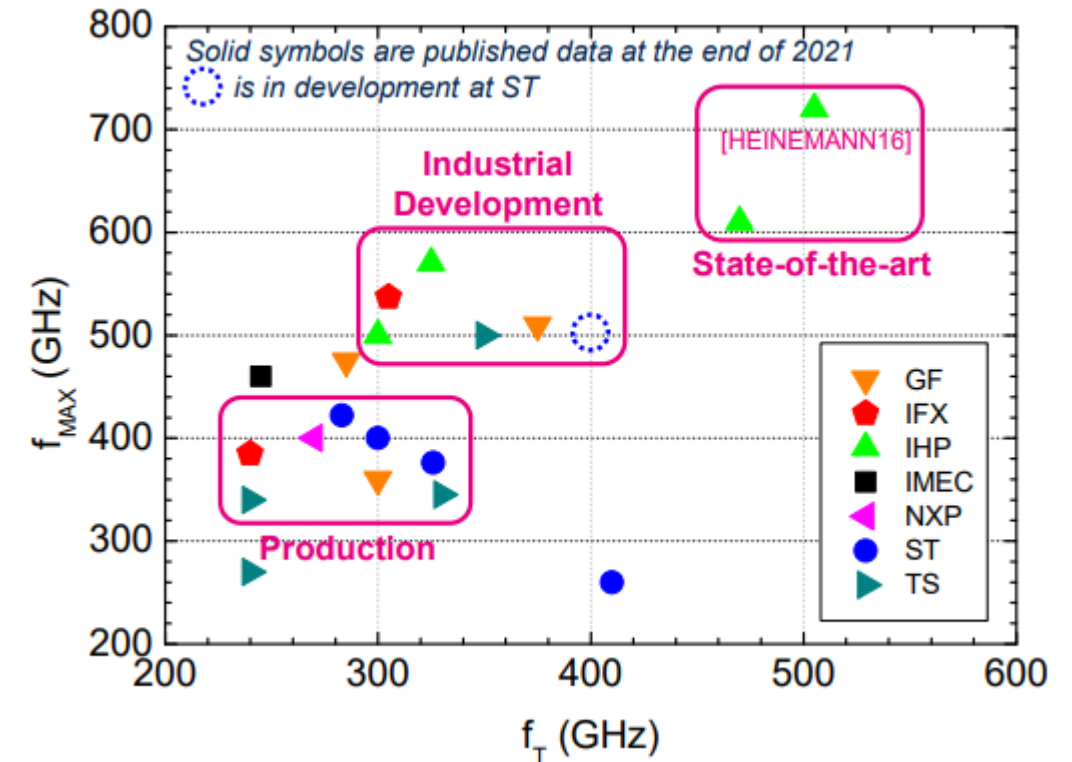


- mmW capable technologies exist
- Key differentiation is availability, scale, integration, and cost

Reference: M. Schroter, U, Pfeiffer, R, Rain, "Future of SiGe HBT Technology and Its applications"

SiGe BiCMOS - context

- Integrated within CMOS (500nm – 45nm)
 - Foundry and IDM players
 - Steady performance evolution and migration to 300mm platforms
 - Good functional integration & backend compatibility
- Showcase has been the SiGe HBT
 - Bandgap engineered device
 - Good noise performance – both low and high frequency
 - Larger breakdown and reliable operation for PA's



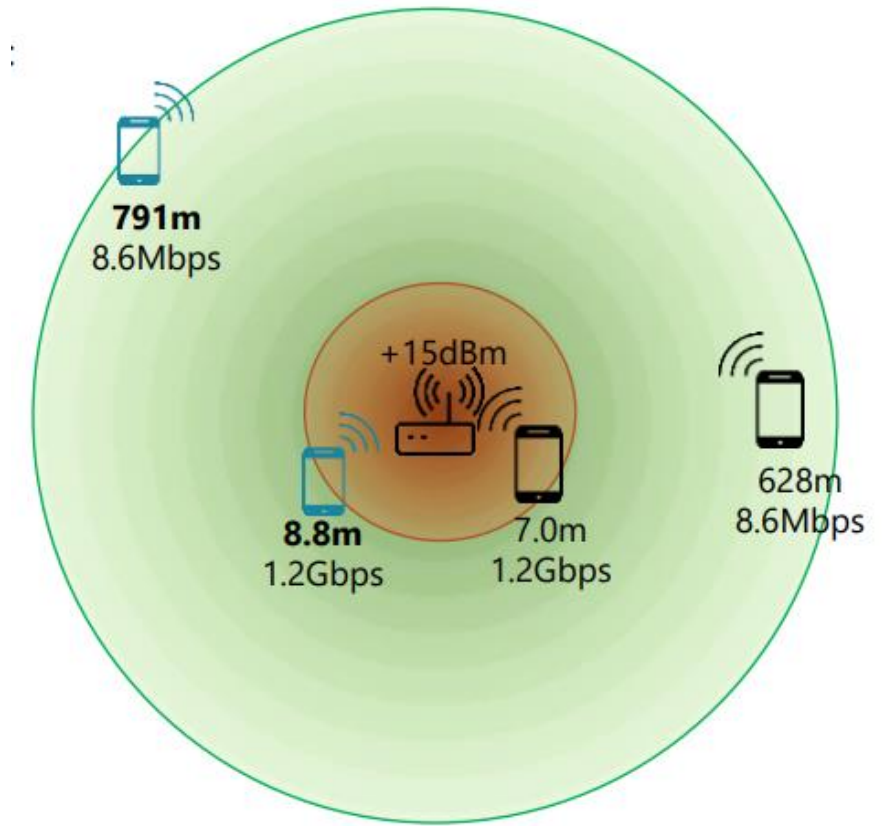
Reference: P. Chevalier, BCICTS short course 2022

