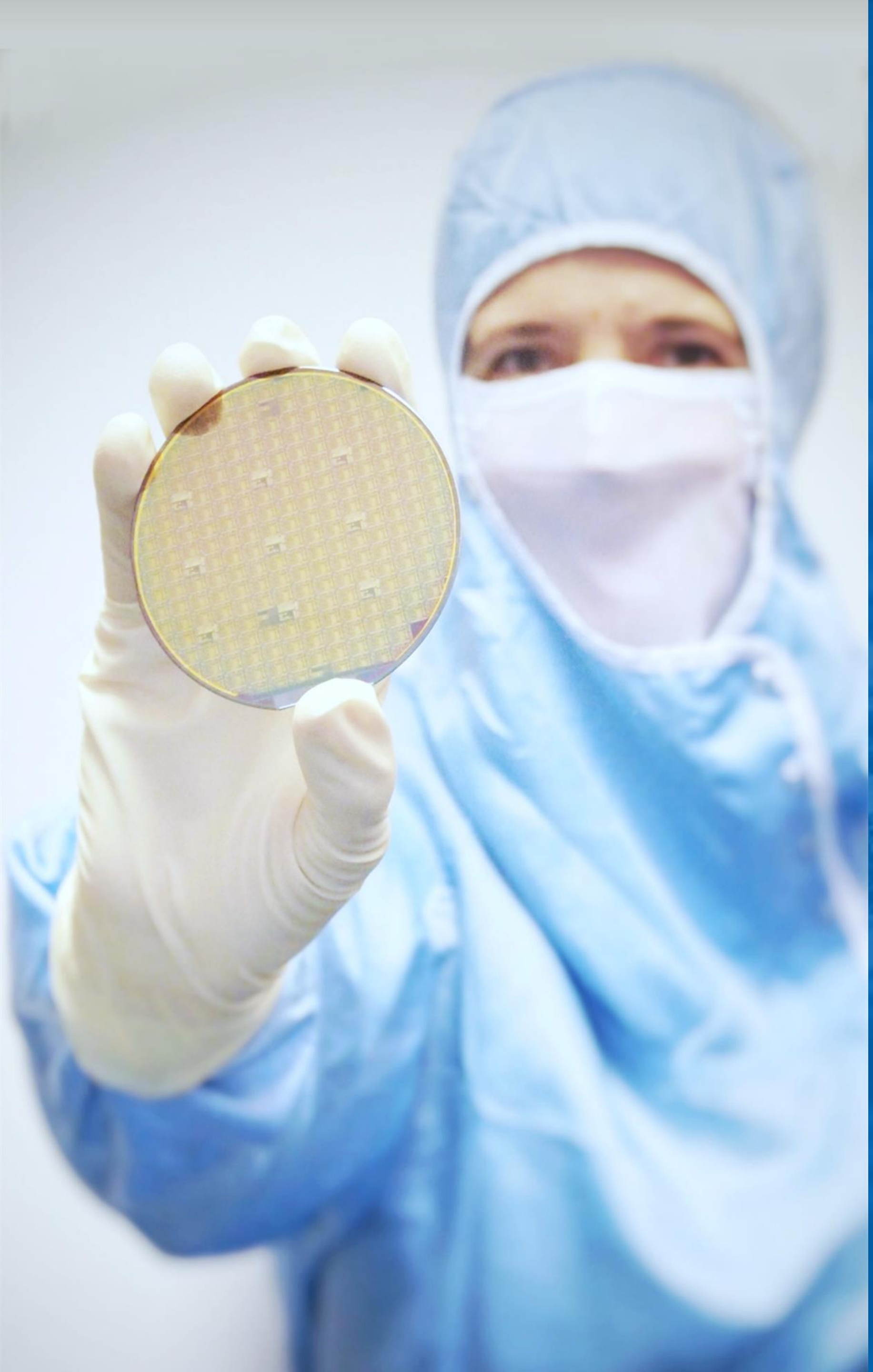


# Europe's Leading Foundry

# OMMIC

## "100nm GaN on Si Technology for mmW 5G Application


EDICON
April 1st 2019

PRESENTED AT THE NEW ENGLAND IMAPS SYMPOSIUM
MAY 7, 2019

PRESENTED BY
TOM TERLIZZI
GM SYSTEMS

**Dr. Charles EDOUA KACOU**
**Dr. Fabien ROBERT**
**OMMIC**

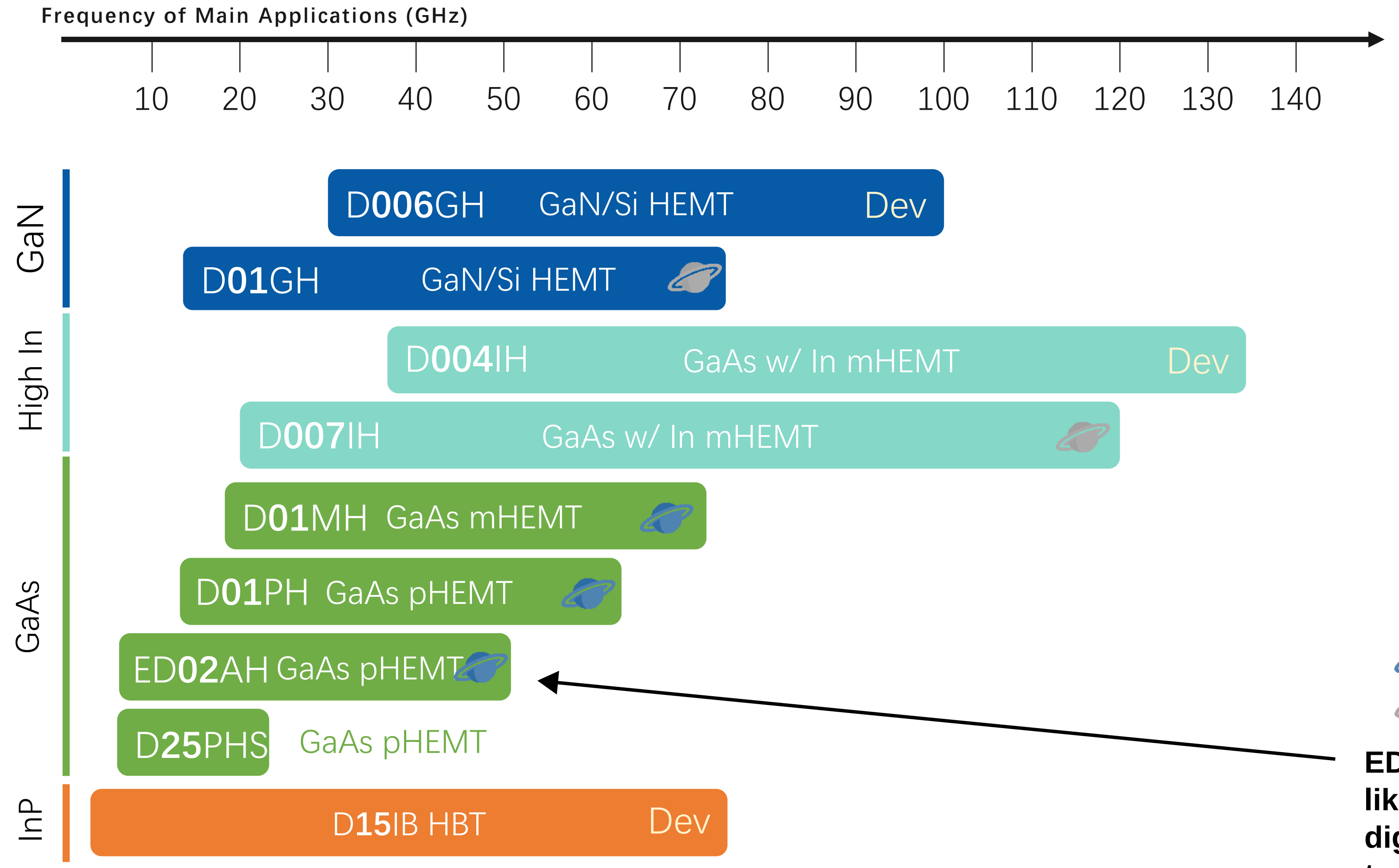
OMMIC
innovating with III-V'S


**1st**

**6 Inch GaN line in Europe**

- Created in 2000
- Former Philips Semiconductor division
- Over 40 years of experience in III-V semiconductors, including GaAs and InP
- Unique GaN Process best suited for upcoming 5G
- Only foundry in Europe offering complete service including Epitaxial Growth, Process Development, MMIC Design & Fabrication, Test & Product Qualification

