Tu2B-2

Highly Linear and Efficient GaN HEMTs and MMIC Amplifiers

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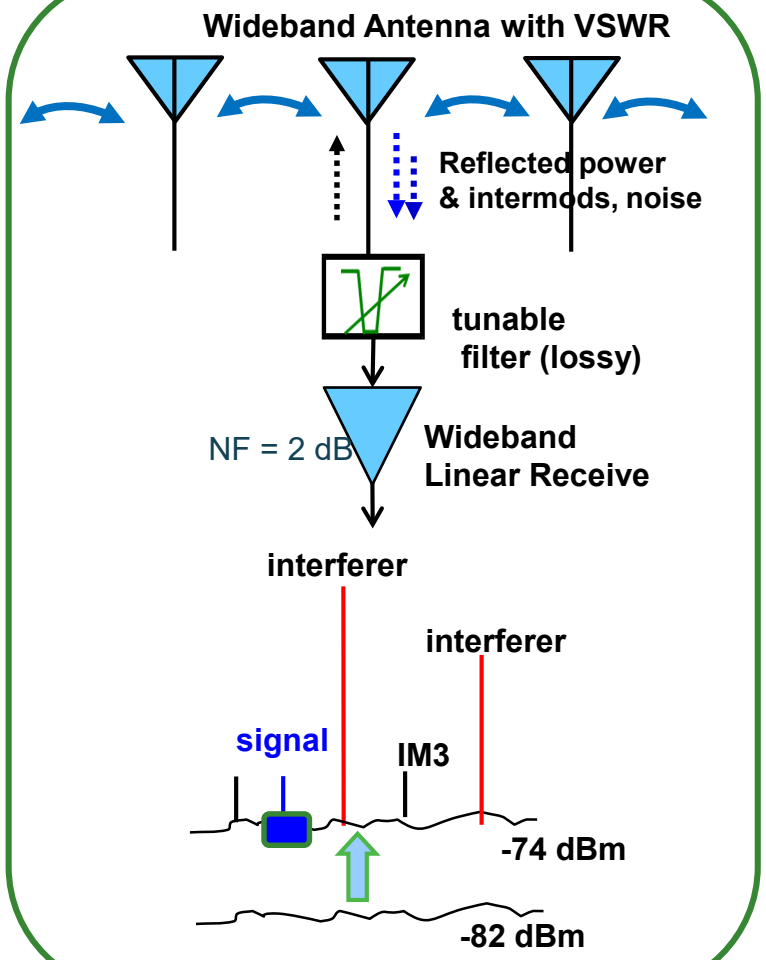
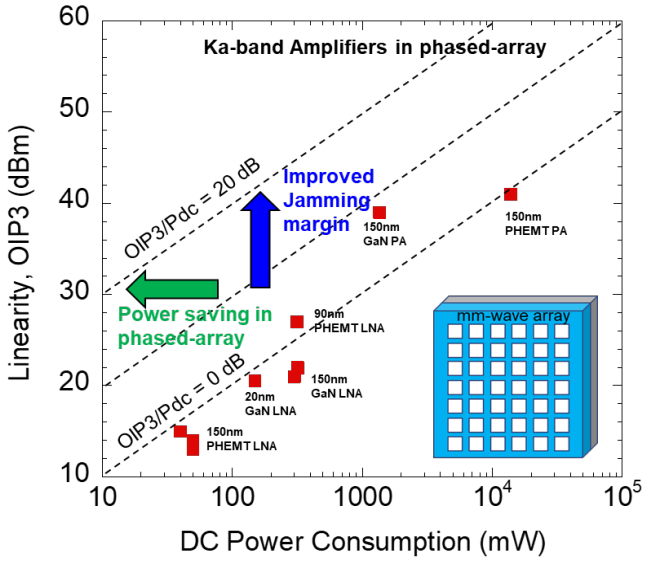
RF/mmW System Challenge: Linearity & Efficiency

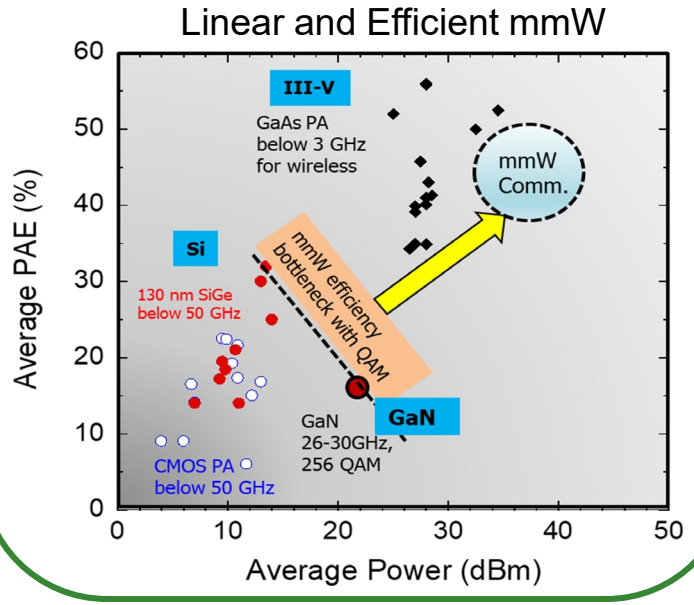
❑ EW systems



❑ Satcom systems

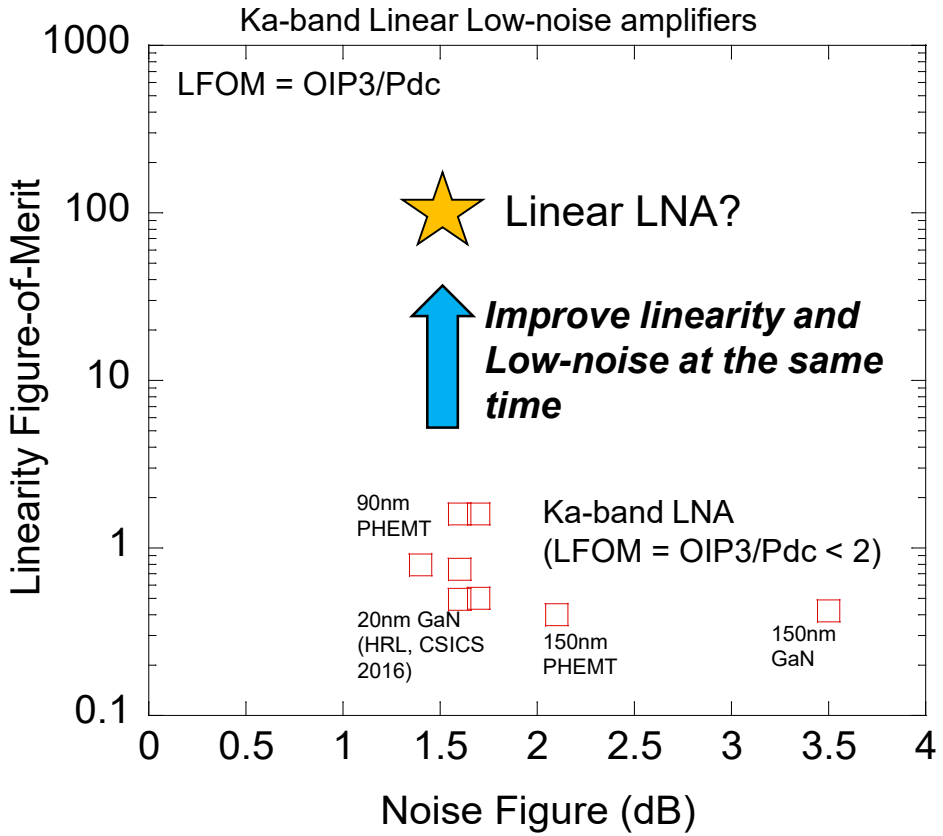


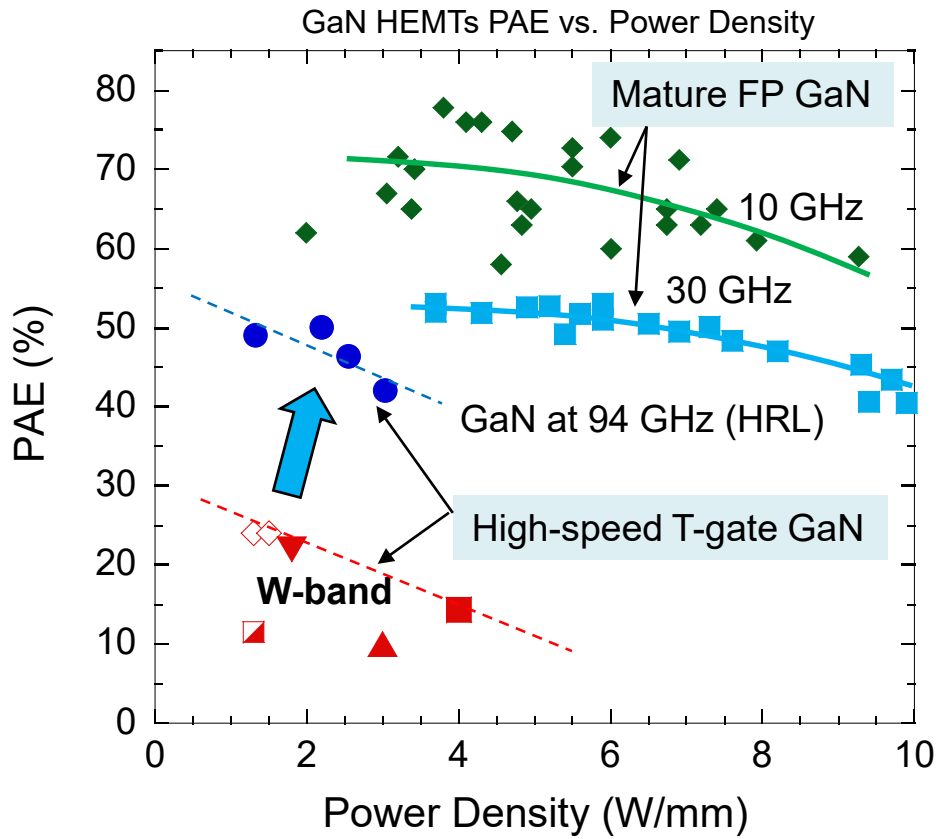
❑ Multifunction mmW



mmW Linearity & Efficiency Challenge

- Receivers' jamming margin can be improved by 6.7 dB per 10 dBm OIP3 improvement.
- The OIP3/Pdc ratio is limited to 1 → dynamic range problems and SWaP challenges.
- Millimeter-wave transmitter efficiency is significantly lower, imposing greater SWaP challenges.