SiGe BiCMOS – opportunity

Calculated maximum LOS range comparison for WiFi FEM with improved SP2T performance. Ref : NXP WLAN8101C

- RF-SOI is the dominant technology for RF switching
 - State of the art RonCoff figure of merits is $< 100 \text{ fs}^1$
 - Whereas SiGe BiCMOS switch performance $> 300 \text{ fs}^2$
- Minimizing RF switching losses is a benefit to the entire RF sub-system
 - Antenna switch (eg FR2 is TDD)
 - Phase shifting
 - Digital attenuators
 - Variable gain amplifiers

} Analogue beamforming

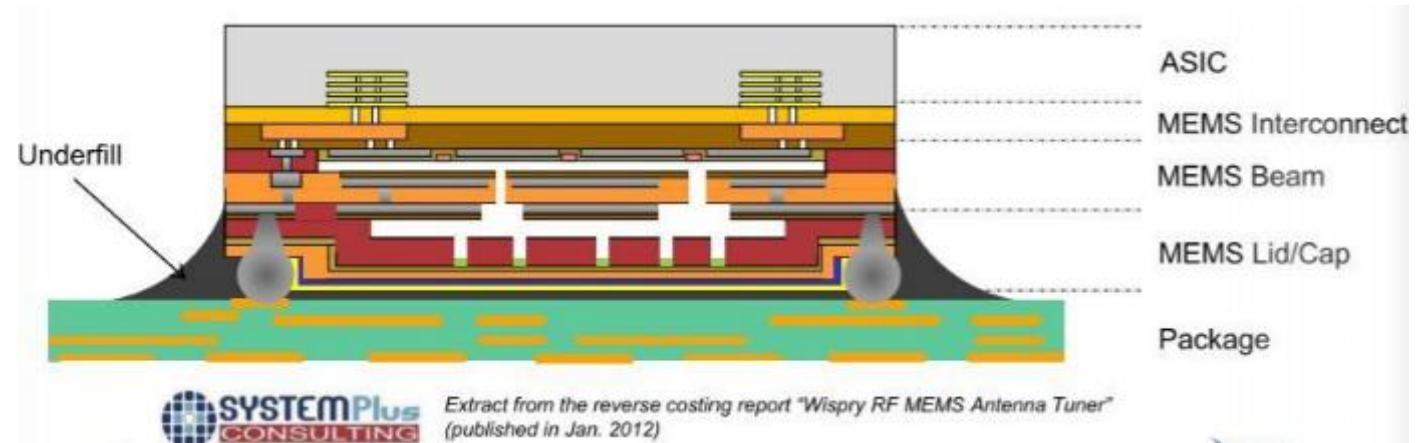


25% additional range

¹ F. Giancesello et al., "Advanced 200-mm RF SOI Technology exhibiting 78fs RonCoff and 3.7 V breakdown voltage targeting sub 6 GHz 5G FEM," 2022 IEEE Radio Frequency Integrated Circuits Symposium (RFIC), 2022, pp. 191-194, doi: 10.1109/RFIC54546.2022.9863082.

² K. A. Moen, et al, "0.18μm SiGe BiCMOS technology for fully-integrated front-end ICs capable of sub-300fs Ron × Coff switch performance," 2015 IEEE Bipolar/BiCMOS Circuits and Technology Meeting - BCTM, 2015, pp. 109-112, doi: 10.1109/BCTM.2015.7340562

- MEMS monolithic integration with HV-CMOS ^{1,2}
 - 8" manufacturing
 - Wafer level process encapsulation
- Electrostatically actuated membrane
 - Excellent switch figures of merit
 - High Q factors and tuning ratios for tuners
- However limited success in RF mobile



¹ S. P. Natarajan et al, "CMOS integrated digital RF MEMS capacitors," 2011 IEEE 11th Topical Meeting on Silicon Monolithic Integrated Circuits in RF Systems, 2011, pp. 173-176, doi: 10.1109/SIRF.2011.5719327.

² http://towersemi.com/wp-content/uploads/2018/08/TowerJazz_PR_20140603-2.pdf

MEMS – opportunity

- RF-MEMS remains relevant
 - Exceptional linearity¹
 - Low DC power consumption
 - Good power handling
- Opportunity & challenge
 - Achieve functional integration, size, and cost
 - Compete in a narrower field where it can win