# OMMIC PROCESSES

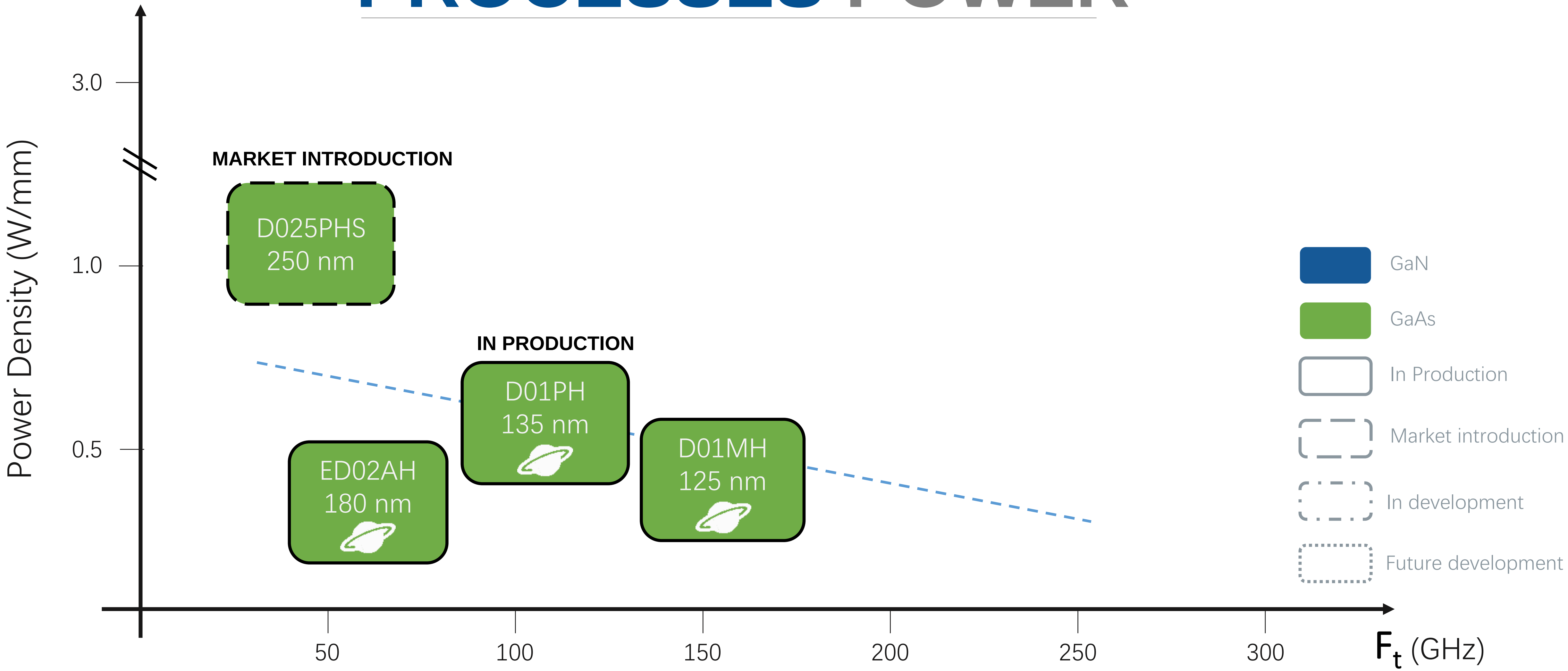



: Space Qualified process

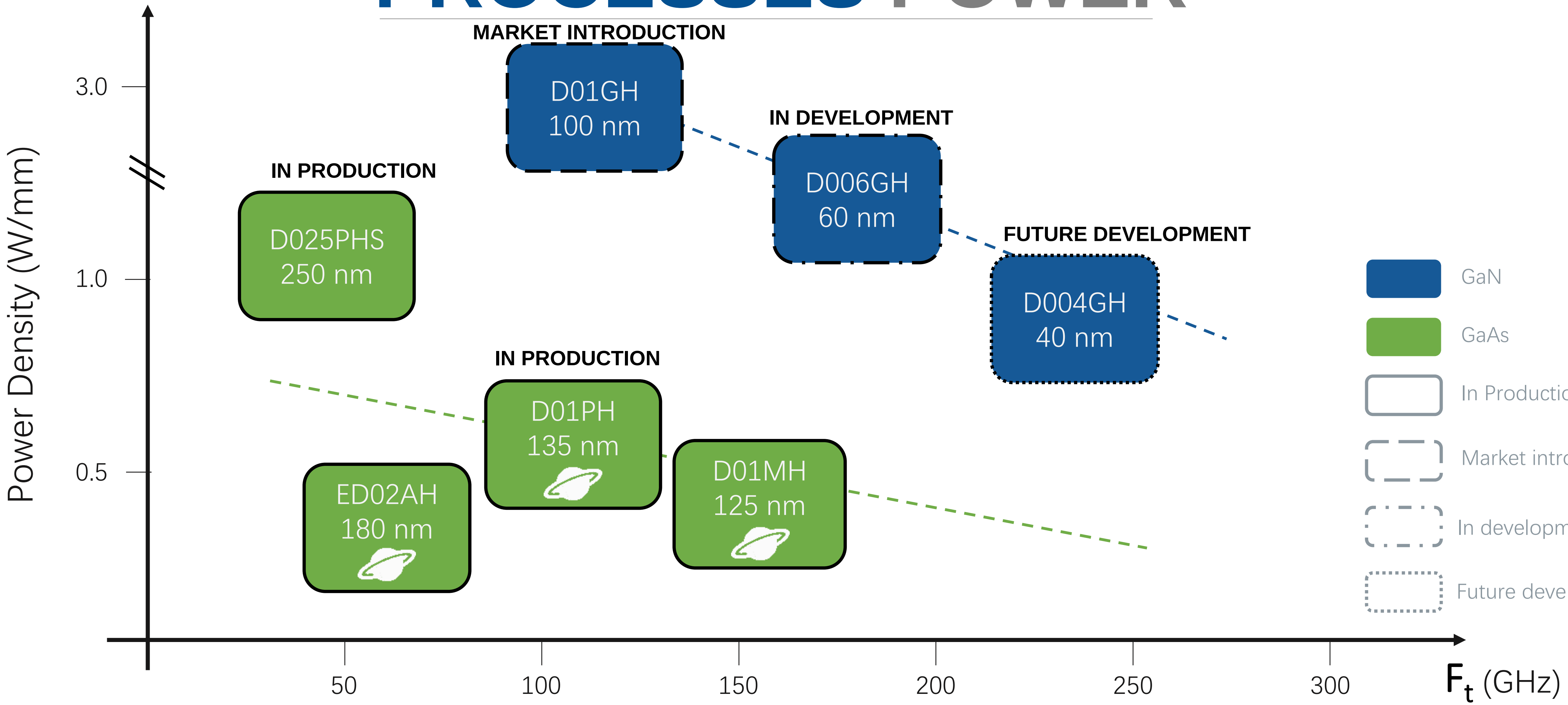
: On-going Space Qualification (2020)

**ED means Enhance / Depletion mode FET. like ED02AH process, means you can do digital function with normaly off and on transistors**