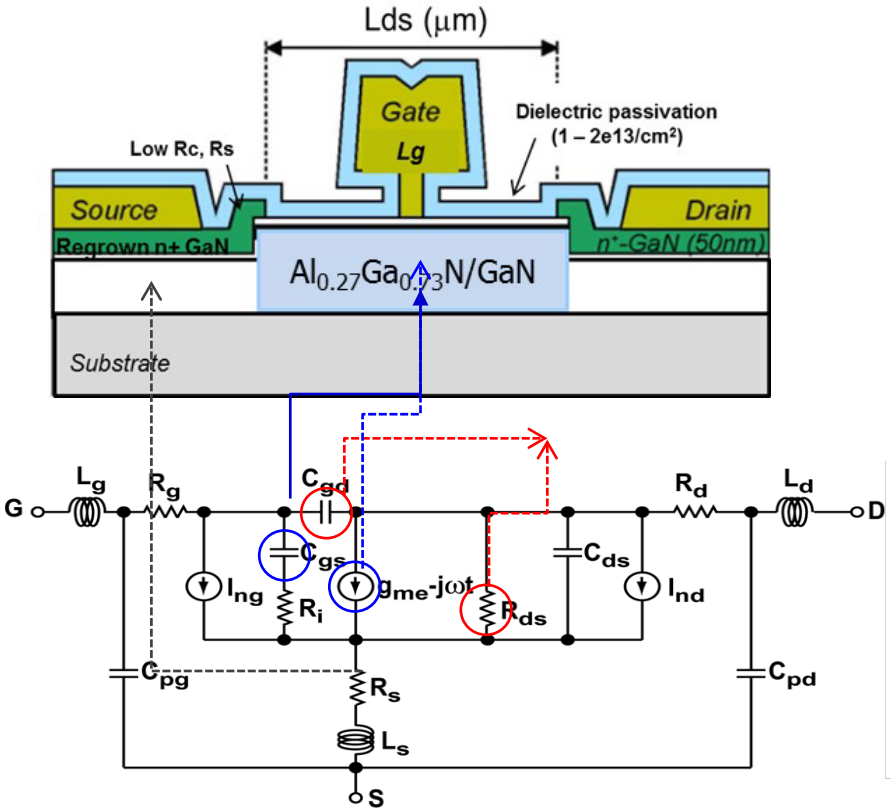


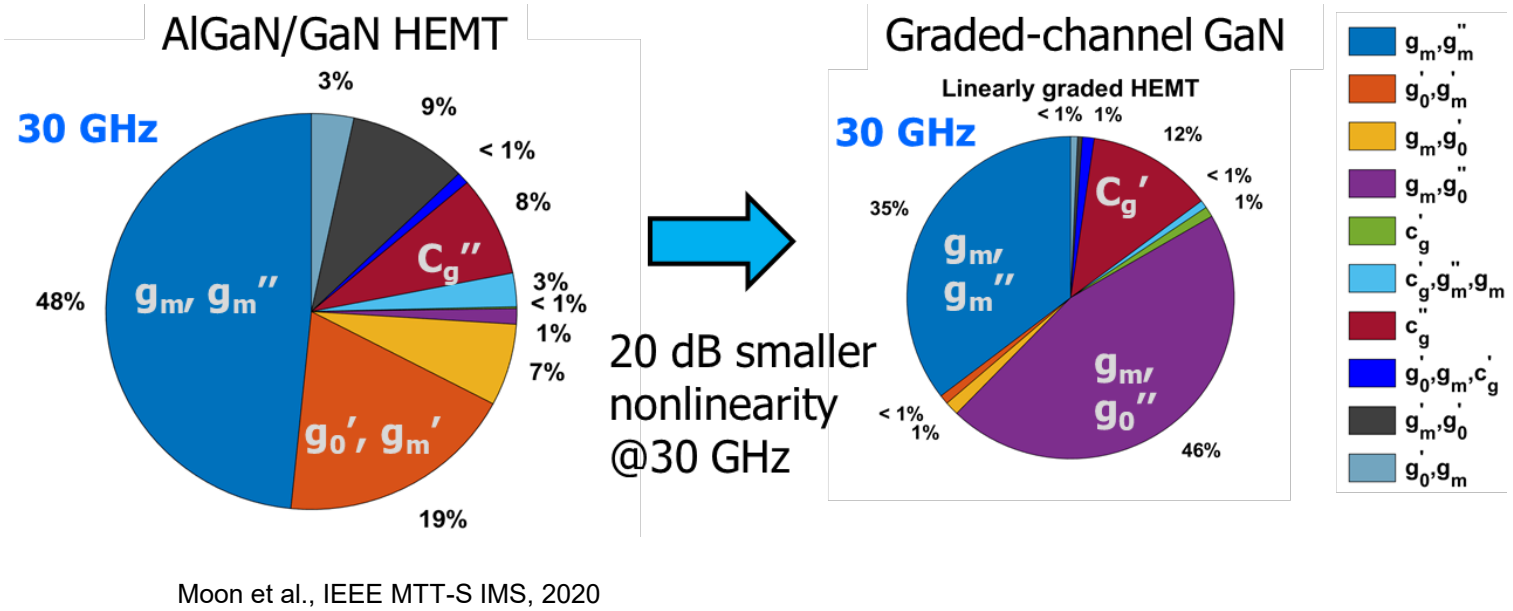


Moon et al., GOMAC 2022, IEEE MWTL, 2022

Linearity Challenge of GaN HEMTs

- $\mathbf{OIP3} \approx \mathbf{4[gm3/gm'' * GL/(Gds + GL)2] + f(cg' * gm', Gds' * gm')}$
- **LFOM = OIP3/Pdc**

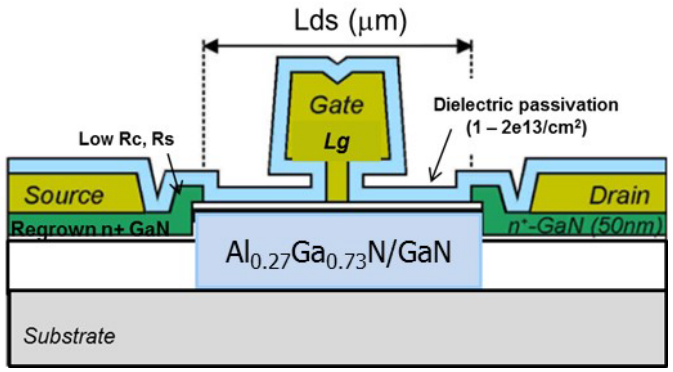




Moon et al., IEEE MTT-S IMS, 2020

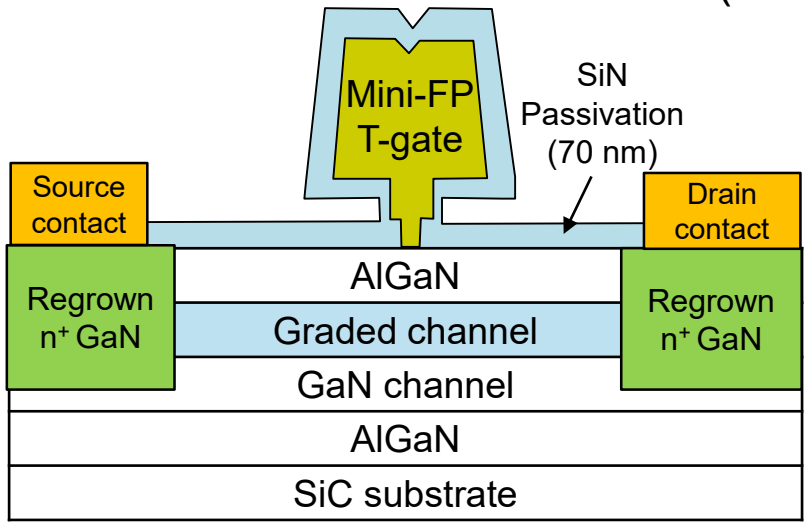
HRL's GaN Transistor with Graded-channel (T3L)