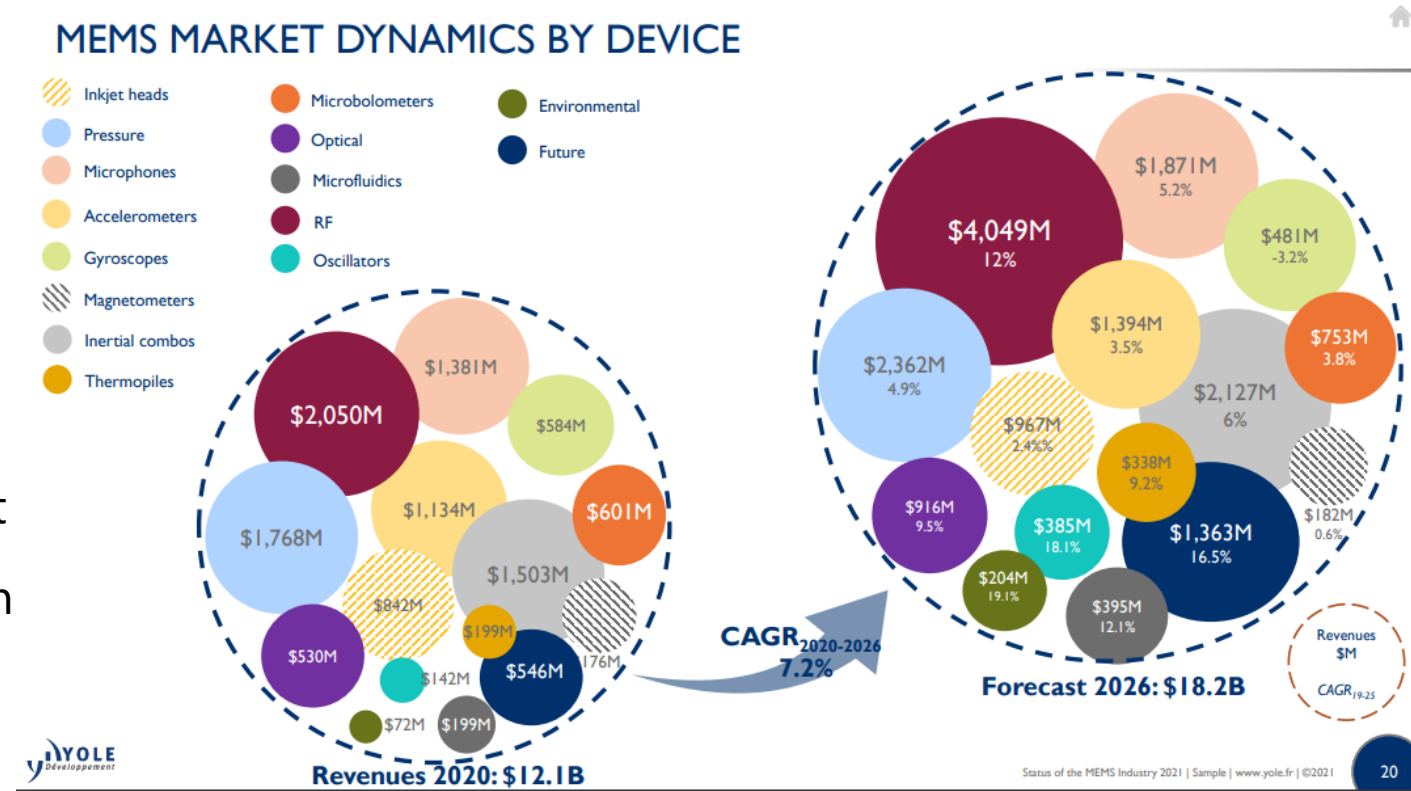


Image reference: Status of the MEMS Industry 2021, Yole Development

¹ D. Molinero, S. Aghaei, A. S. Morris and S. Cunningham, "Linearity and RF Power Handling on Capacitive RF MEMS Switches," in IEEE Transactions on Microwave Theory and Techniques, vol. 67, no. 12, pp. 4905-4913, Dec. 2019, doi: 10.1109/TMTT.2019.2945273

- Compelling RF performance but
- Many formidable challenges to overcome to achieve scale and cost expectations
 - Specialty and expensive manufacturing processes, materials, eg epitaxy, lift-off, e-beam lithography, and gold
 - Poor economy of scale with small diameter wafers
 - Limited supply. Technology is also subject to export restrictions
 - Low functional integration
 - SiP integration – incompatibilities with advanced methods
- Only applications that can bear the cost and have no viable alternatives use these technologies

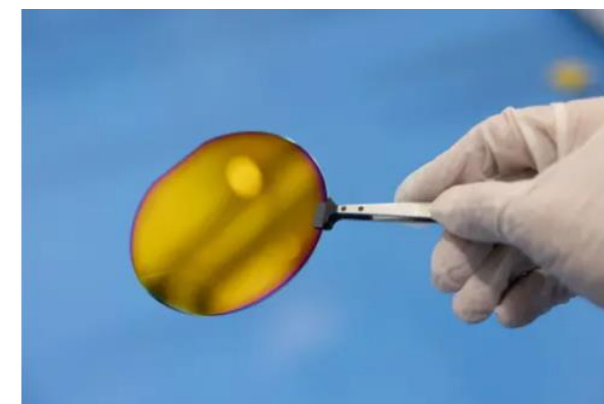


Image reference: <https://www.powerelectronicsnews.com/semiconductor-wafer-manufacturing-with-gan/>

GaN –a better economy of scale

- XFAB has been a pioneer with 8" GaN/Si manufactured in a shared CMOS fab environment
- 5+ year track record with ramp starting 2017
- RF GaN is different, but proof of concept done with power GaN

X-FAB and Exagan Partner to Develop Robust Production Process for High-Volume GaN-on-Silicon Devices on 200mm Wafers