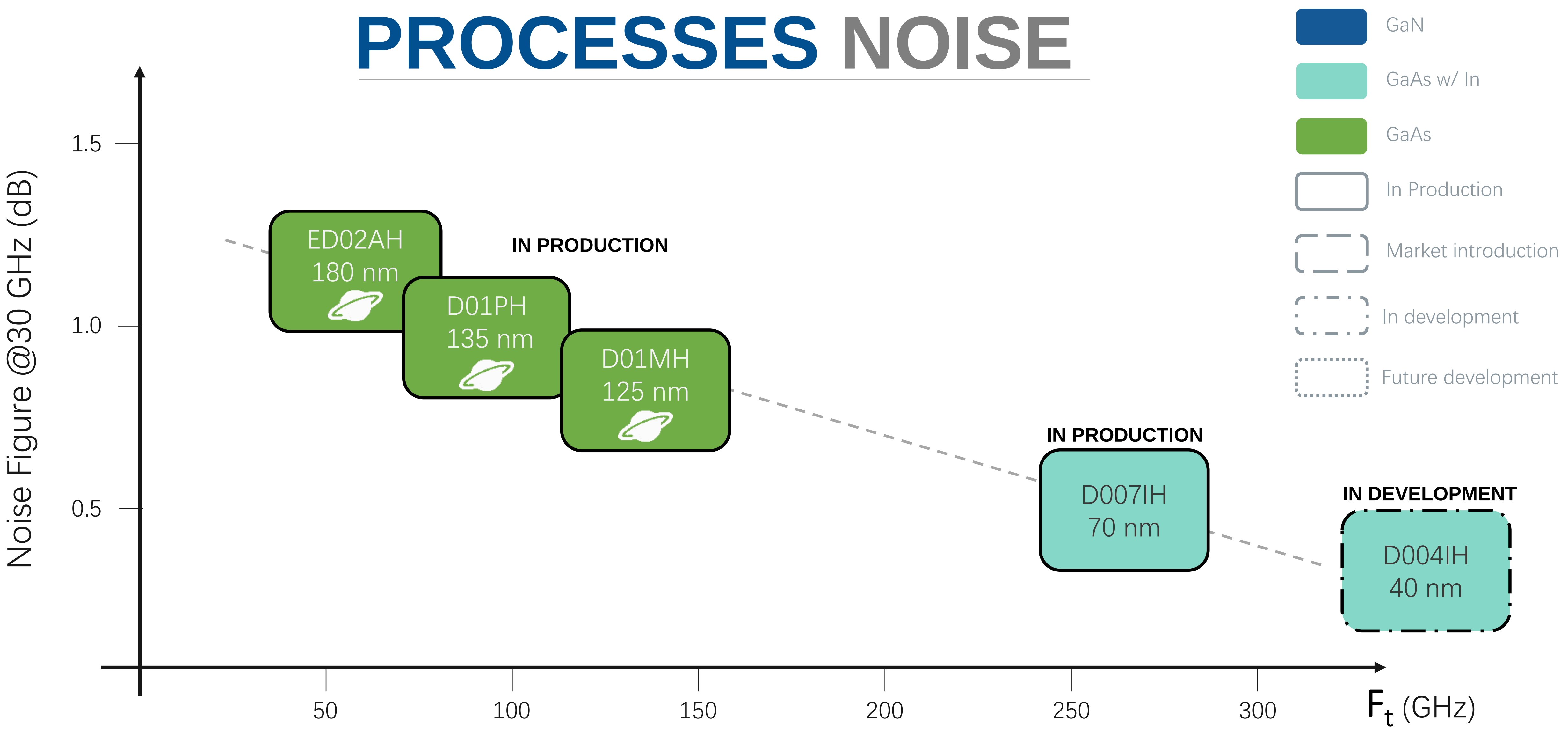
# PROCESSES POWER



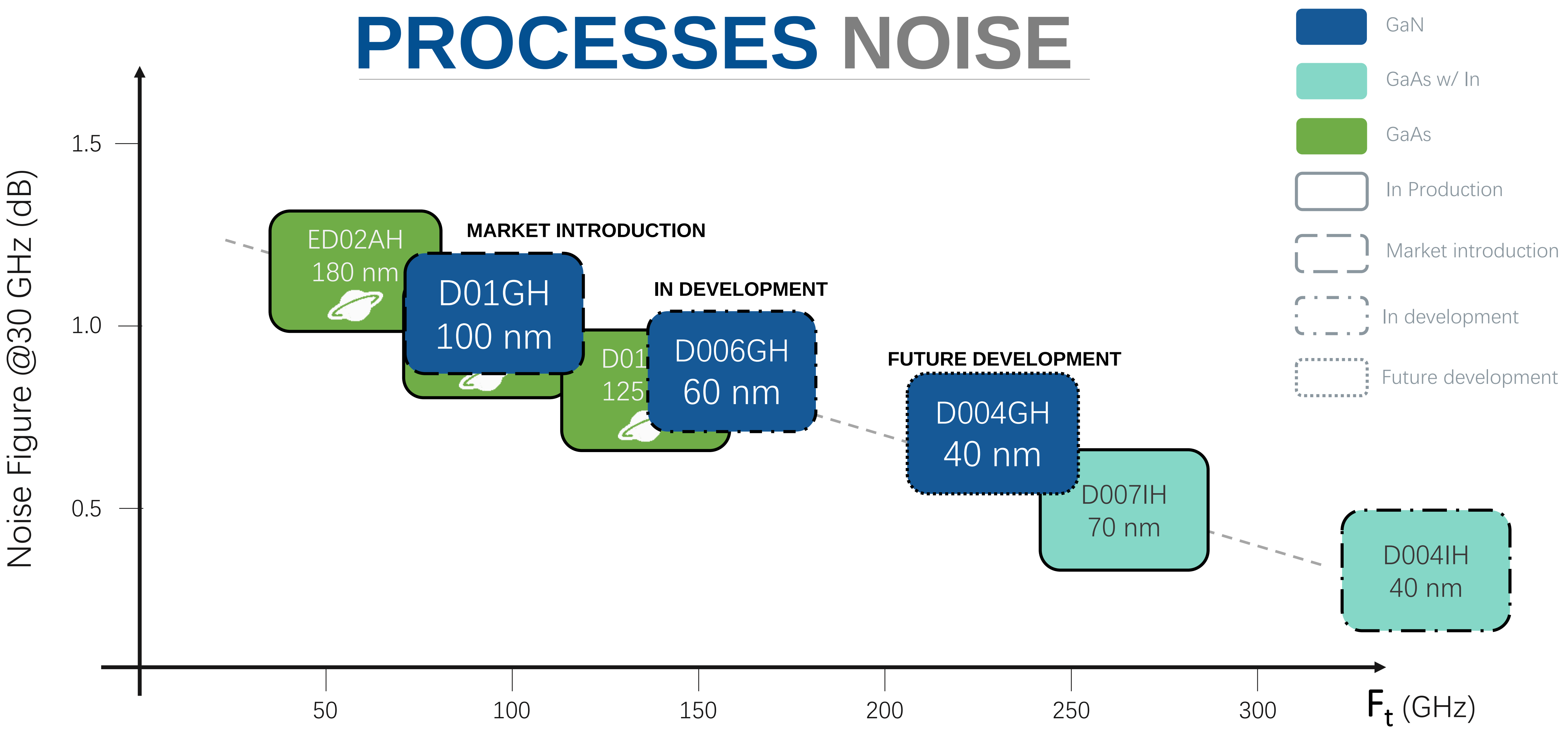
# PROCESSES POWER



# PROCESSES NOISE



# PROCESSES NOISE



# D01GH GaN/Si

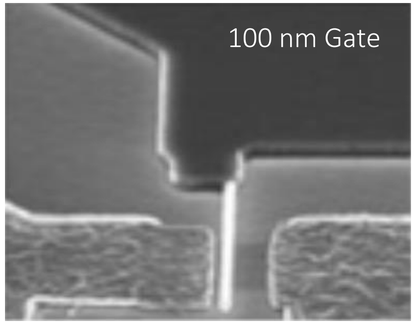
**D01GH FEATURE**

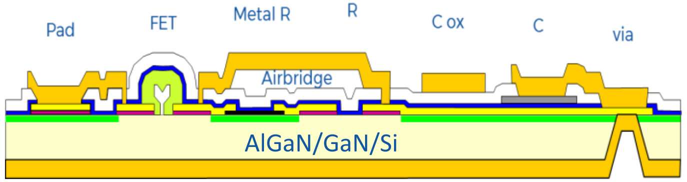
$f_{max}$ : 180 GHz
$f_t$ : 100 GHz

Gate length: 100 nm
$V_{bgd}$ : 40 V

**PRELIMINARY ON-WAFER MEASUREMENTS**

PW @ 30 GHz : 3.5 W/mm
PAE : 48%



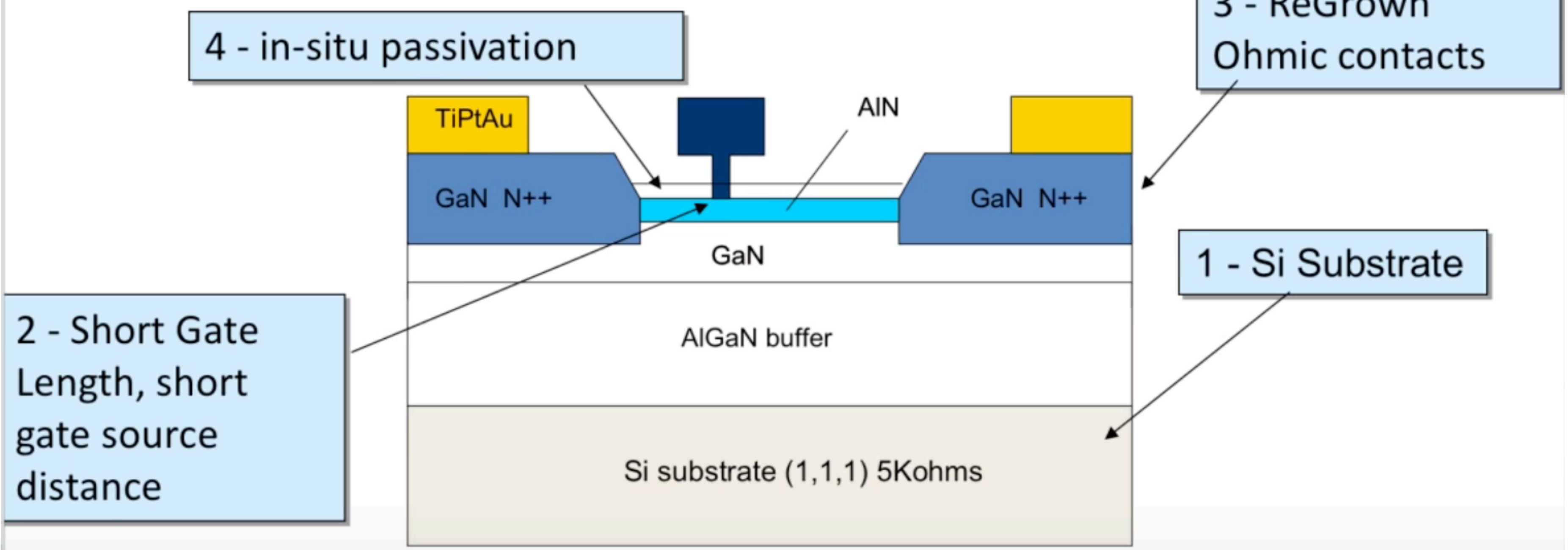




**MAIN APPLICATIONS**

- High Linearity Mixers
- High frequency PA 15 GHz to 50 GHz
- Instrumentation wide band amplifier DC - 50 GHz
- Robust LNA (< 40 GHz) : up to 35dBm Pin CW for

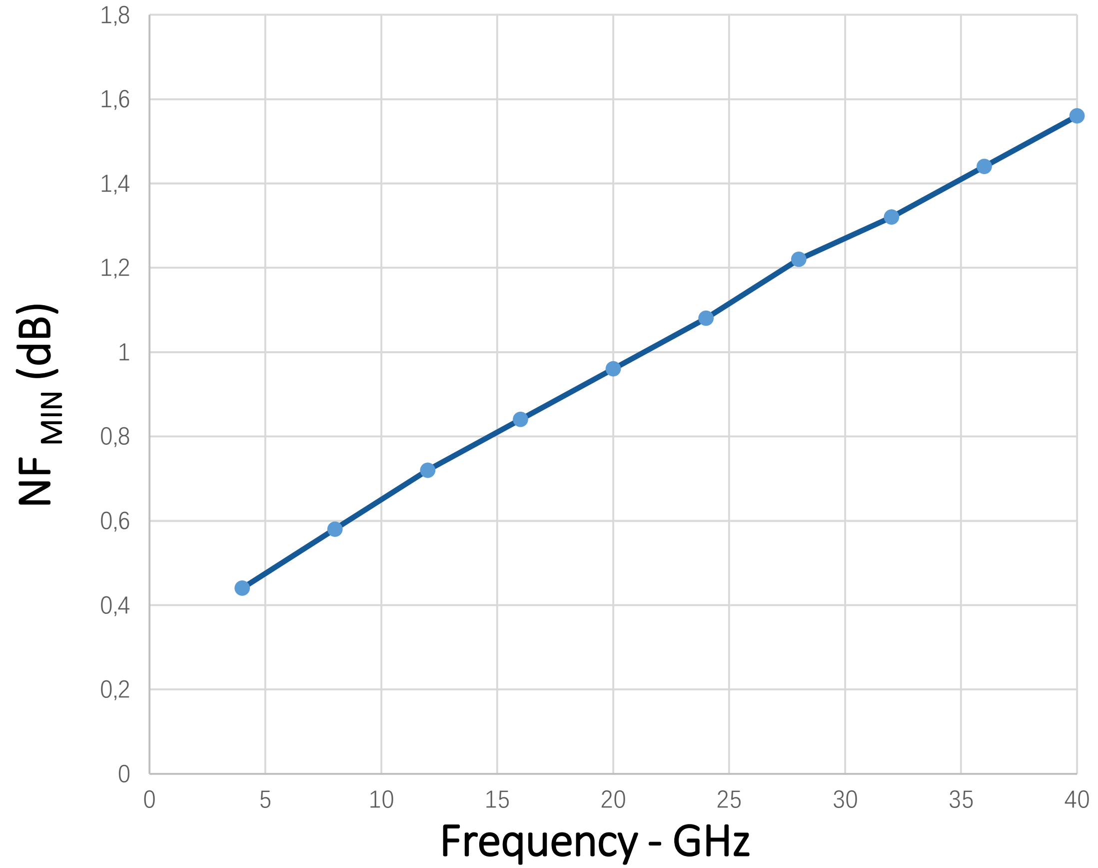
# The 4 specificities of OMMIC GaN

- Silicon substrate for D01GH (not SiC !)
  - Easier access to the epitaxial material, lower cost, 6”
  - Power of up to 3W/mm @12V is compatible with the thermal conductance of Si (still 3 x GaAs) and reduces reliability troubles



# D01GH GaN PROCESS

## D01GH $NF_{min}$ v.s. Freq

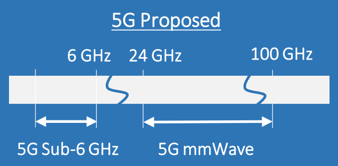



## GaAs v.s GaN

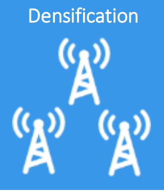
| | D01PH<br>GaAs pHEMT<br>135 nm | D01GH<br>GaN/Si HEMT<br>100 nm | D01MH<br>GaAs mHEMT<br>120 nm |
|---|---|---|---|
| $V_{ds}$ (V) | 3 | 5 | 1 |
| $I_{ds}$ (mA) | 15 | 42 | 30 |
| $R_s$ (Ohm) | 1,0 | 1,2 | 0,8 |
| $R_g$ (Ohm) | 0,65 | 0,70 | 0,7 |
| $NF_{min}$ | 1,72 dB | 1,54 dB | 1,13 dB |
| Associated Gain | 4,5 dB | 8 dB | 12,4 dB |