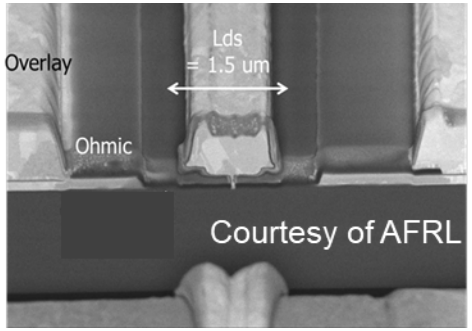
Conventional AlGaN/GaN HEMT



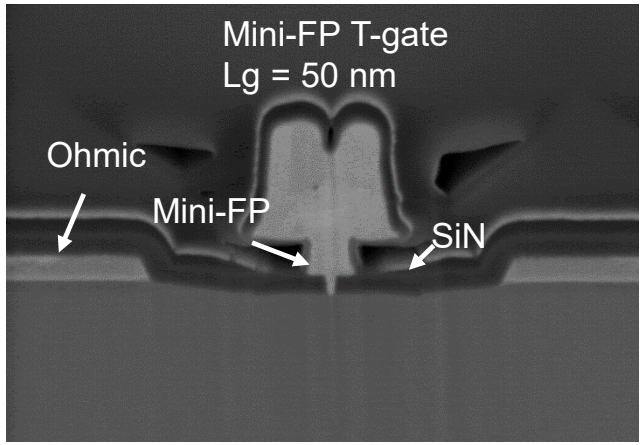
- GaN channel engineering

Graded-channel GaN HEMT (T3L)





- New high-speed gate process with improved yield and reduced current collapse
- Lateral scaling
- Speed*Power product

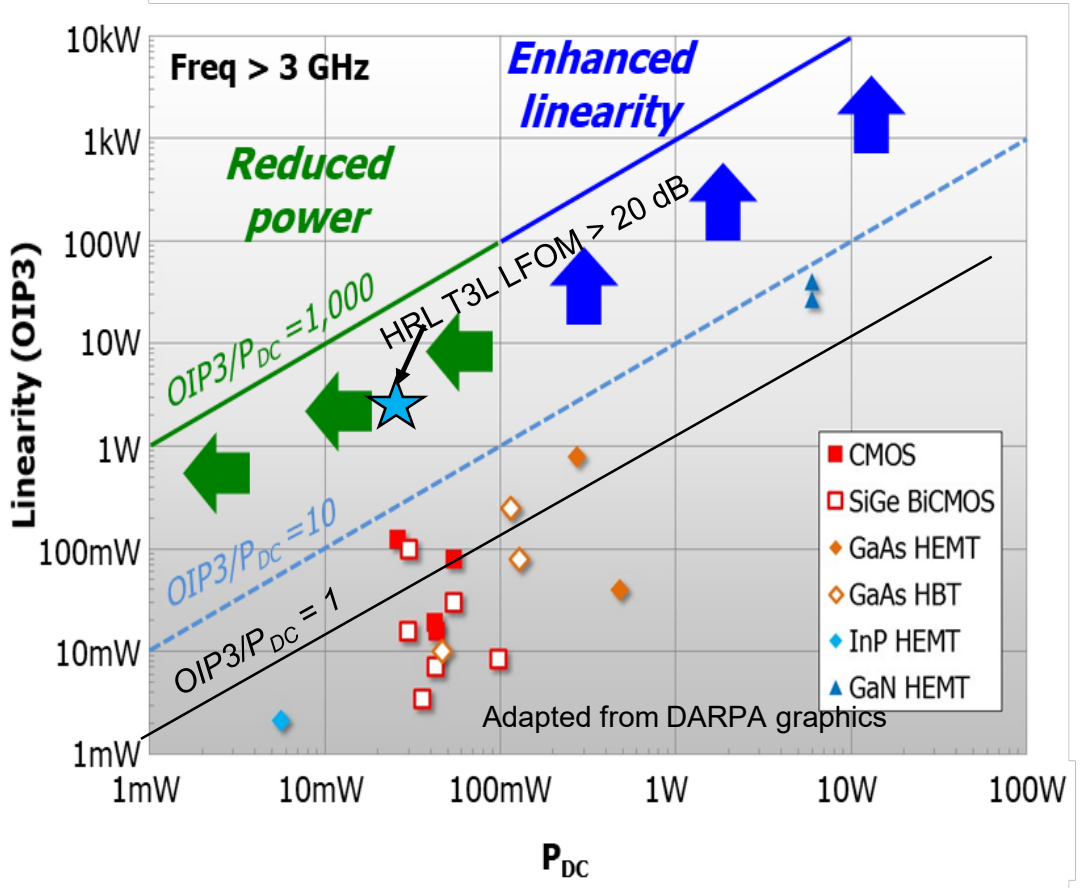


Moon et al., IEEE MWTL, 2022

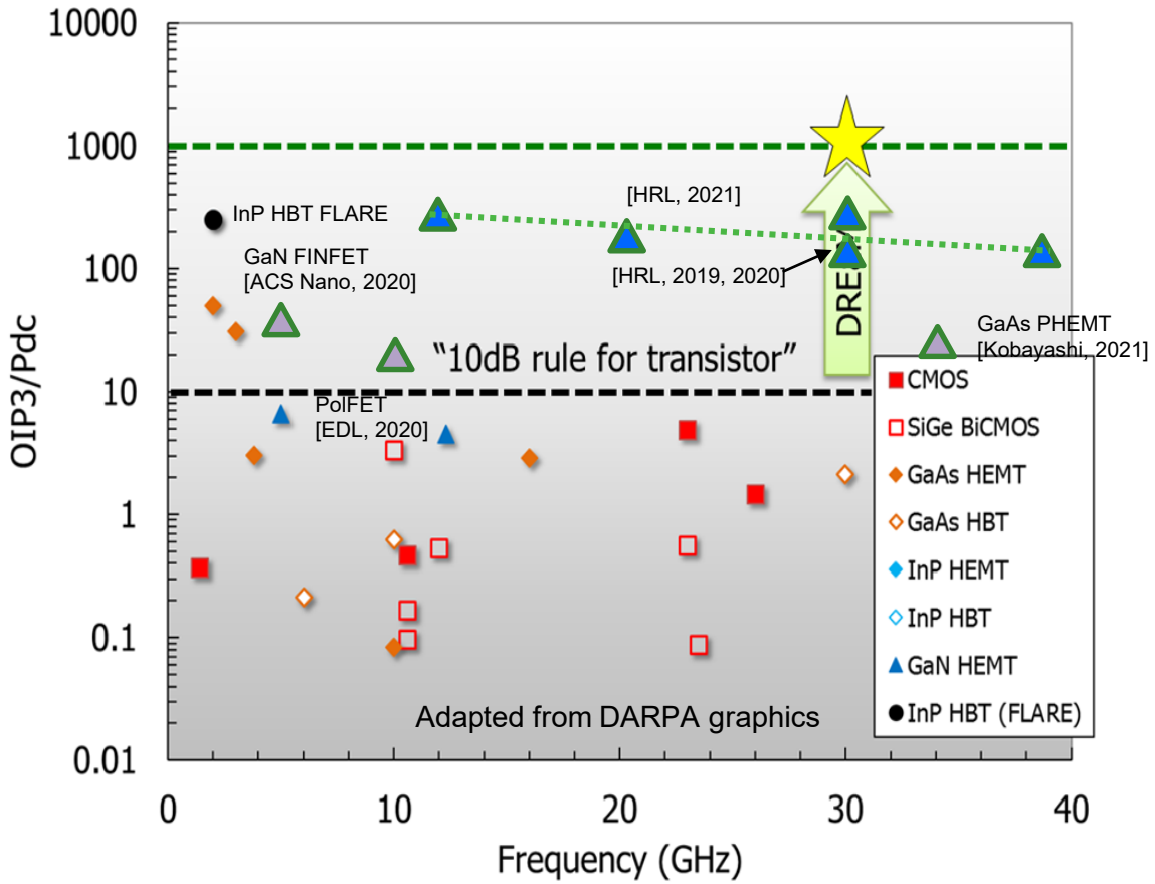
T3L GaN FET Linearity FOM

❑ **Linearity FOM = OIP3/Pdc**

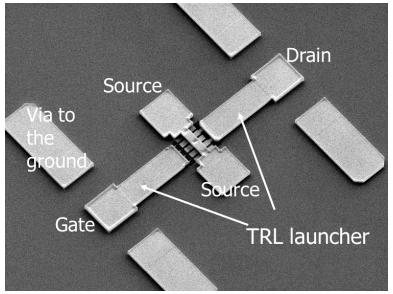
HRL(2019-2020) OIP3/P_{DC} > 100 at 30 GHz