Erfurt, Germany – May 18, 2015

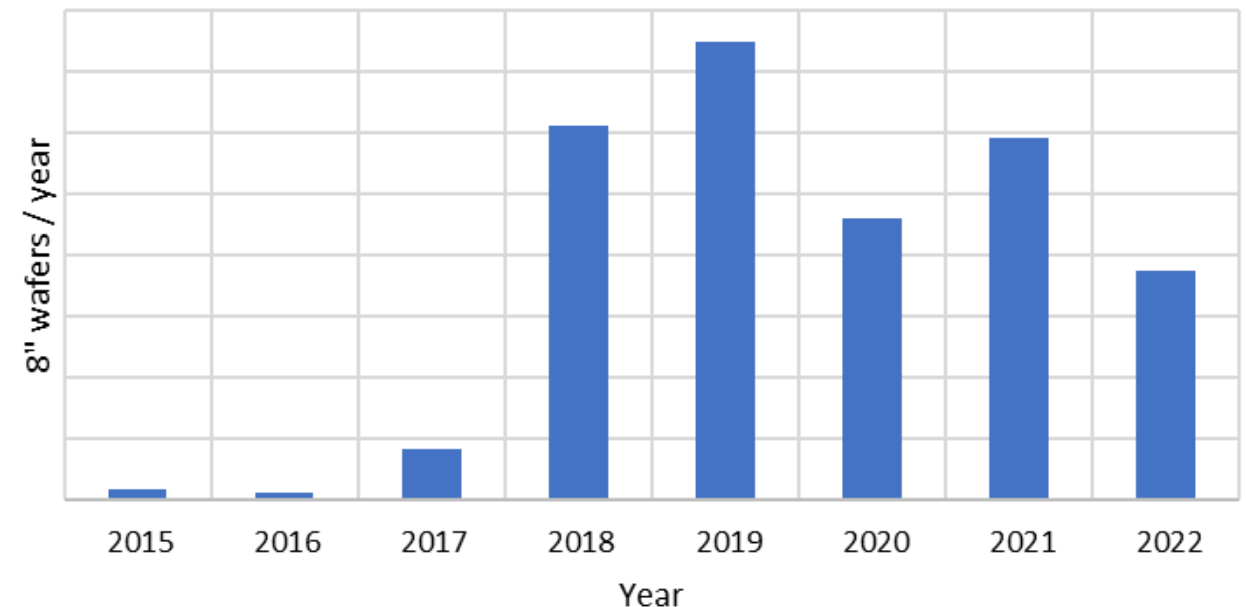
Leading Silicon Foundry and New GaN Start-Up Collaborate to Increase Manufacturability and Reduce Costs for Highly Efficient Power Switches

Leading Silicon Foundry and New GaN Start-Up Collaborate to Increase Manufacturability and Reduce Costs for Highly Efficient Power Switches

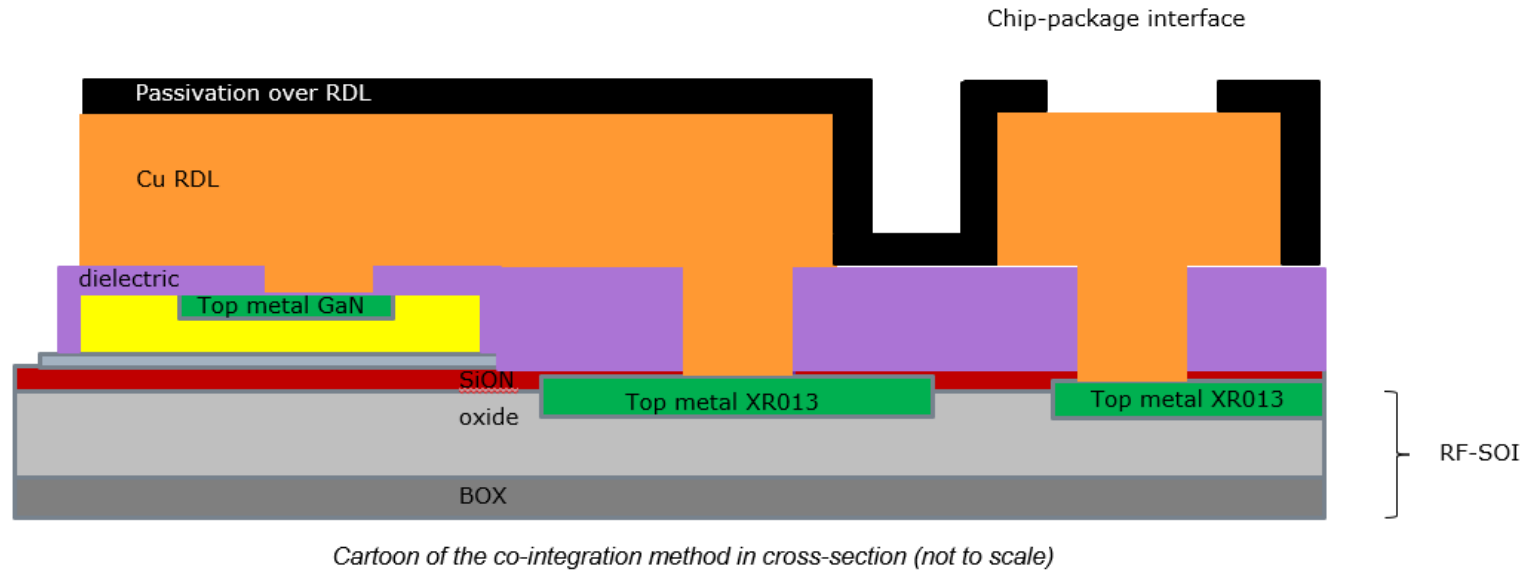
X-FAB Silicon Foundries and **Exagan**, a start-up innovator of Gallium Nitride (GaN) semiconductor technology that enables smaller and more efficient electrical converters, have entered into a joint development agreement to industrialize Exagan's GaN-on-silicon technology, begin producing high-speed power switching devices on 200mm wafers and establish a European production center where the two partner companies will manufacture GaN devices for the solar, industrial, automotive, IT electronics and other markets. The two companies already