# GaN/Si FOR 5G

- High frequency
- High efficiency

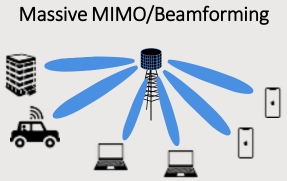



- Low voltage
- Small size
- High linearization




- Small size
- High temperature
- High reliability


- Ultra-wide band linearization
- Small package/high power

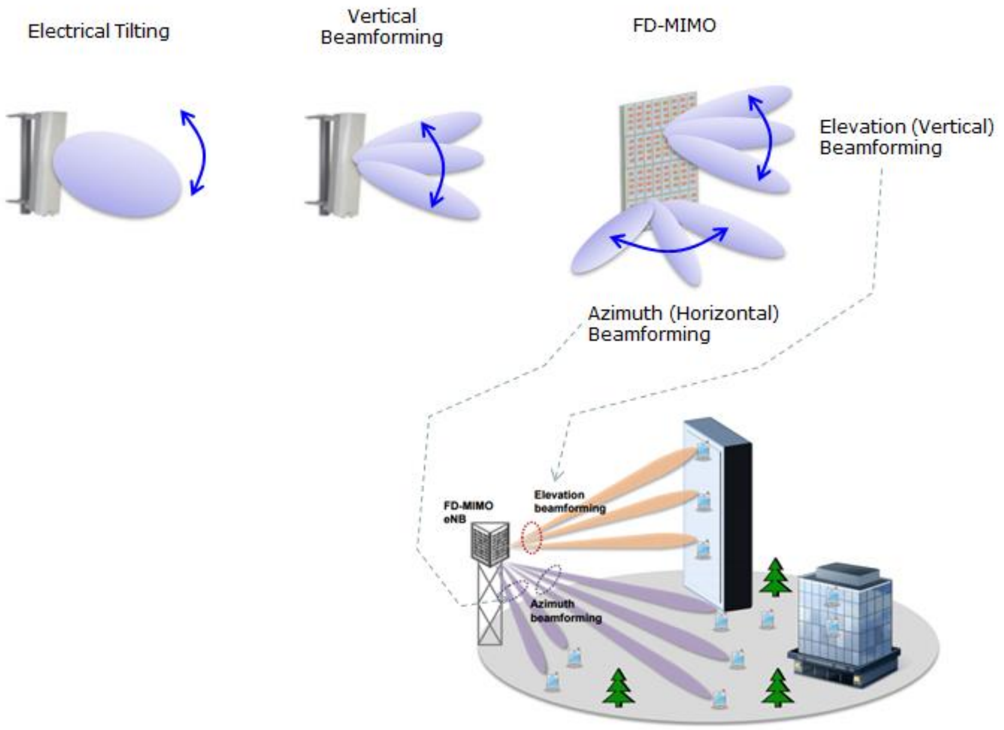



5G

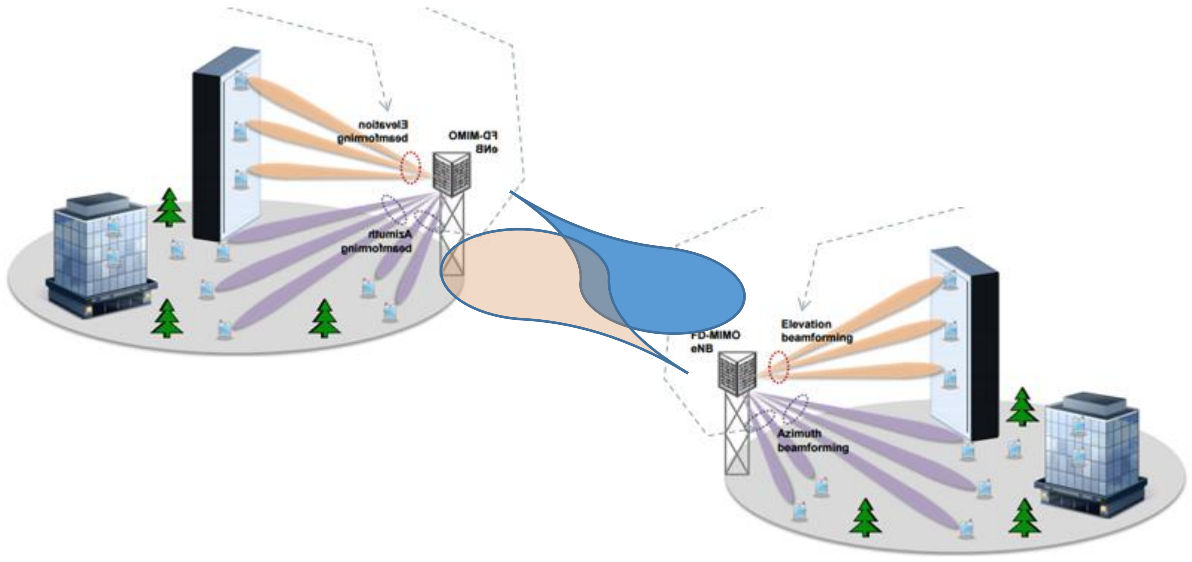
- Only GaN technology can offer enough power at high frequency 28 GHz/ 40 GHz
- OMMIC proposes state-of-the-art GaN/Si technology for higher frequency of 5G application
- OMMIC's 100nm GaN/Si process is unique in the world and perfectly suited for 5G

# GaN/Si for mmW 5G

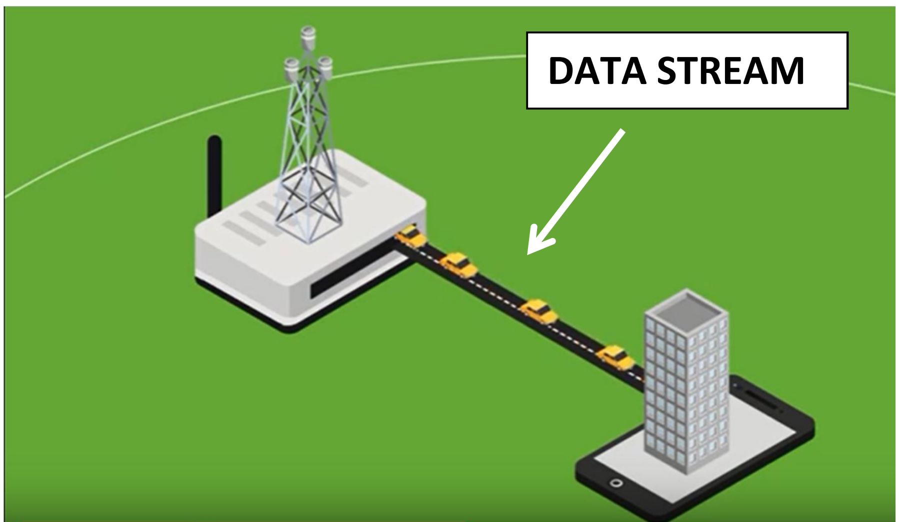
Massive MIMO mmW transceiver (28/40GHz)




Point to Point radio backhaul (71-76GHz)

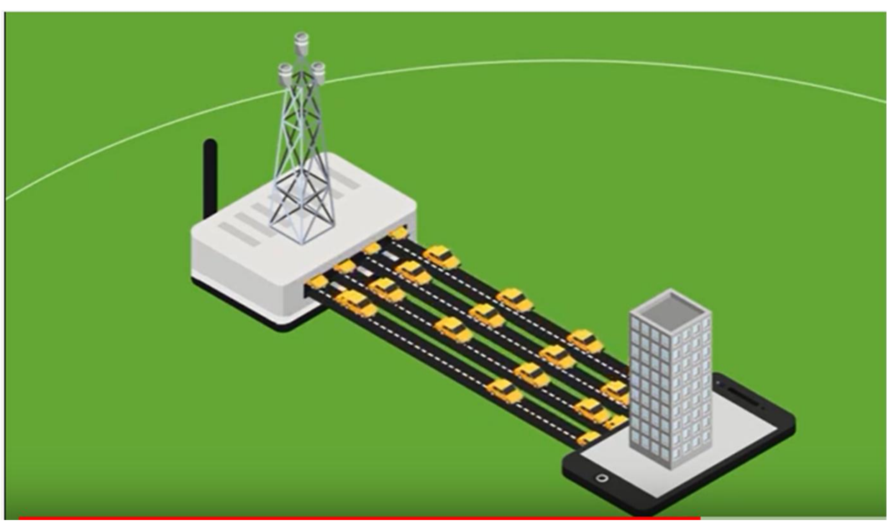


# SIMPLIFIED MIMO ANALOGY

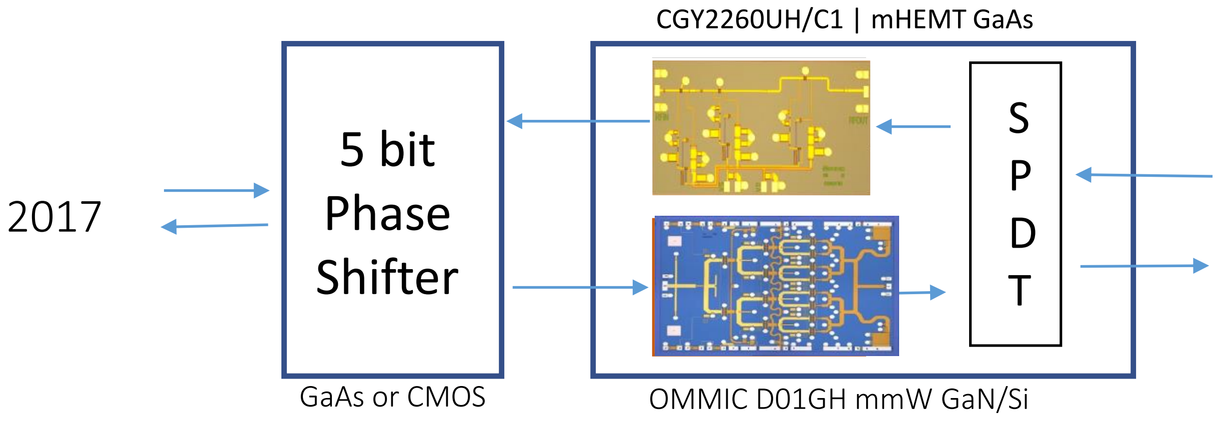



**4X4 MIMO**

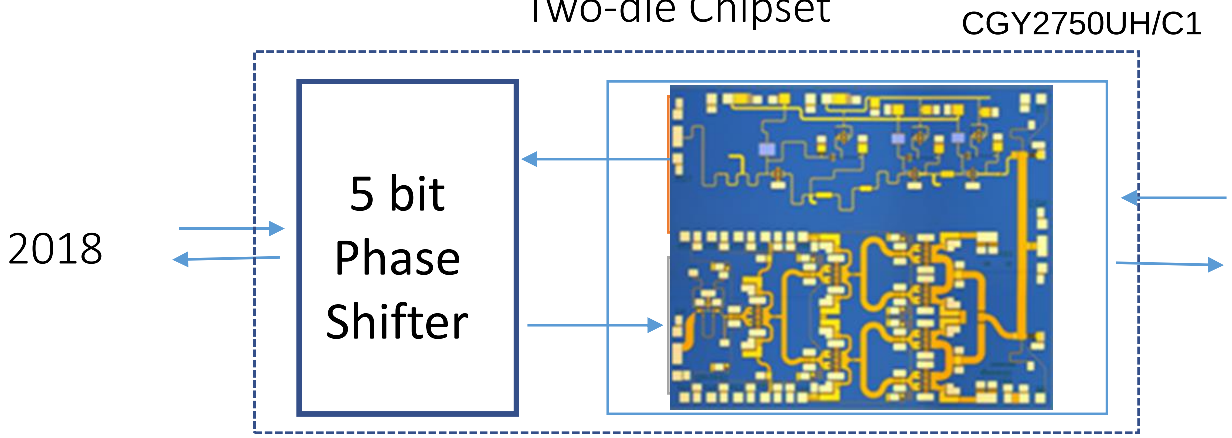
(Multiple Input Multiple Output)



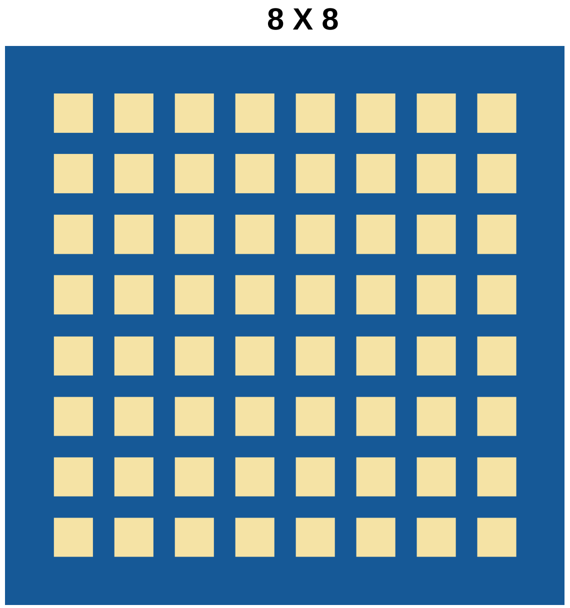
# 5G GaN SOLUTION



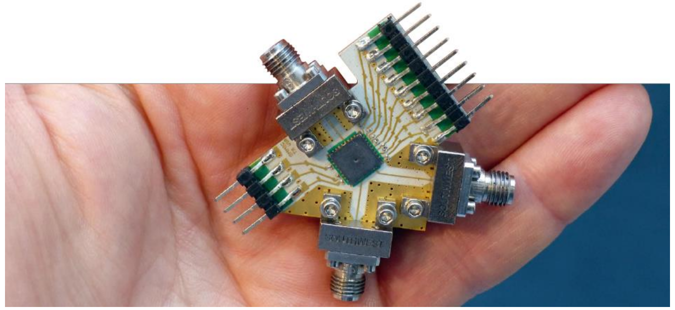

Two-die Chipset




Single Chipset ED GaN/Si (ED01GH)