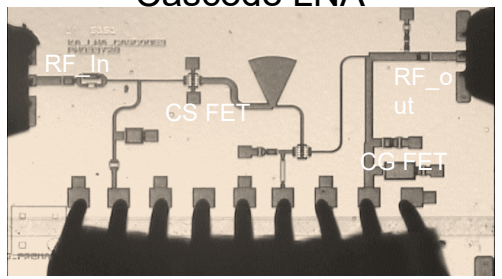
Wideband linearity over 20 – 40 GHz

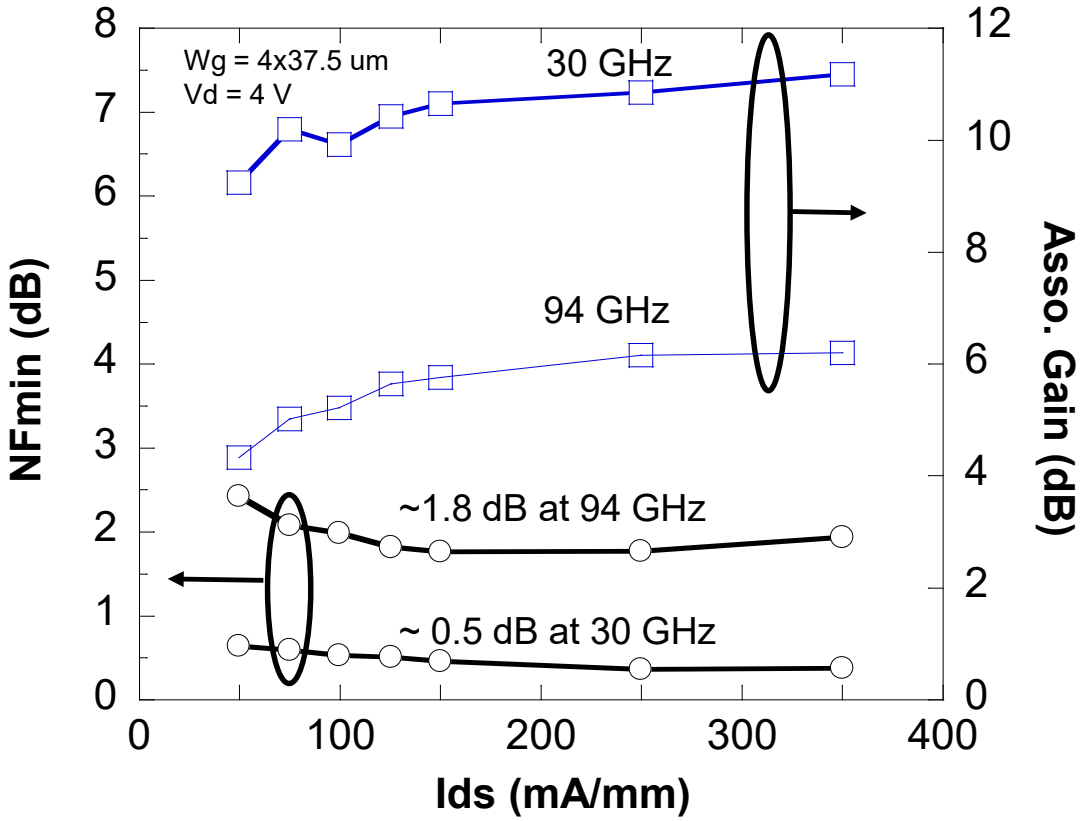


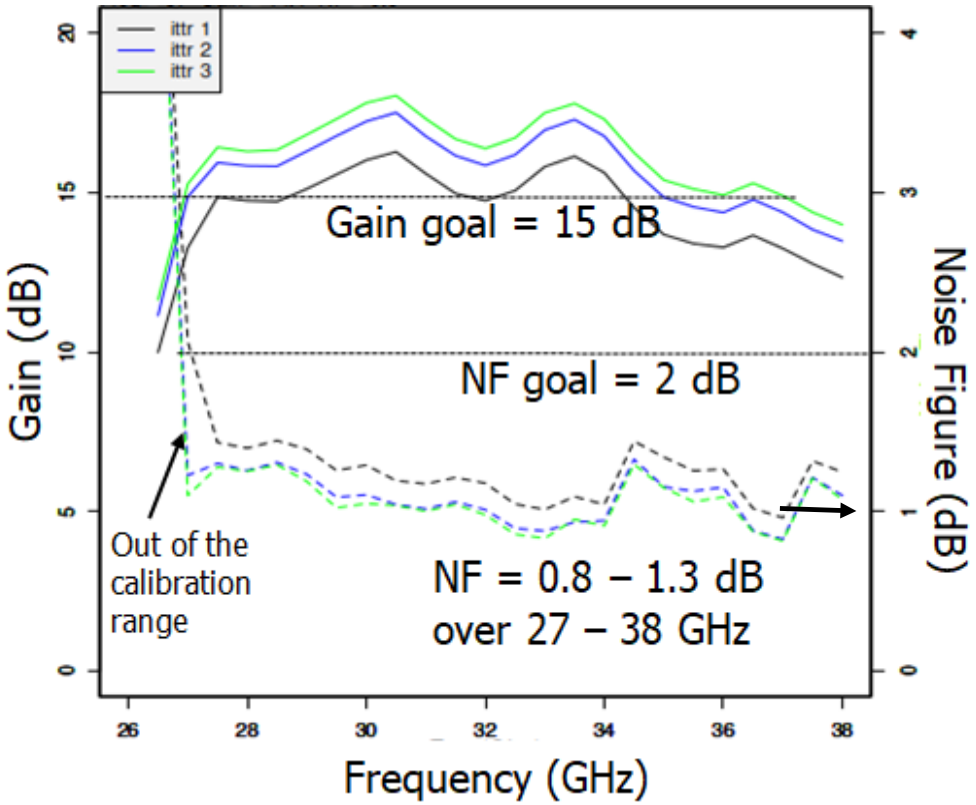
SOA Low-noise Performance up to W-band



Cascode LNA



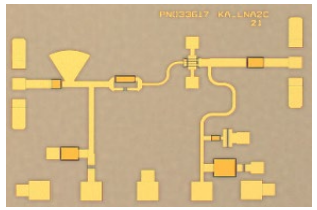


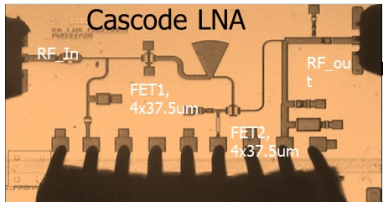


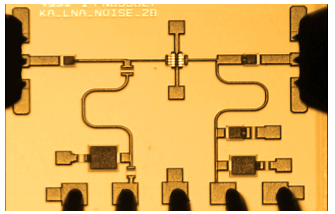
Measured at the AFRL

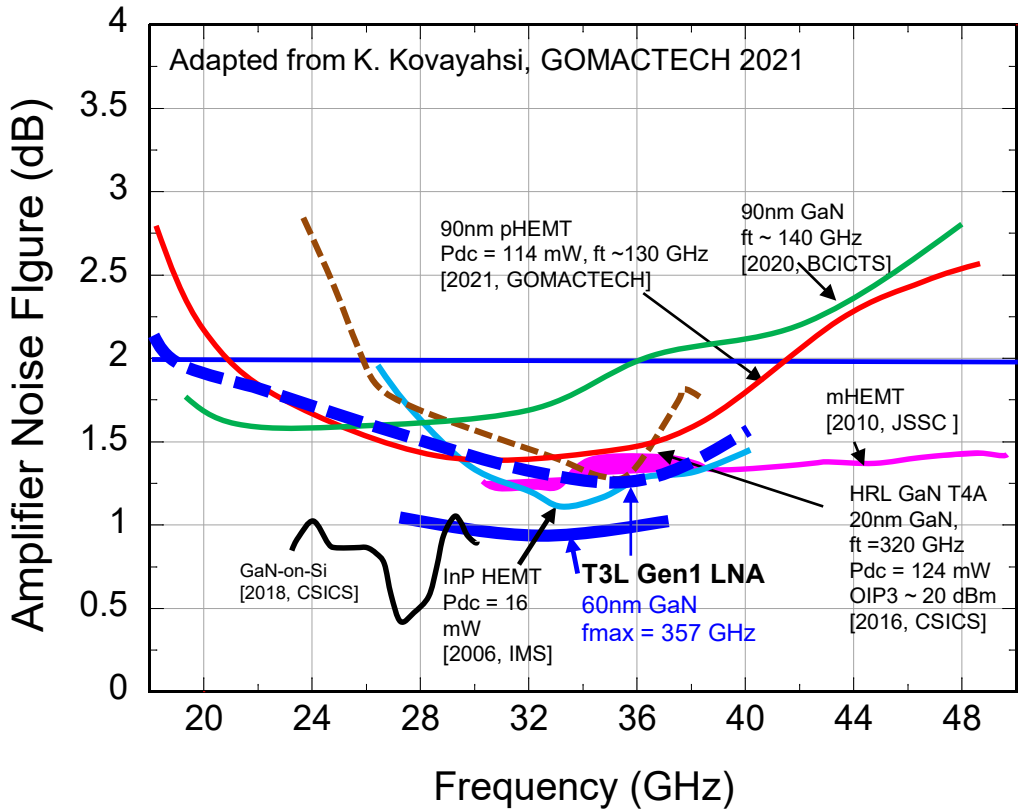
Linear Low-noise Amplifiers with a Record LFOM