XFAB GaN/Si wafer production history



RF-GaN – a wafer level heterogeneous integration approach



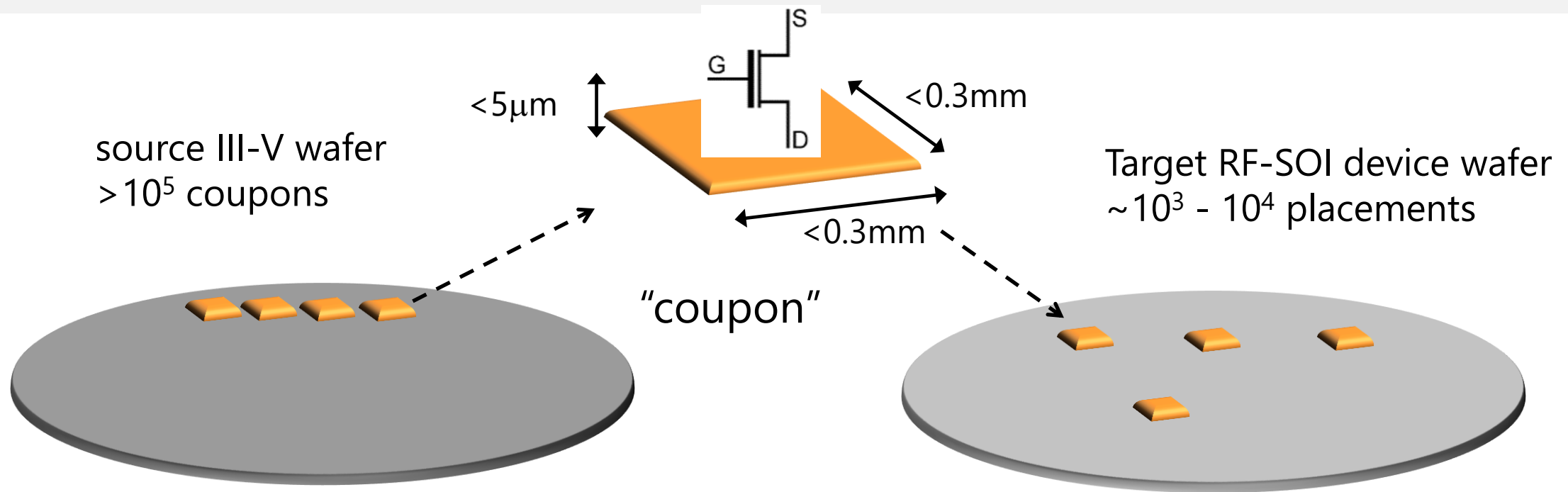
Cartoon of the co-integration method in cross-section (not to scale)

- GaN coupon placed face-up
- Cu RDL connects GaN to RF-SOI.
- RDL / RF-SOI serves as the chip-package interface
- Interconnect density on the order of micrometers

F. Drillet *et al.*, "RF SPST Switch Based on Innovative Heterogeneous GaN/SOI Integration Technique," *2020 15th European Microwave Integrated Circuits Conference (EuMIC)*, 2021, pp. 117-120.

J. Loraine, H. Saleh, F. Drillet, O. Sow, I. Lahbib and G. U'Ren, "5.9-7.1GHz High-Linearity LNA Using Innovative 3D Device Level Co-Integration of GaN HEMT and RF-SOI," *2021 IEEE MTT-S International Microwave Symposium (IMS)*, 2021, pp. 20-22, doi: 10.1109/IMS19712.2021.9574971.