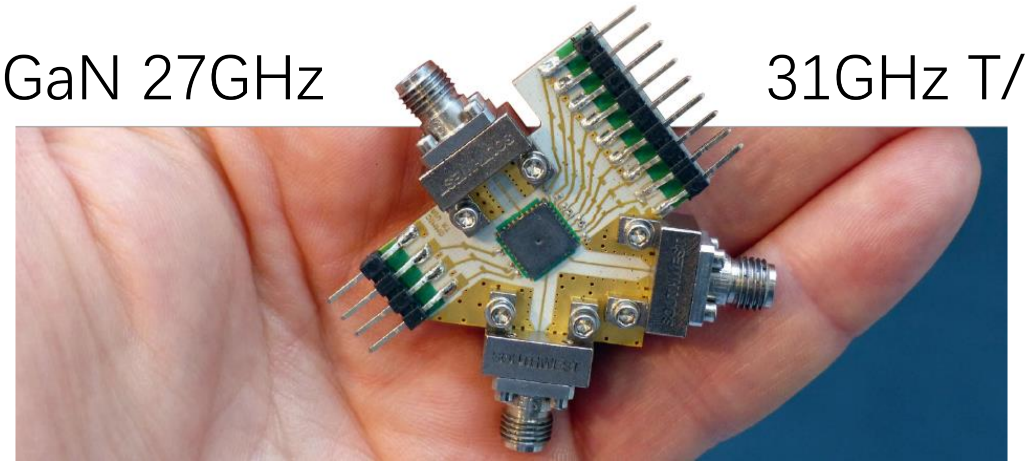



Massive MIMO Array Antenna

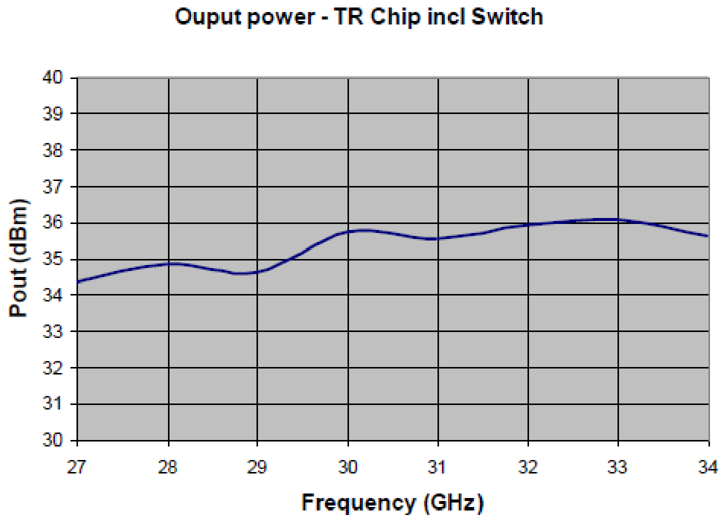


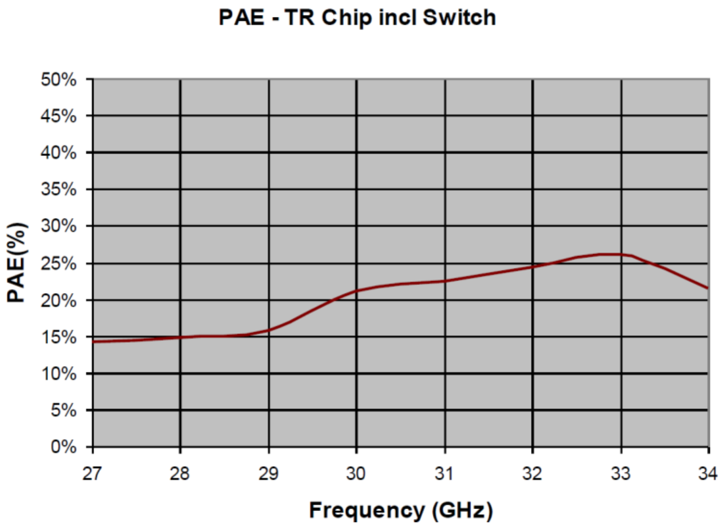
# 5G MAJOR REALISATION

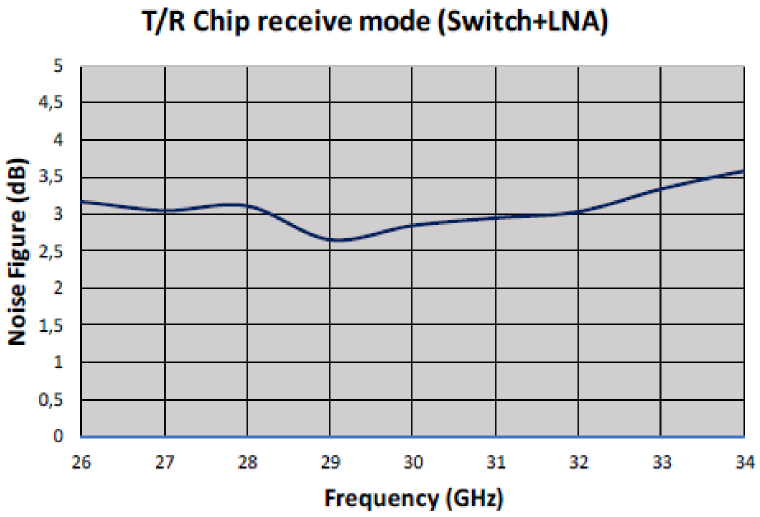
Best GaN 27GHz 31GHz T/R chip




**CGY2750UH/C1**

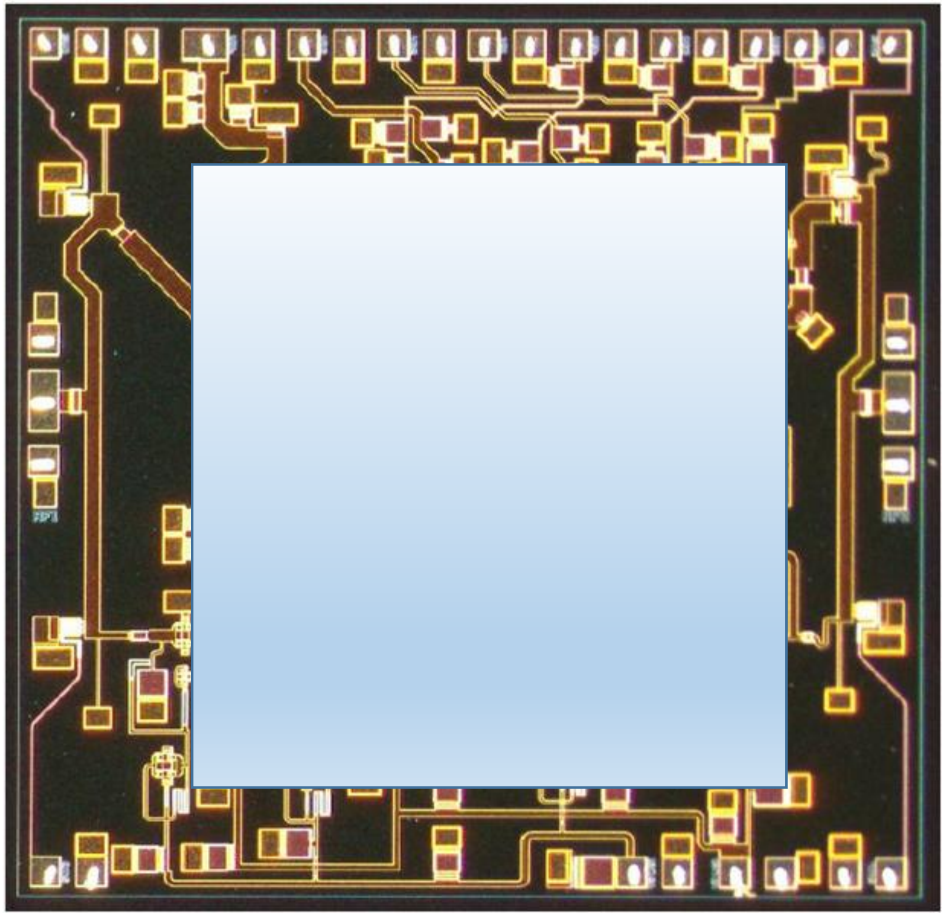


# 5G MAJOR REALISATION

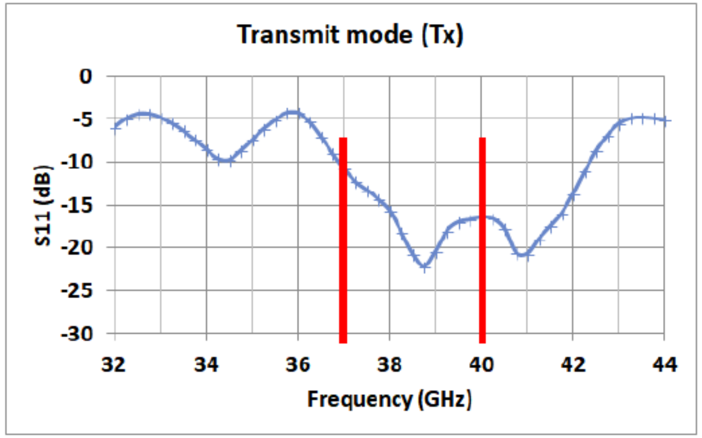
37-40GHz 4W T/R chip*

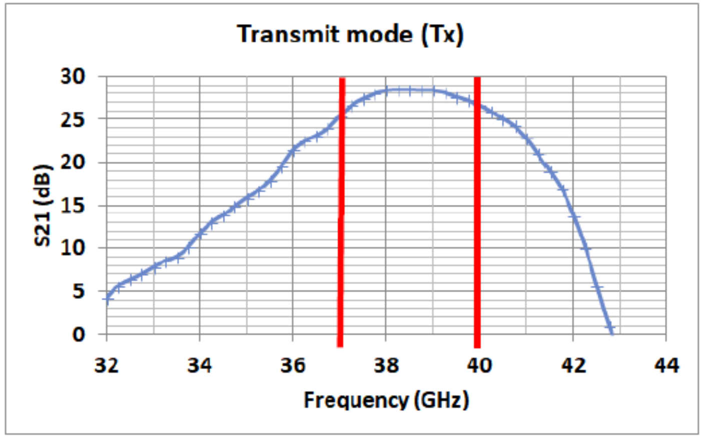


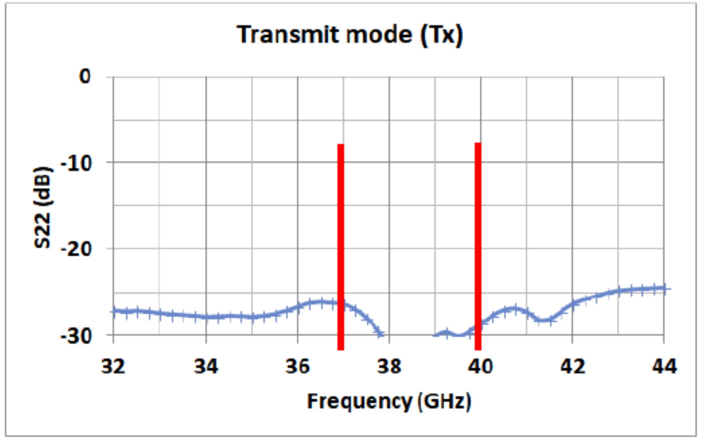

* H2020 Project SERENA

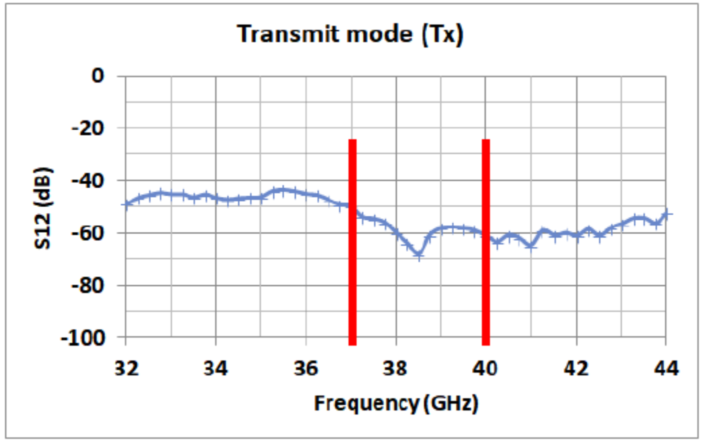