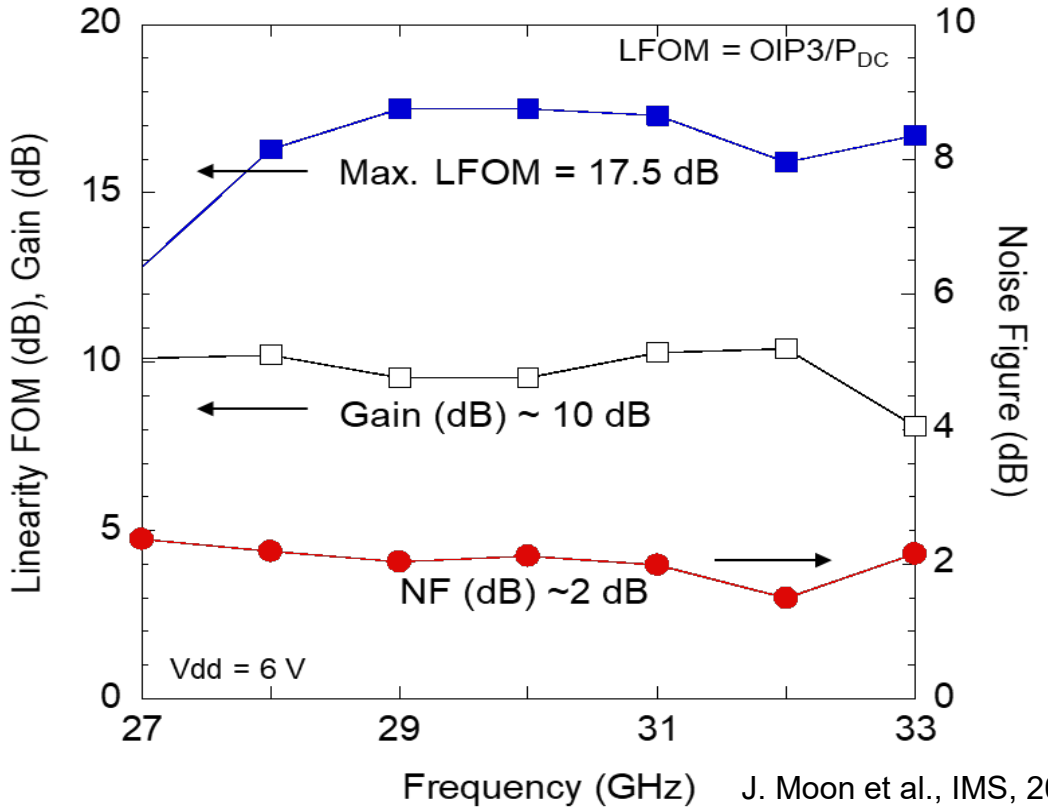
- NF < 2 dB over 20 – 40 GHz
- LFOM = OIP3/Pdc = 17.5 dB