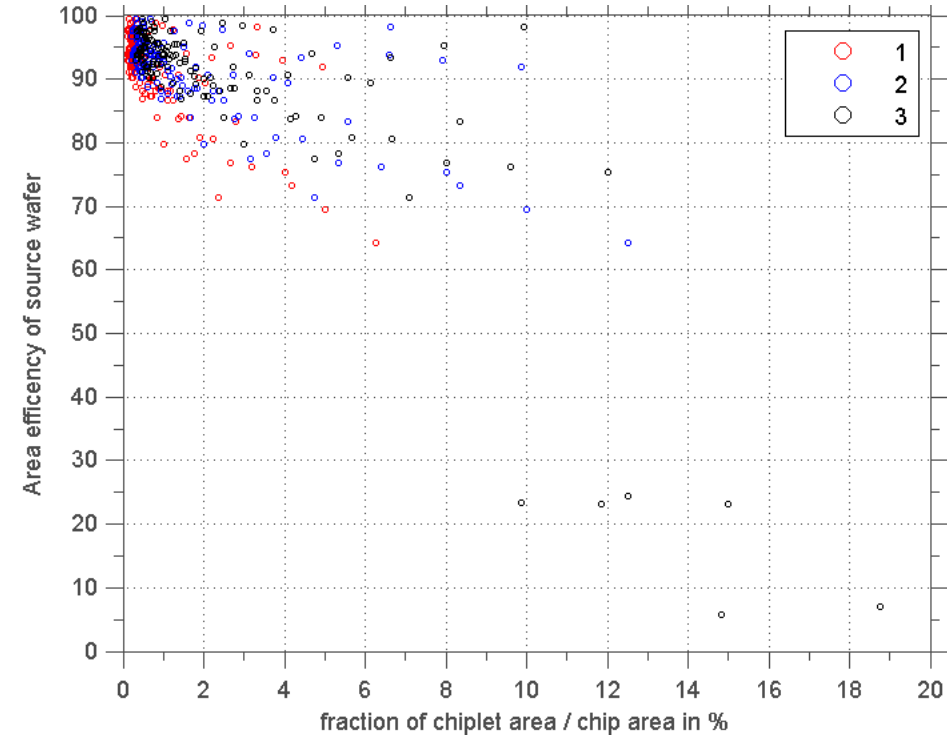
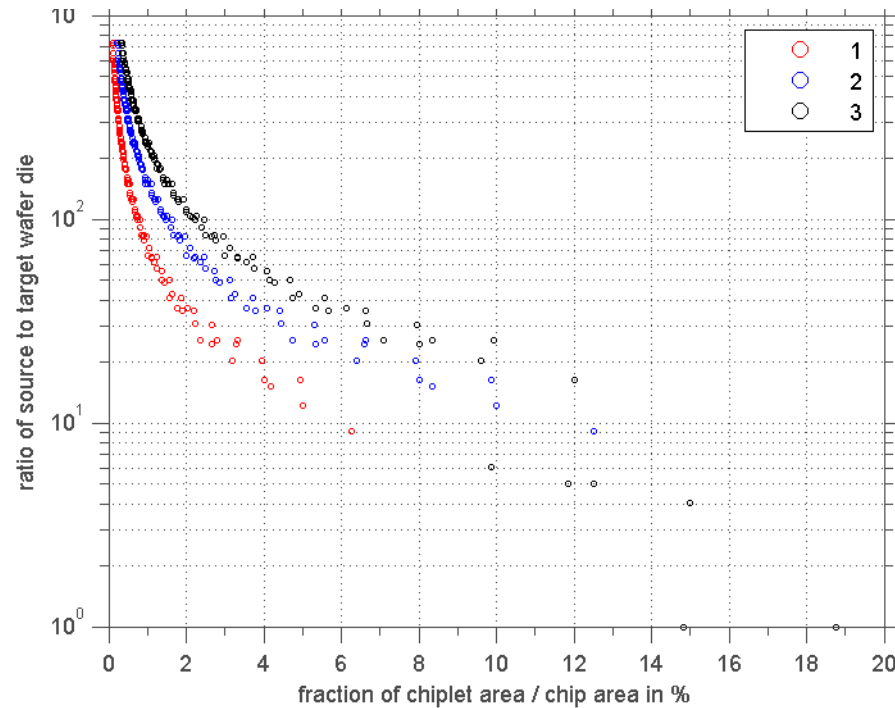
Wafer level integration of III-V's



- Efficient area utilization of a high value source material
- Coupon contains 1 or more components

Target use case : sparsely populated III-V's within a Si die

Numerical calculations of ratio source/target wafer and area utilization for 1 to 3 coupons each sized $200 \times 200 \mu\text{m}^2$ populated on a Si die

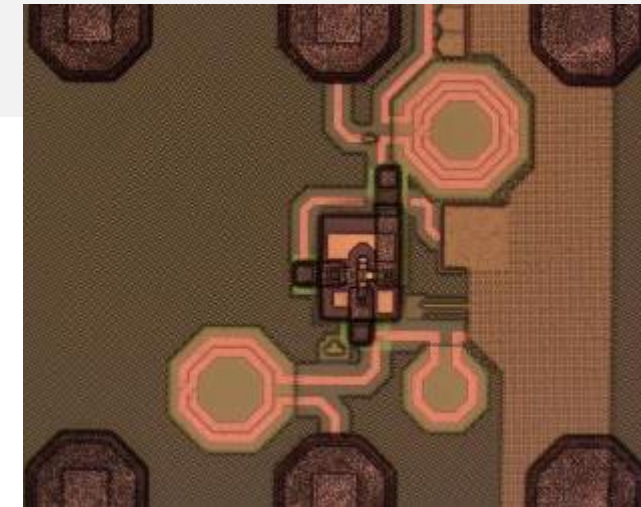
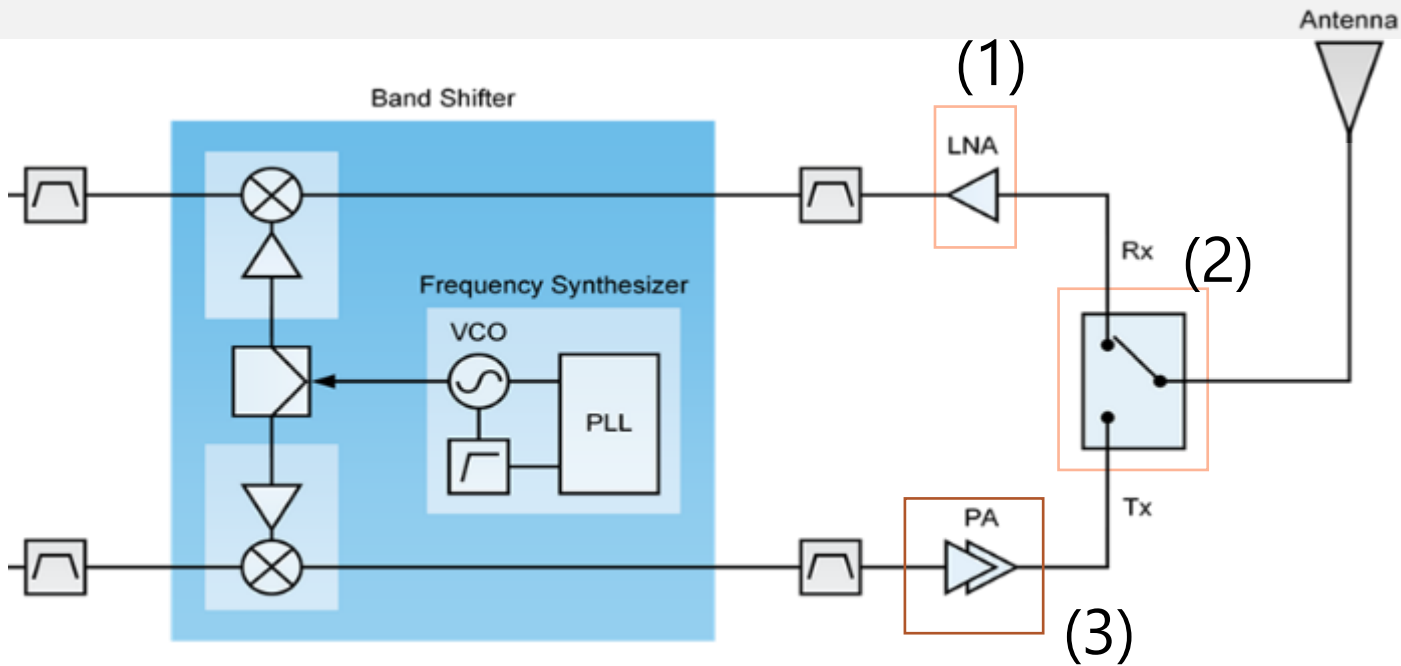