# 5G MAJOR REALISATION

## 37-40GHz 4W T/R chip



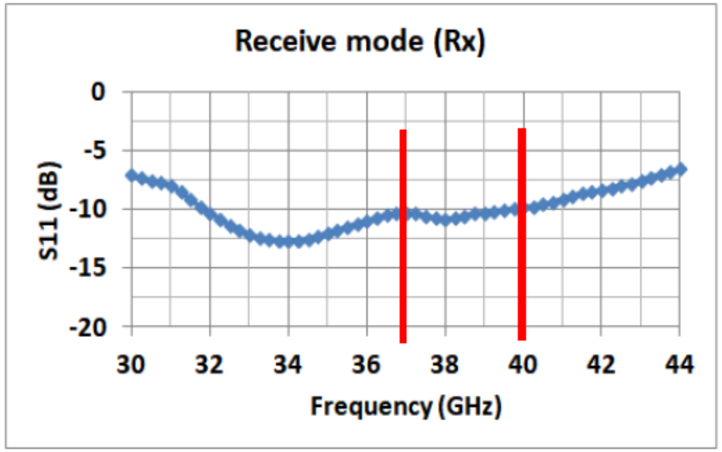



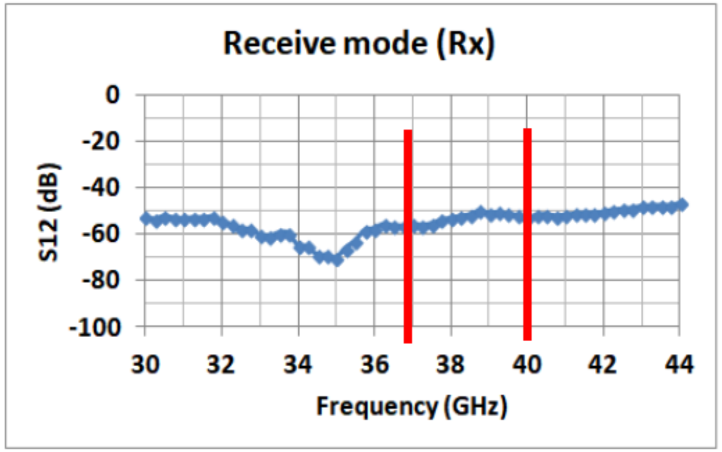



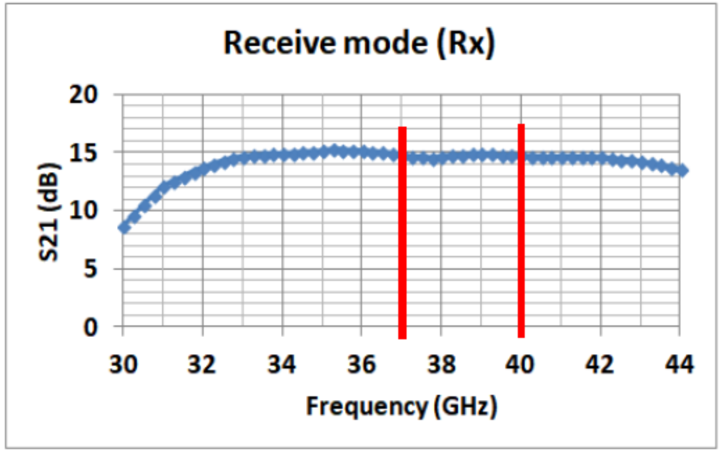



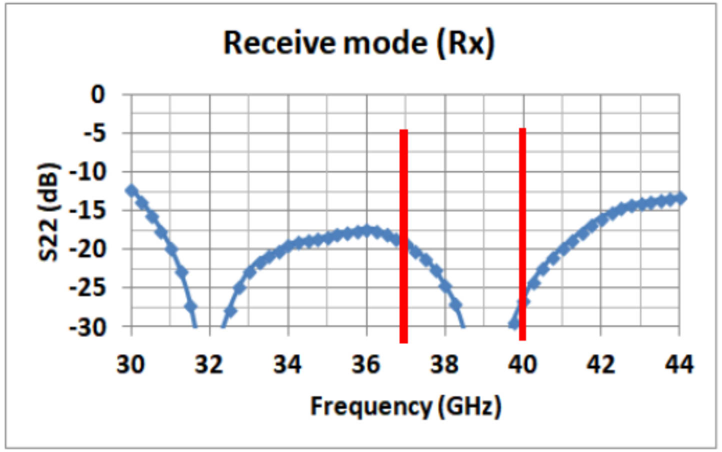
# 5G MAJOR REALISATION

## 37-40GHz 4W T/R chip

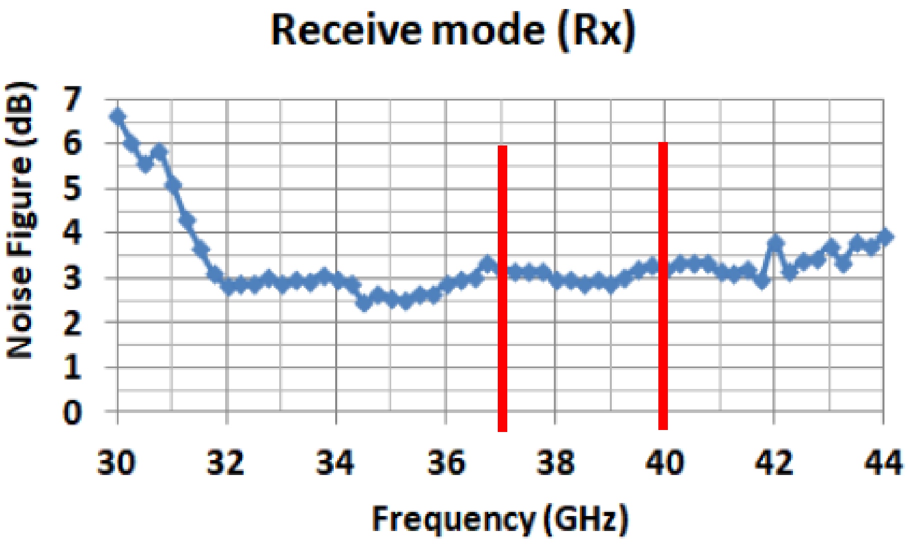


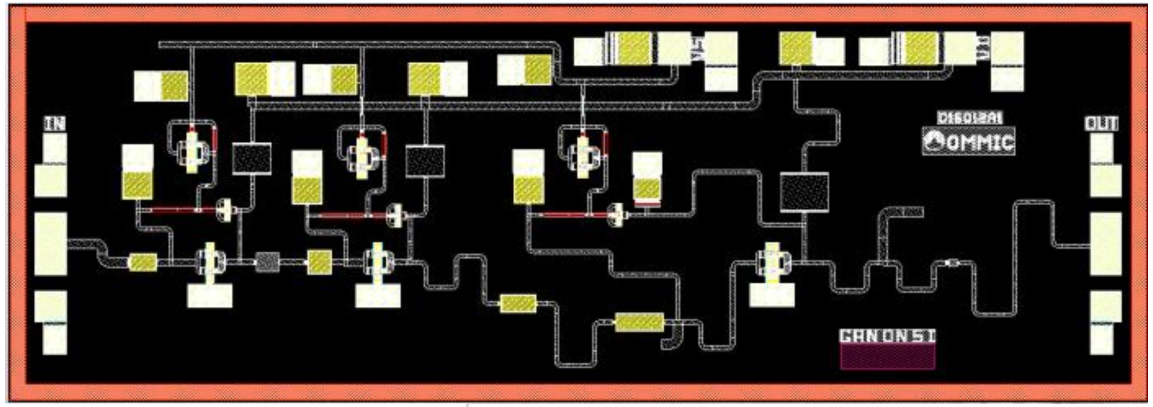

Including switches

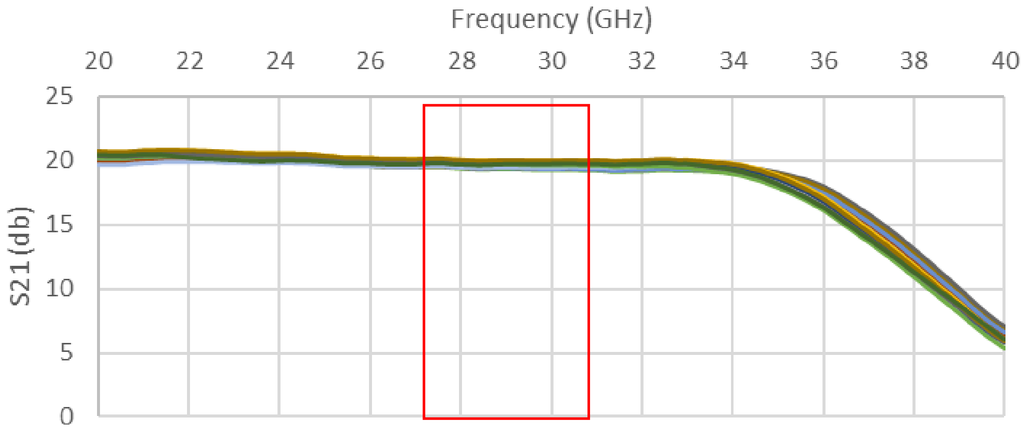


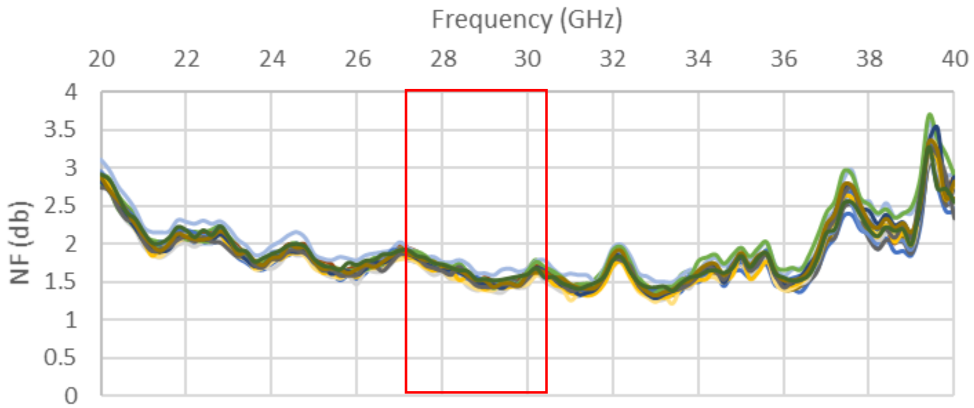
# MAJOR REALISATION

## Robust Ultra Low Noise 24-34GHz LNA

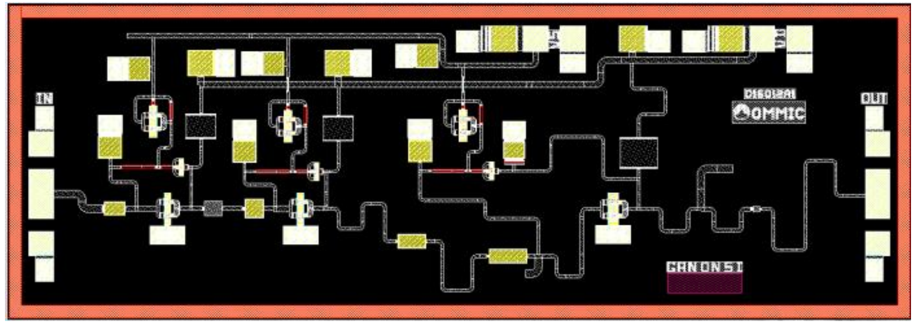
**CGY2250UH/C1 (GaN)**

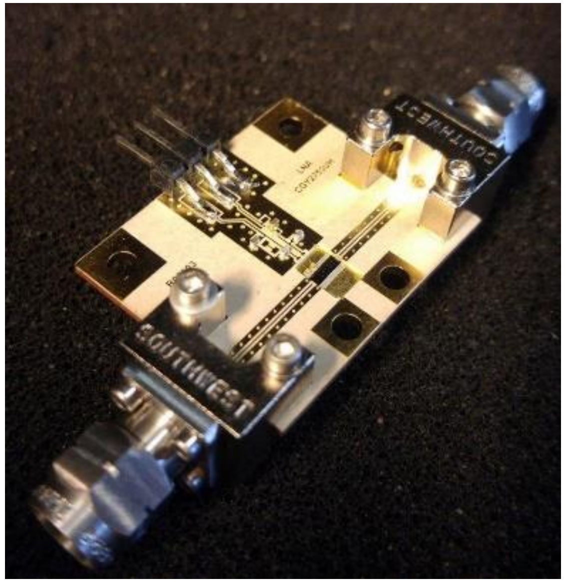