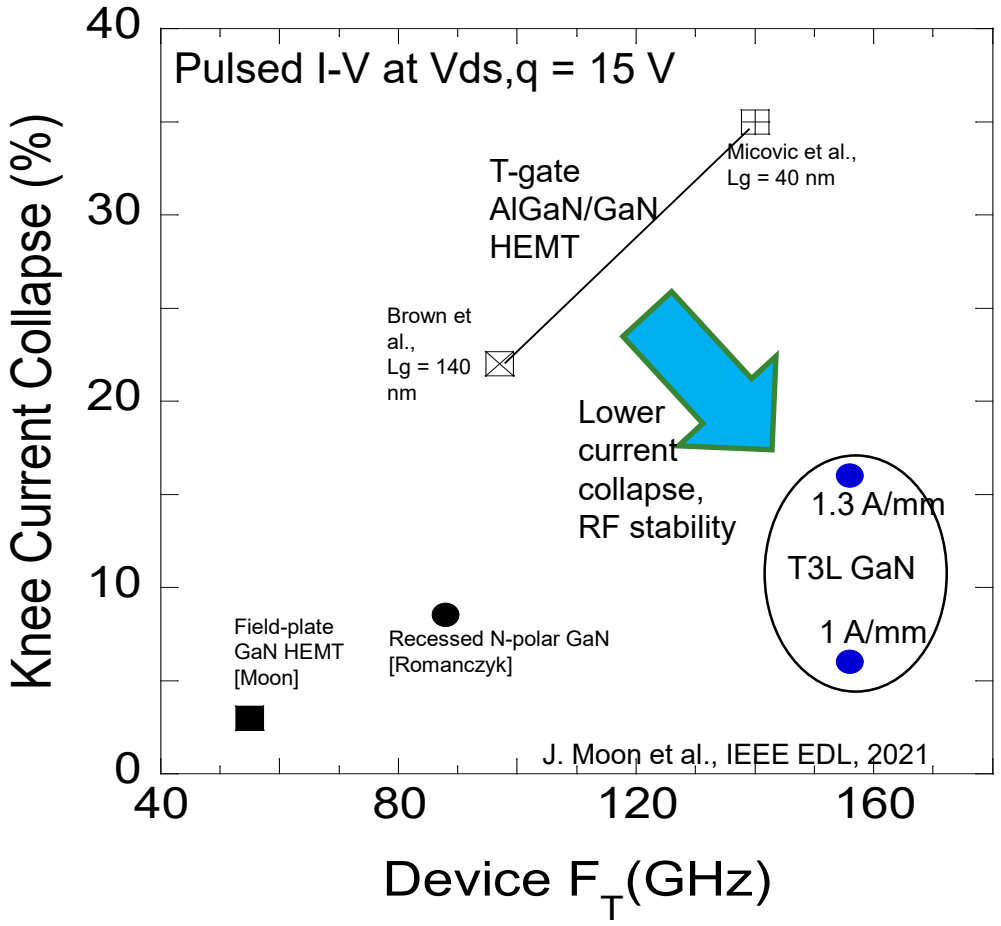




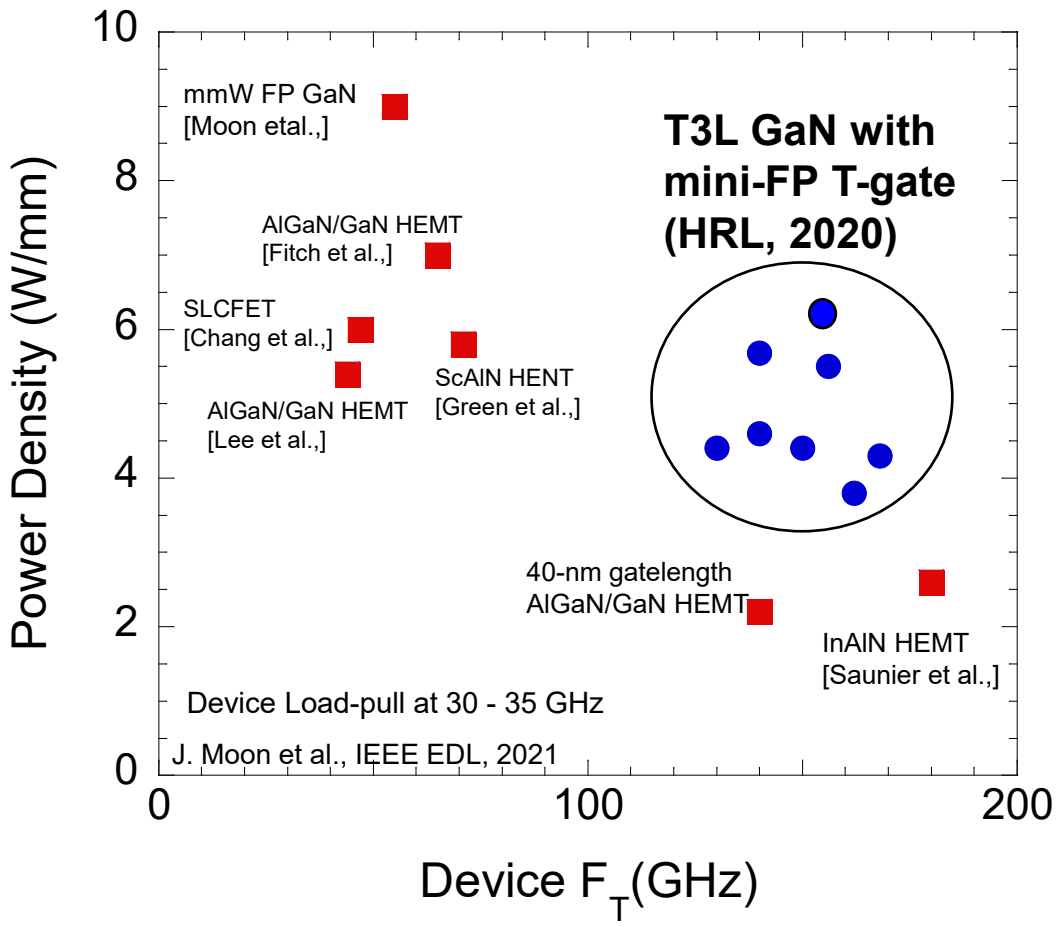
J. Moon et al., IMS, 2022

Lower Current Collapse and 6 W/mm Power Density at 30 GHz

Reduced current-collapse in T-gated GaN FETs

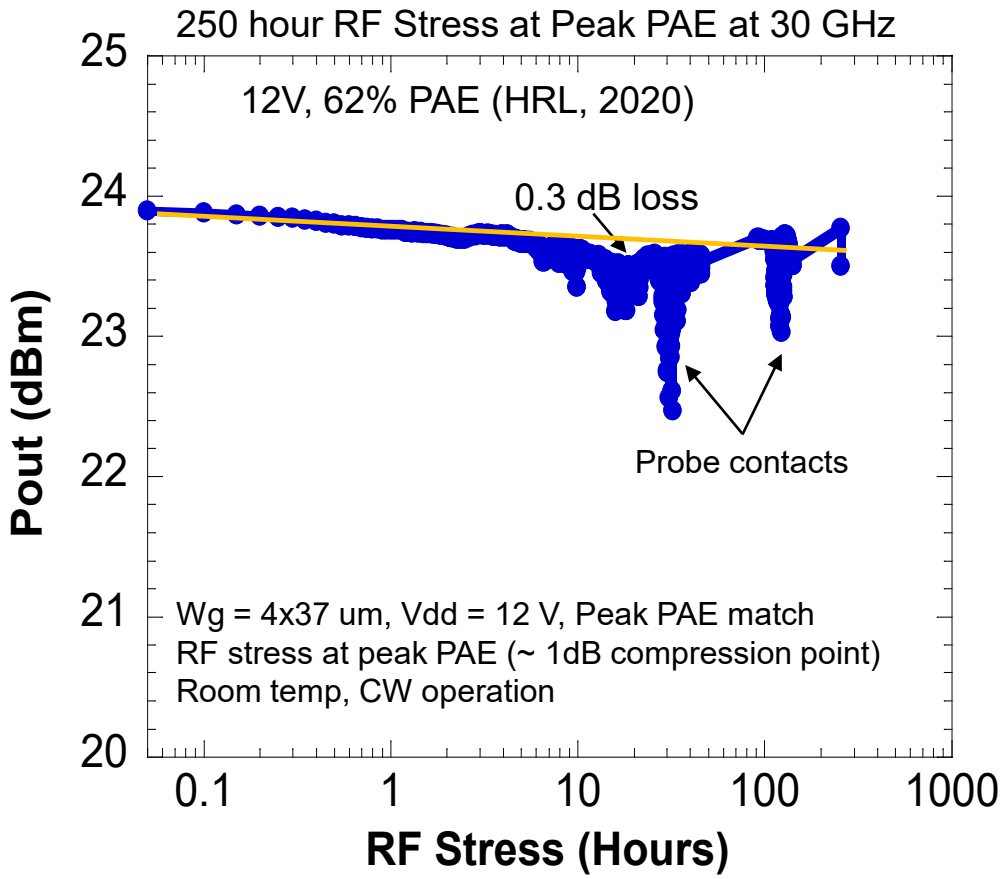


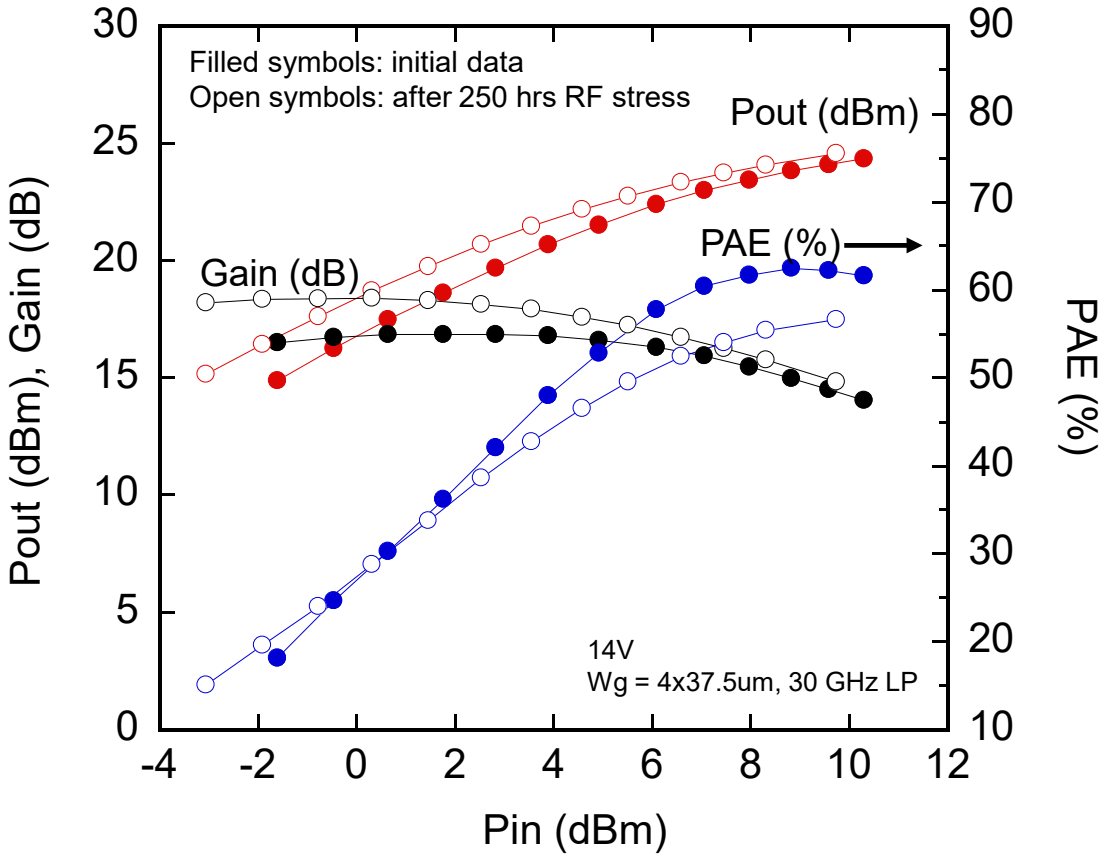
*SOA power*speed FOM = 900 GHz*W/mm*



The lower current-collapse enables 6W/mm power density operation at 30 GHz.

250-hours RF Stress Test at P1dB



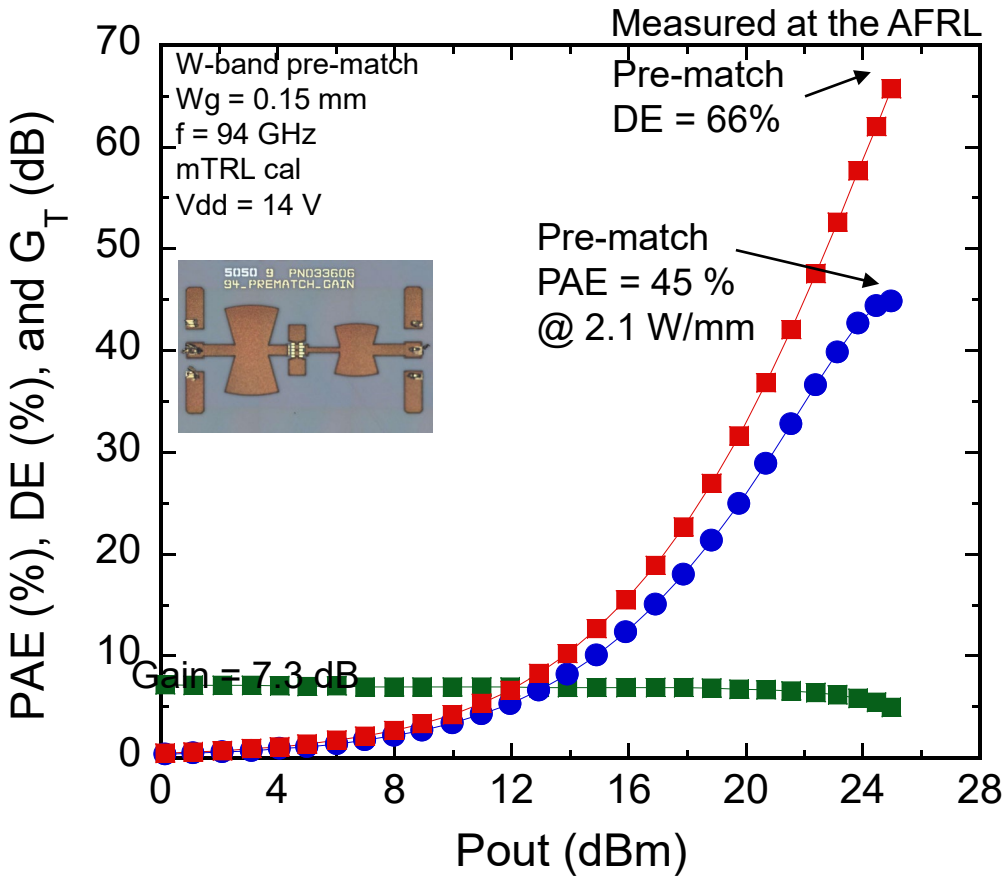


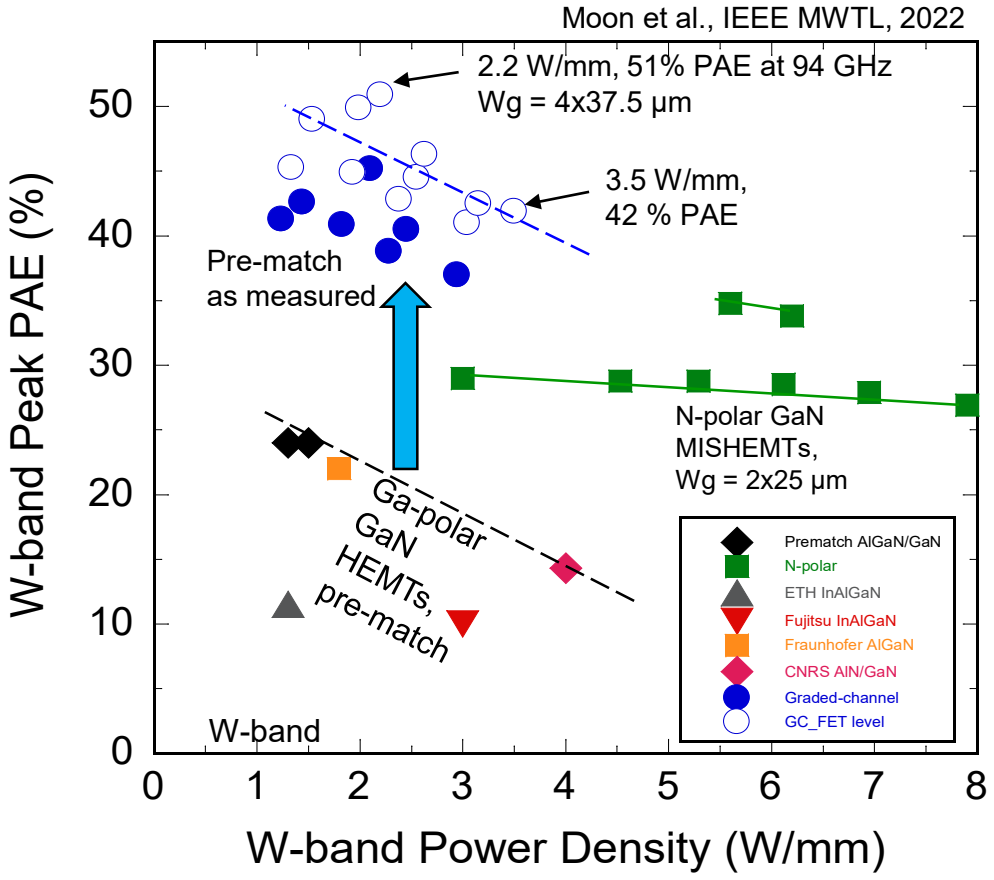
RF soak test over 250 hours at the peak PAE
→ 0.3 dB burn-in loss

After 250 hours RF stress, ~ 5% PAE reduction is observed, while the Pout is increased.