- High ratio between source to target wafers and >90% utilization of the source wafer
- Sparse utilization dilutes III-V wafer cost and significantly expands scale with more efficient material use

GaN/RF-SOI circuit demonstrators

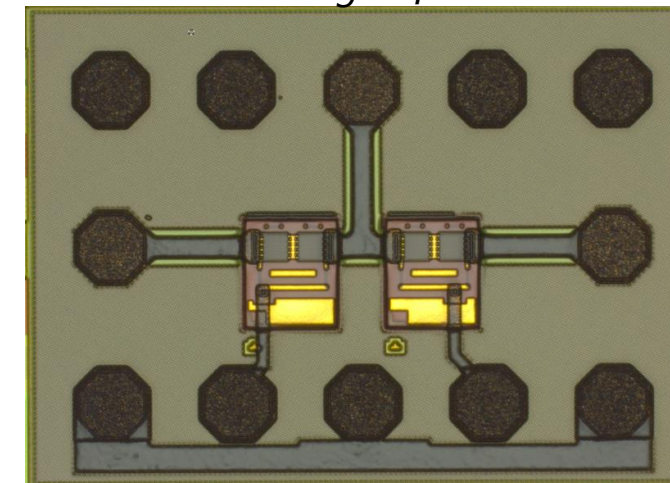
Die image of LNA

xfab



(1)

Die image of SPDT



(2)

G. U'Ren, RFIC workshop 2022

(1) High linearity <6GHz LNA

Output IP3 ~ 28dBm
Pdc <75mW

(2) High power switching

RF power ~ 48 dBm

(3) Efficient / high power density PA

Up to 6W/mm

- XFAB is a specialty foundry with a diverse set of technologies
 - Power technologies including GaN, SiC, and highly integrated Si solutions with high temperature NVM
 - Medical solutions that combine MEMS and analogue/mixed signal CMOS technologies
 - Mobile and communications including RF-SOI

- RF development roadmap focused on RFFE
 - Continuous improvement with RF-SOI (XR013)
 - SiGe BiCMOS (XB012) and IHP collaborations
 - RF GaN heterogenous integration
 - Exploration of InP with partners

Selection of collaboration partners



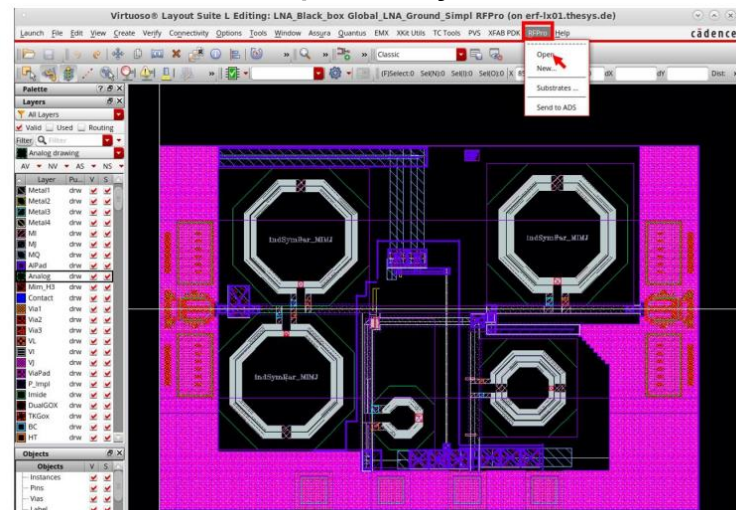
CENTRE FOR NANOSCIENCE
AND NANOTECHNOLOGY