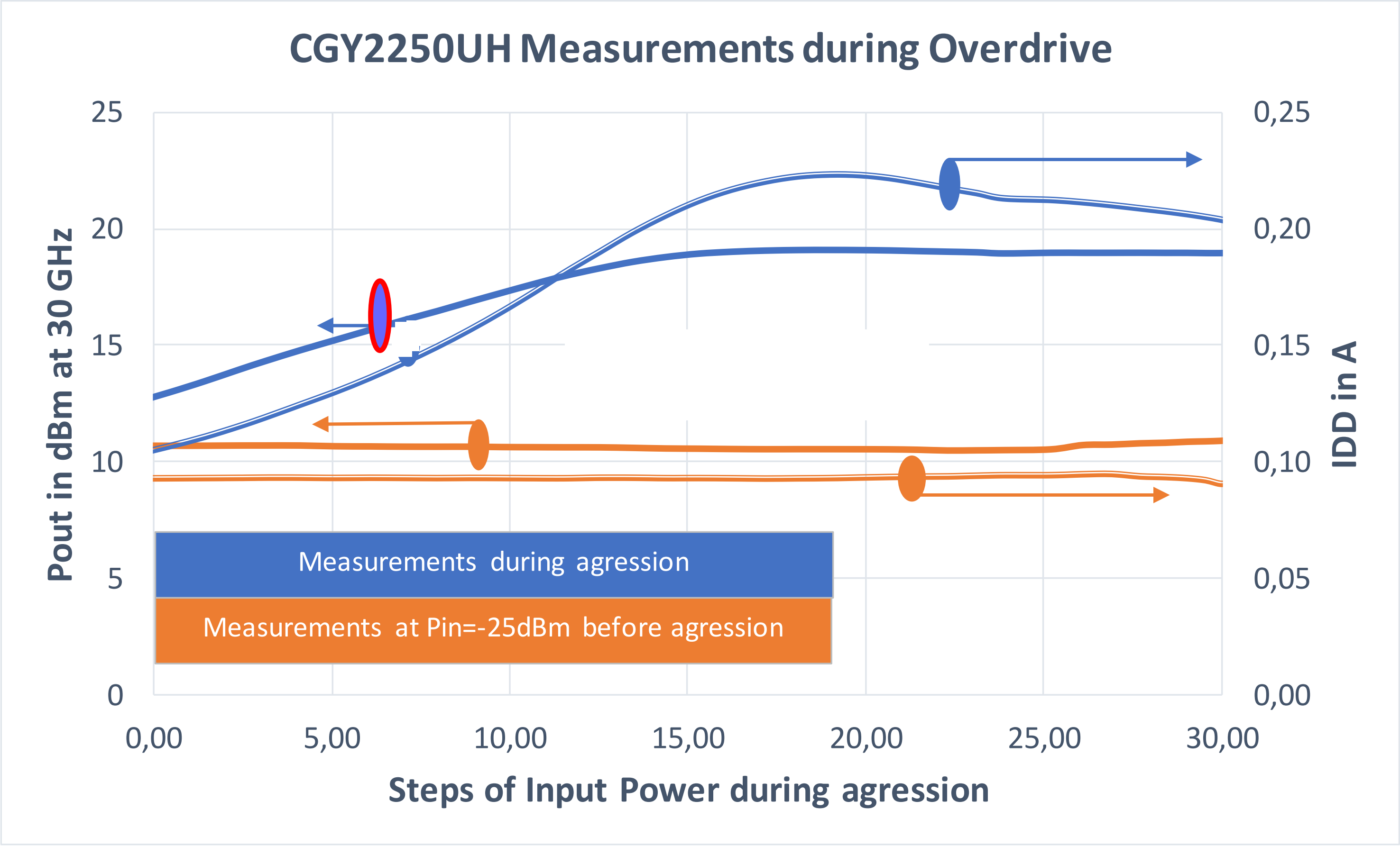



# MAJOR 5G REALISATION



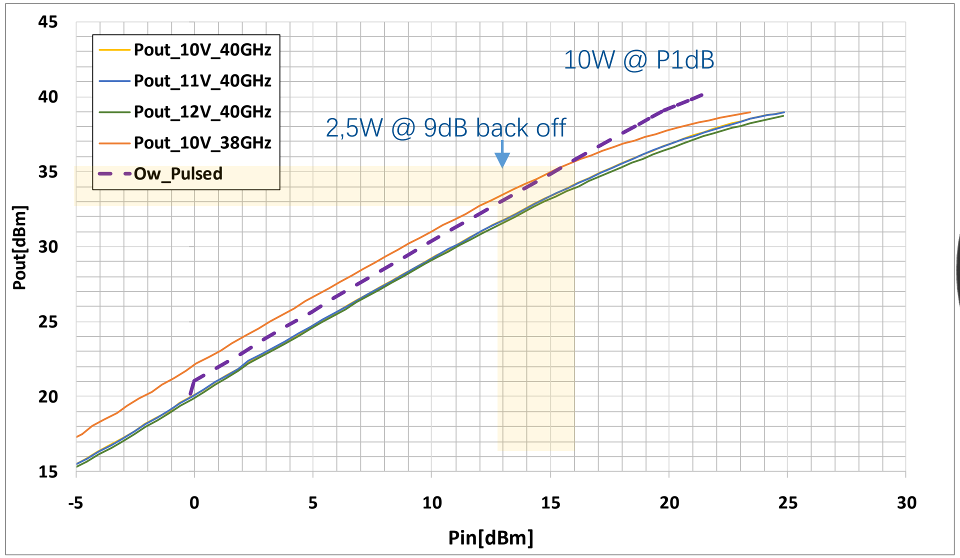



# 5G MAJOR REALISATION

## Best GaN 37-43 GHz 10 W PA

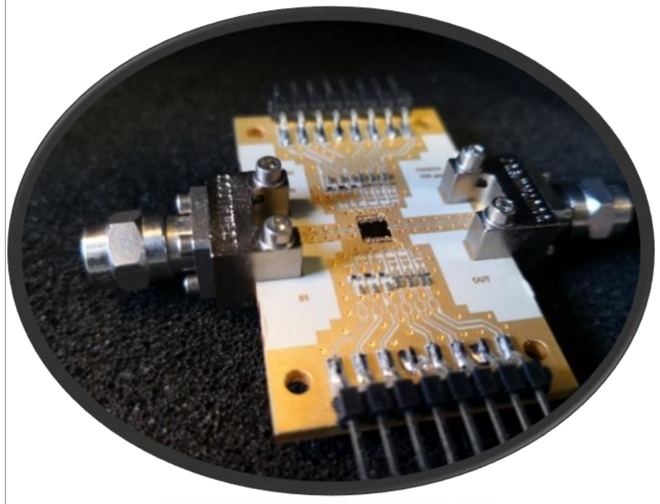
CGY2651UH/C1

### Outuput Power

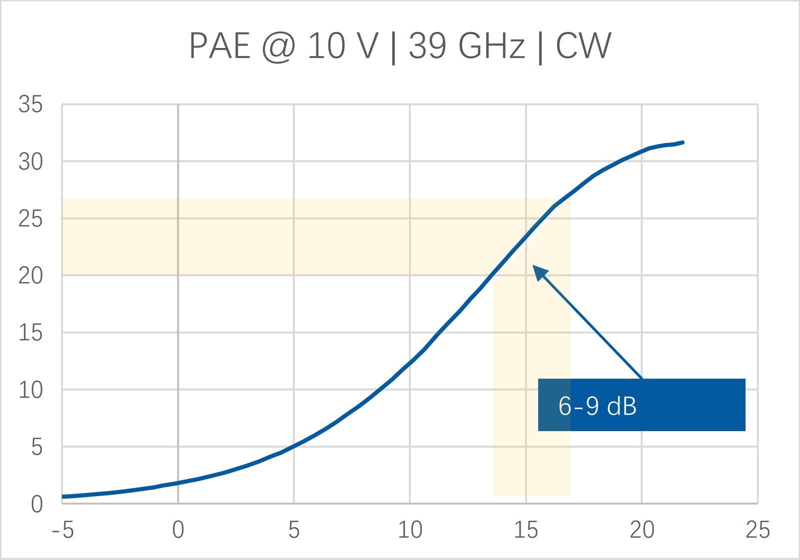



OW pulsed *vs.* PCB CW

(OW = ON WAFER TESTS )



### State of the Art Power Efficiency



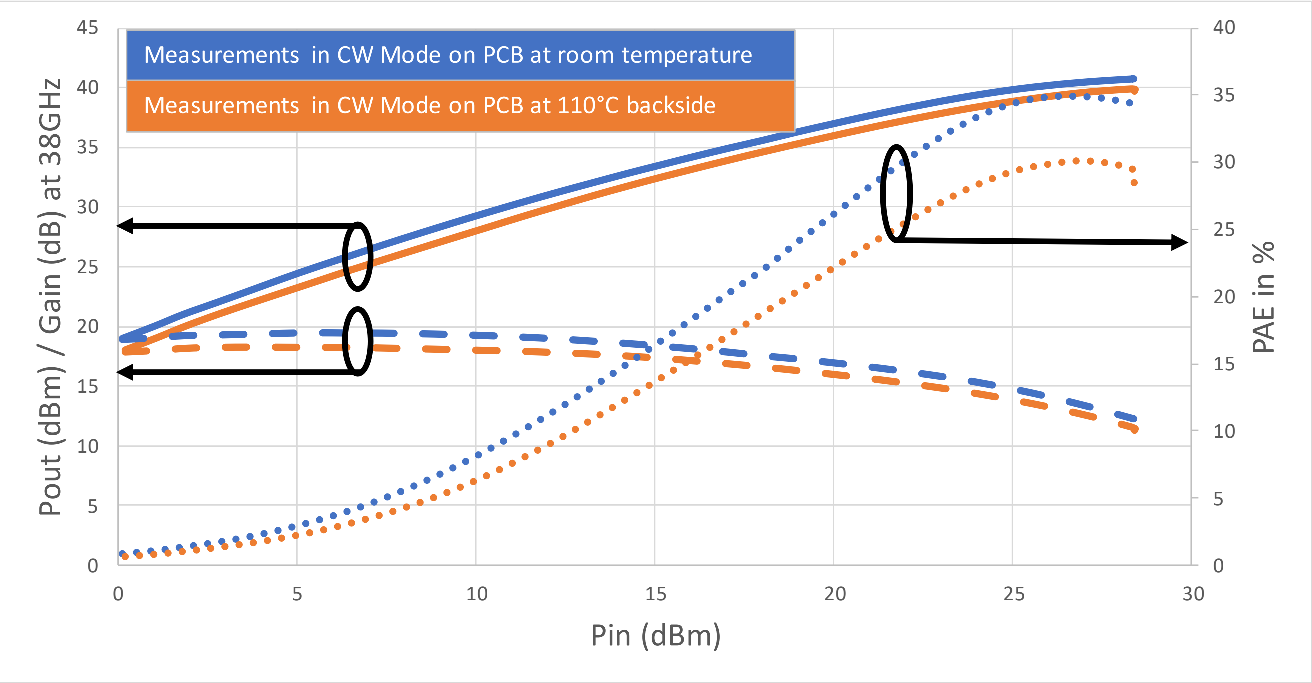

6-9dB is the back off. Means that when amplifying a 128QAM signal with 6dB PAPR , if you want to keep linearity you need to take a margin to stay in the linear area.