2.2 W/mm Power Density w/ Record 51% PAE at 94 GHz

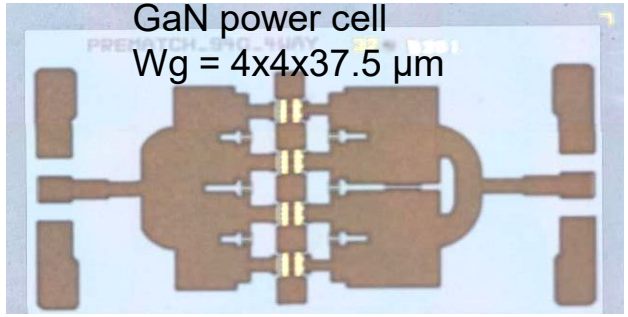
T3L Gen1 GaN HEMTs: gm = 600 mS/mm, Ft, Fmax = 155, 350 GHz, current collapse = 6 – 18 %

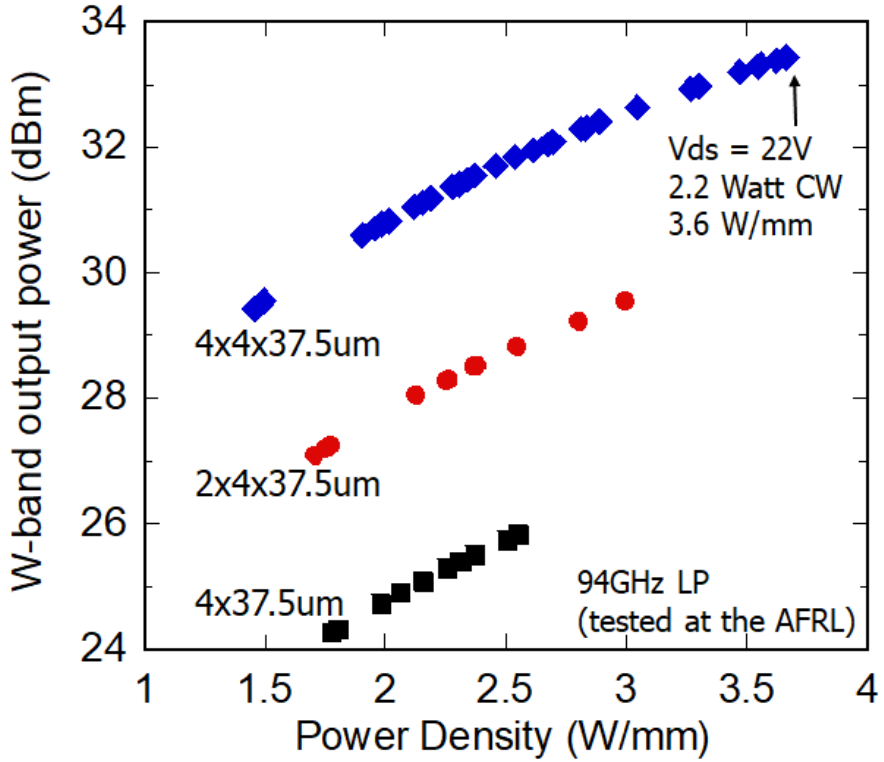


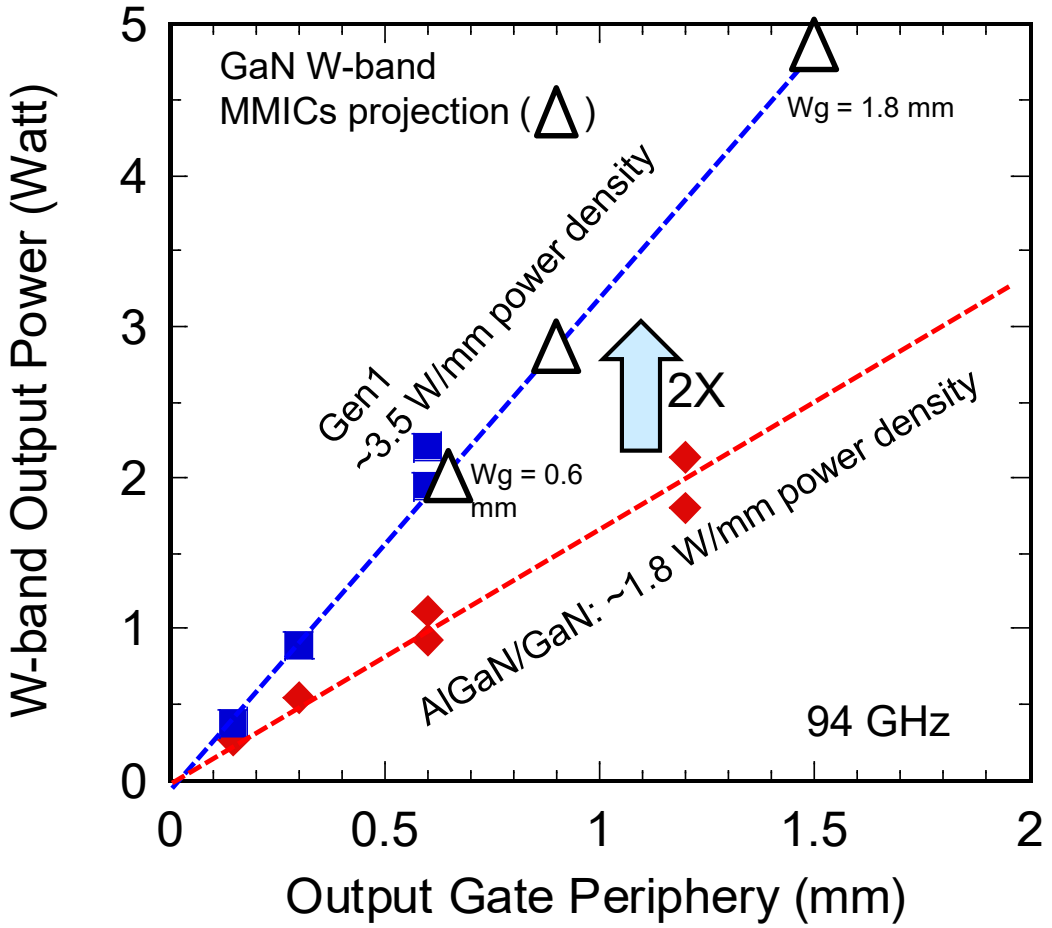


T3L W-band FETs with record PAE of 51% at 2.2 W/mm power density at 94 GHz

~3.5 W/mm W-band Power Density in Circuits

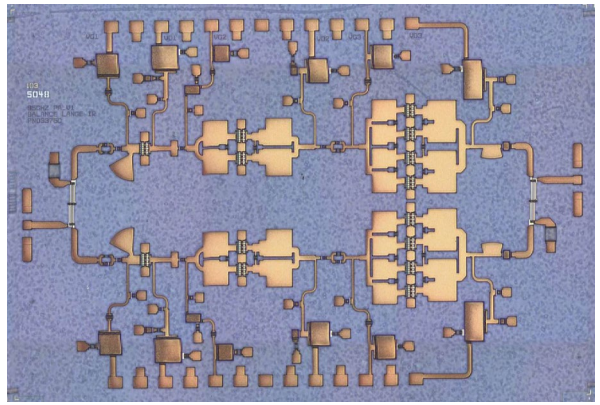


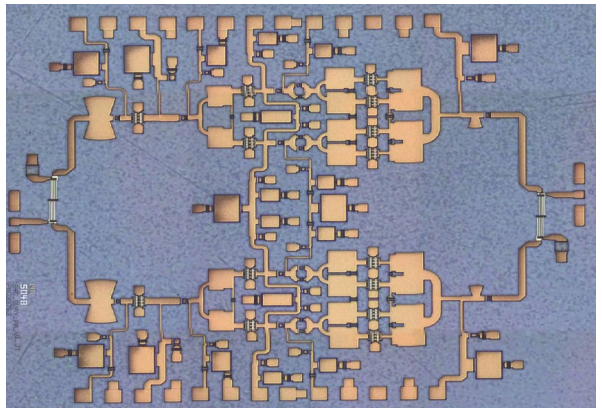




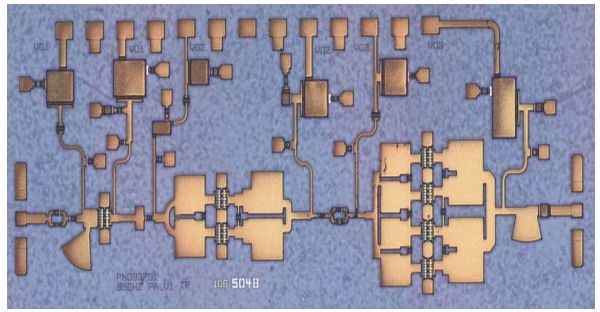
High-power W-band MMIC PAs

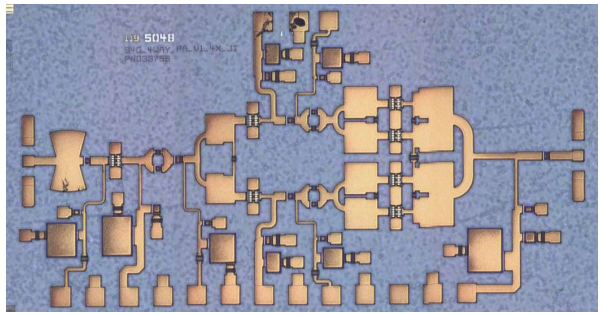
~5 Watt PA with output stage gate periphery of 1.8 mm