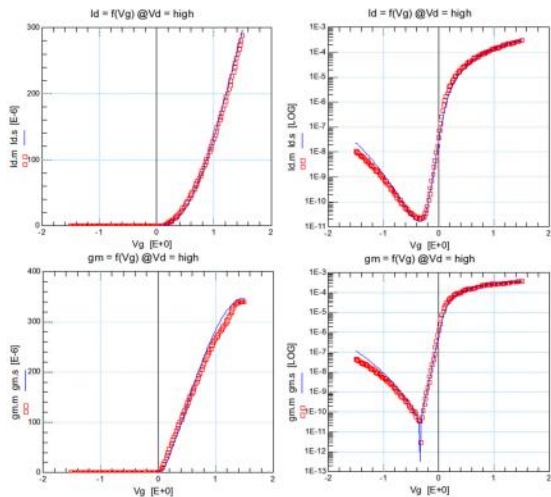
Technology includes design enablement



Si-validation of RF/mmW design flow with specialty EDA tools



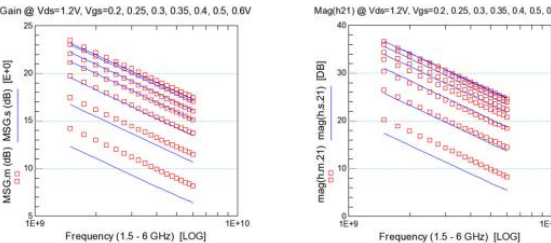
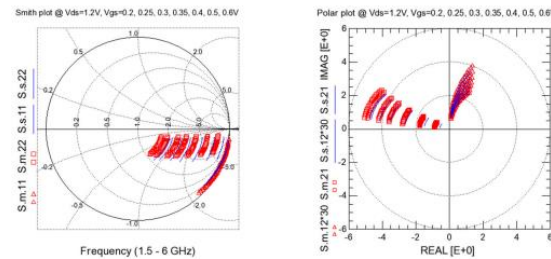
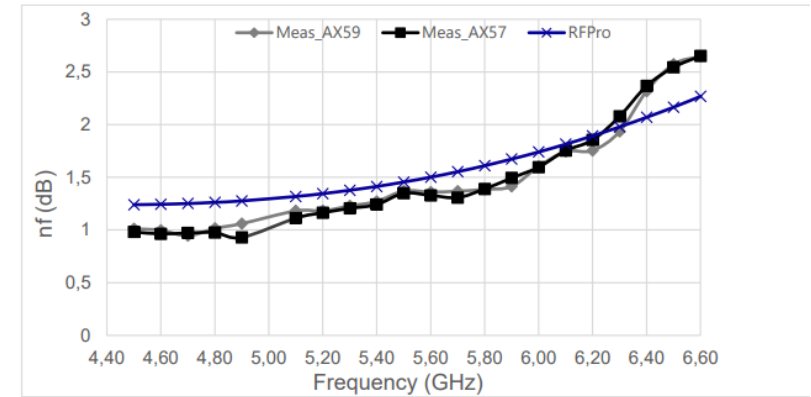
Physical based modeling strategies



Foundational design IP:
Digital, analogue, IO, and ESD solutions

The following Digital I/O Pad Cell Libraries are available in X-FAB XR013 technology:

Library name	Category	Key features
Bulk CMOS I/O Pad Cell libraries, process module: CORE + 1V2DT + 2V5DT		
IO_CELLS_2V5	Multi Supply Voltage, Vcore ≤ Vio	Vcore: 1.2V, 1.5V, 1.8V, 2.5V range, Vio: 1.2V, 1.5V, 1.8V, 2.5V range
IO_CELLS_GP1V2	Multi Supply Voltage, Vcore > Vio	Vcore: 1.8V, 2.5V range, Vio: 1.2V range, target ESD level: 2kV HBM
IO_CELLS_F2V5	Multi Supply Voltage, Vcore ≤ Vio, core limited	Vcore: 1.2V range, Vio: 1.2V, 1.8V, 2.5V range, target ESD level: 2kV HBM, wide layout with small cell height
Bulk CMOS I/O Pad Cell libraries, process module: CORE + 2V5DT		
IO_CELLS_GP1V8	Multi Supply Voltage, Vcore ≥ Vio	Vcore: 1.8V, 2.5V range, Vio: 1.8V, 2.5V range, target ESD level: 2kV HBM
IO_CELLS_FC2V5	Single Supply Voltage, Vcore=Vio, core limited	Vcore=Vio: 1.8V, 2.5V range, target ESD level: 2kV HBM, wide layout with small cell height



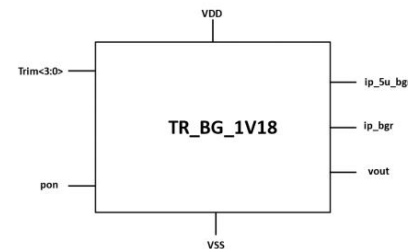
XR013 **TR_Band Gap 1V18** xfab

Description:

Trimmed BG_1V18 is a 1.18V bandgap voltage reference with poly resistors and analog diodes.

- Physical size (h x w): 360 μm x 620 μm
- XR013, CORE, MIM, compatible with all metal stacks: MET3, MET4, METTHK1, METTHK2.

Symbol:





RF-SOI



MEMS



SiGe



Heterogeneous GaN



Heterogeneous InP

› Accommodating SNR constraints is the key driver for next generation integrated device technologies

- Lower noise (NF, insertion loss)
- Better linearity than CMOS / RF-SOI offers today
- Transmit power and power efficiency especially in mmW

› Industrial and commercial expectations must also be satisfied to realize a successful deployment

- Cost-effective
- Scale and availability



Thank you.

guren@xfab.com



www.xfab.com