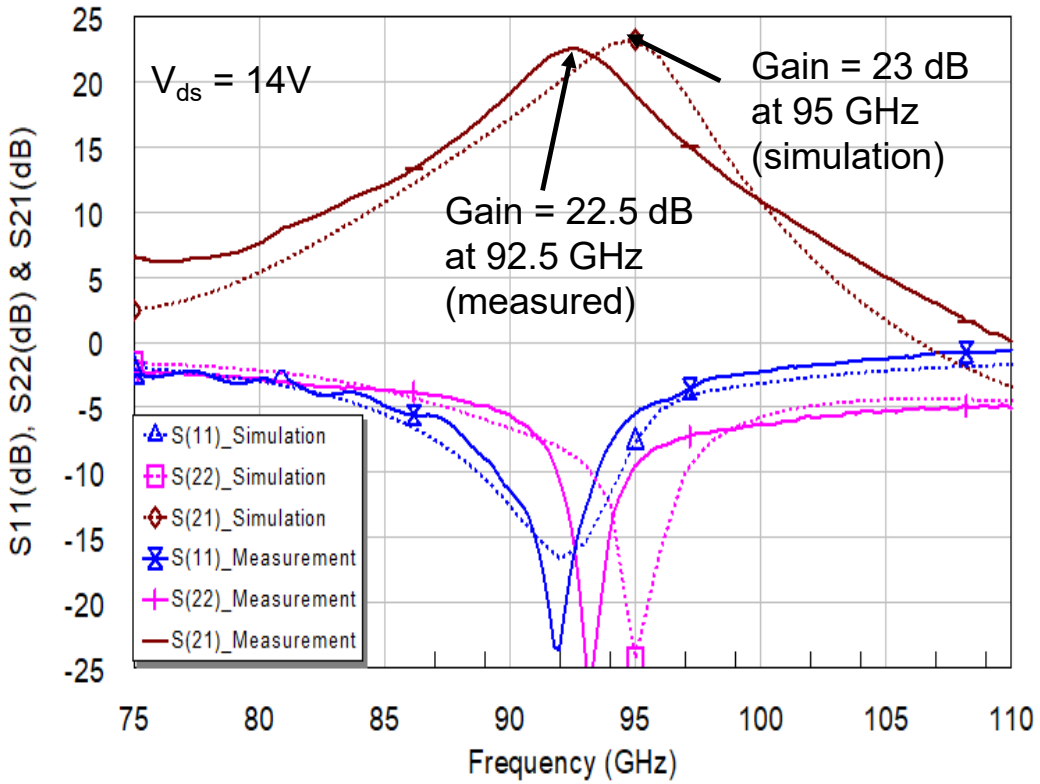


2-3 Watt with output stage gate periphery



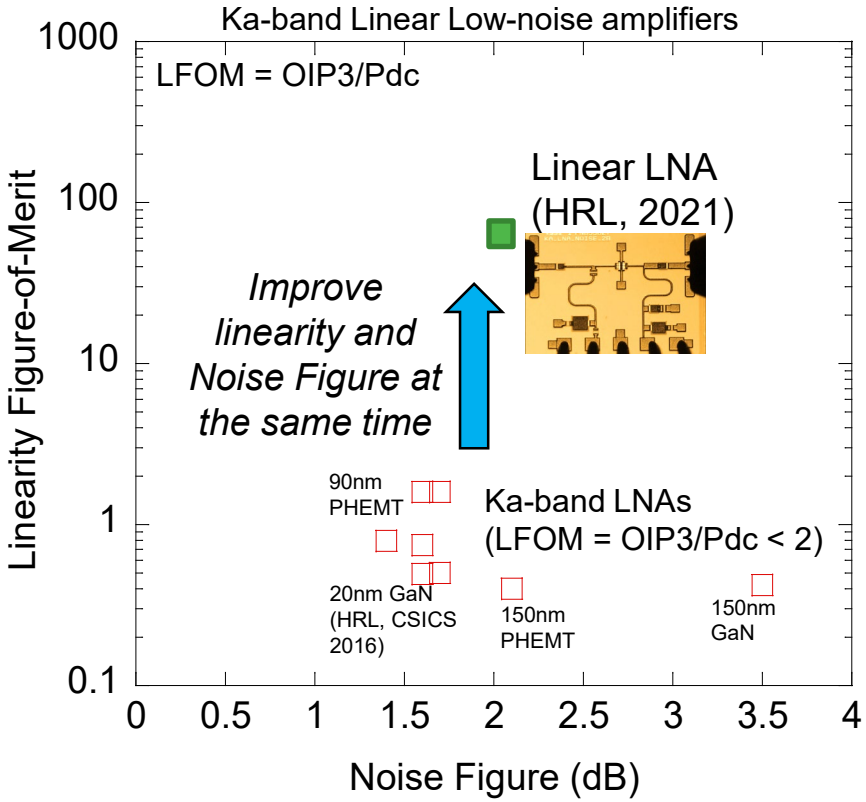


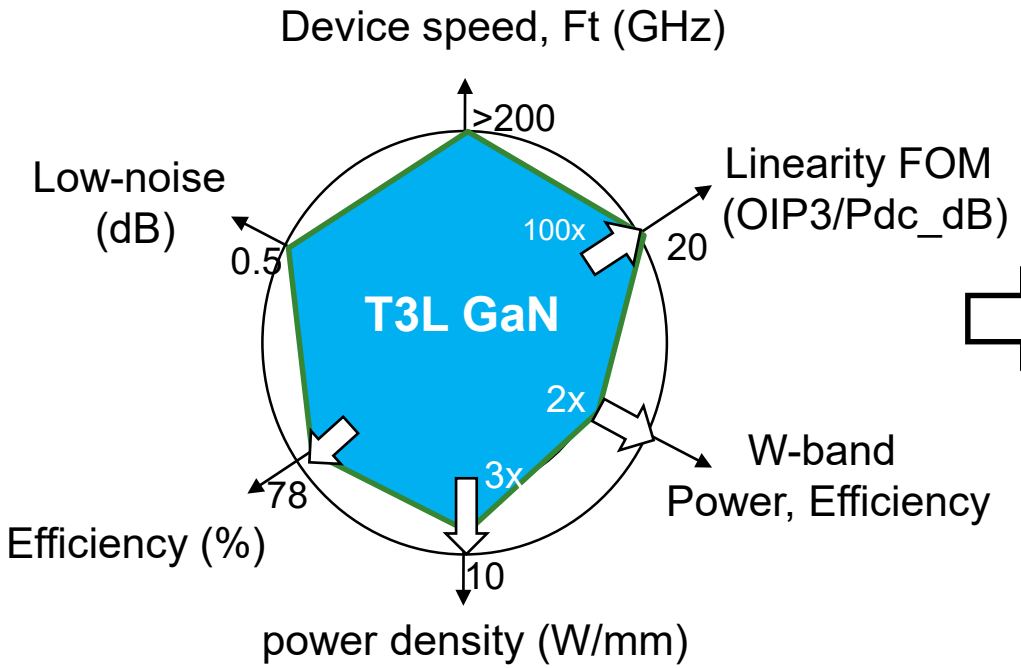
- T3L GaN
- The first design and fab of W-band PAs
- High gain = 22.5 dB at 92.5 GHz
- No circuit oscillations
- Wg = 4-way combination of 4x37.5 um cell



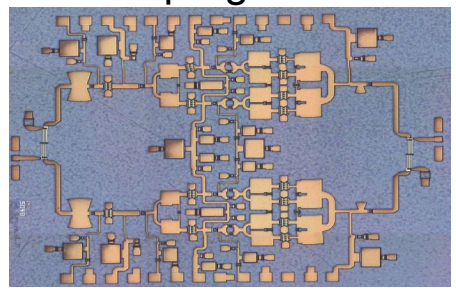
Summary

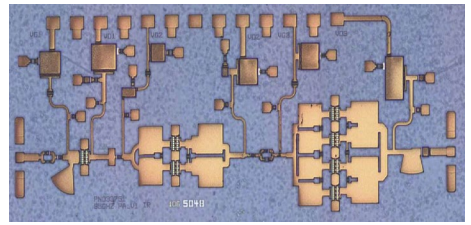
- ❑ >10X improved linearity figure of merit in Ka-band low-noise amplifiers.
- ❑ Record 51% PAE at 2.2 W/mm power density at 94 GHz.
- ❑ High-power W-band compact PAs feasible with 3.5 W/mm power density.
- ❑ Initial reliability testing seems encouraging, needs more rigorous REL testing.





High-power and efficient W-band PA in progress





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- HRL Team members: Bob Grabar, Joel Wong, Erdem Arkun, Chuong Dao, Peter Chen, Mike Antcliffe, Shyam Bharadwaj, Dave Fanning, Joe Tai, Ignacio Ramos
- Univ. of Notre Dame: Nivedhita Venkatesan and Patrick Fay

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