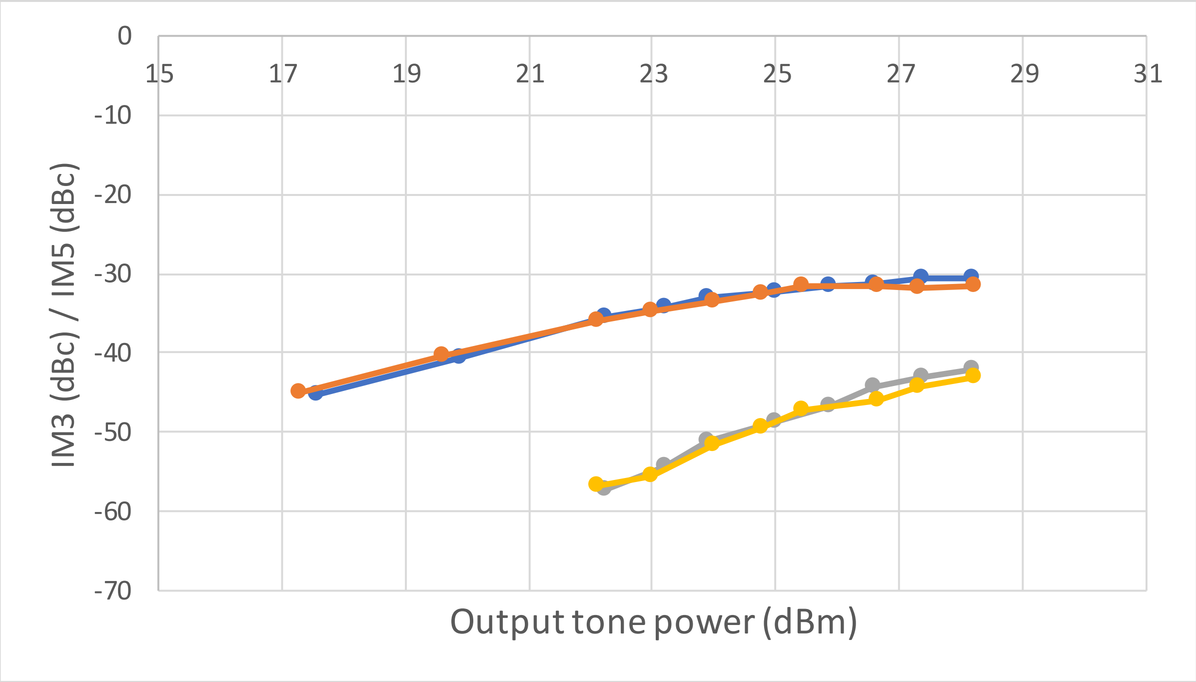
# 5G MAJOR REALISATION

## Best GaN 37-43 GHz 10 W PA

**CGY2651UH/C1 (GaN)**

**PCB measurements**



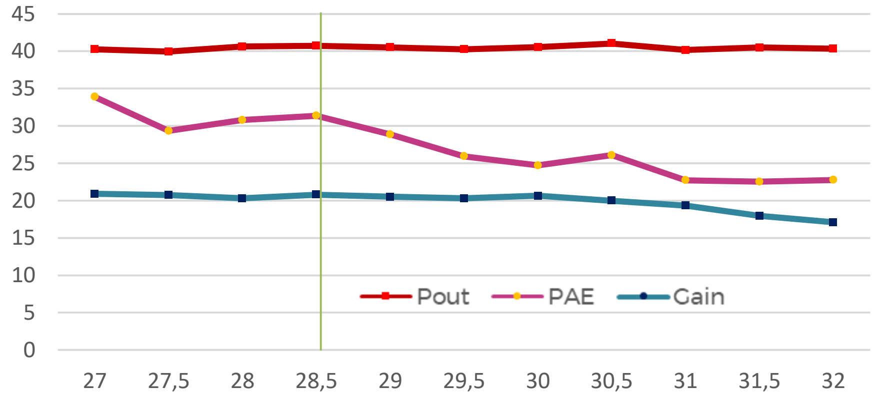
# 5G REALISATION

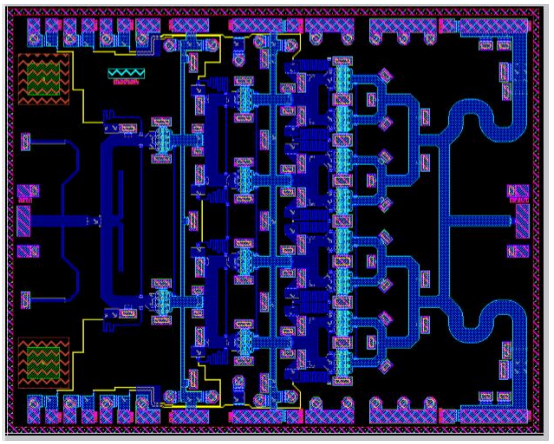
GaN 27-31 GHz 10 W PA

## CGY2652UH/C1 (GaN)

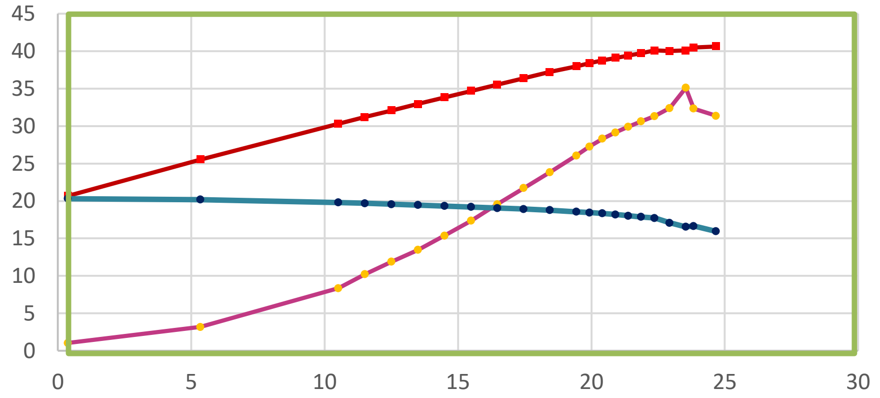
4.4 x 3.5 mm²

### Pout, Gain, PAE *vs.* Freq

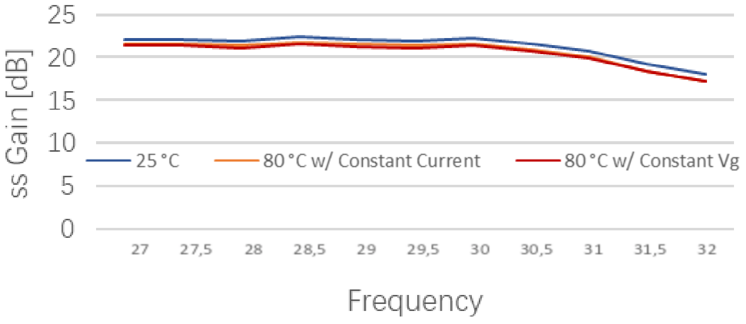


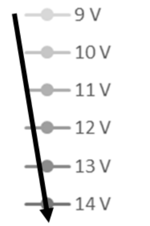



### Pout, Gain, PAE *vs.* Pin

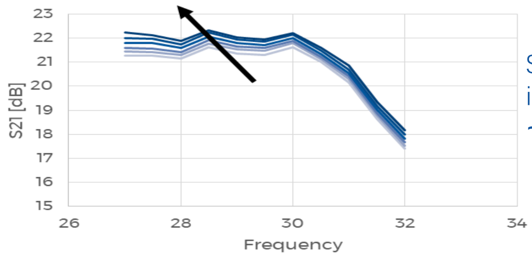



### Temperature variation



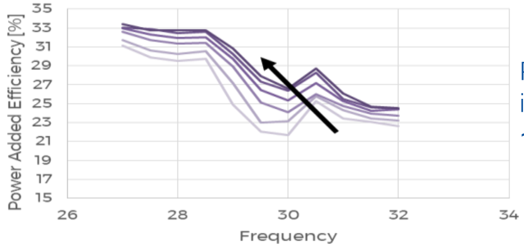




### ss Gain *vs.* Freq



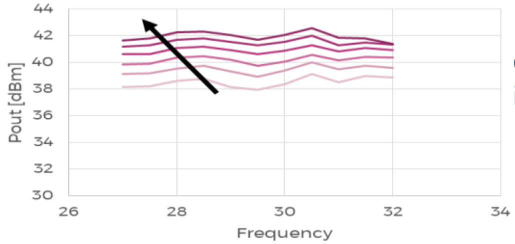

Small signal gain increases with Vd
**~0.1 dB / V**

### PAE *vs.* Freq



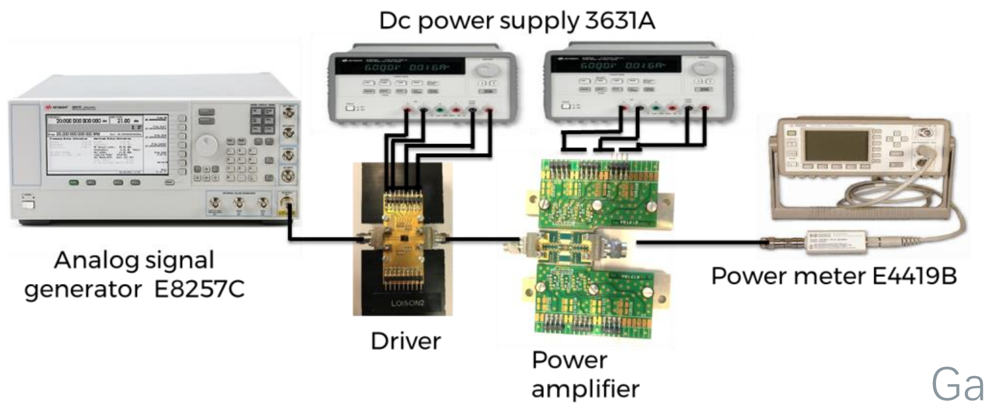

PAE increases with Vd
**~0.5 % / V**

### Pout *vs.* Freq




Output power increases with Vd
**~0.5 dBm / V**

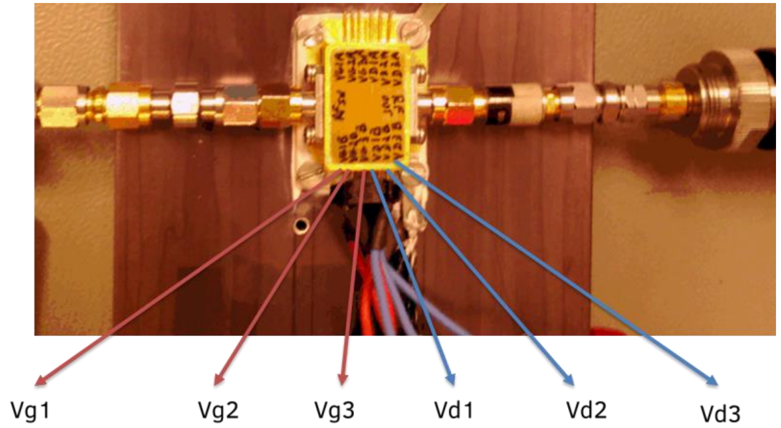
# 5G REALISATION



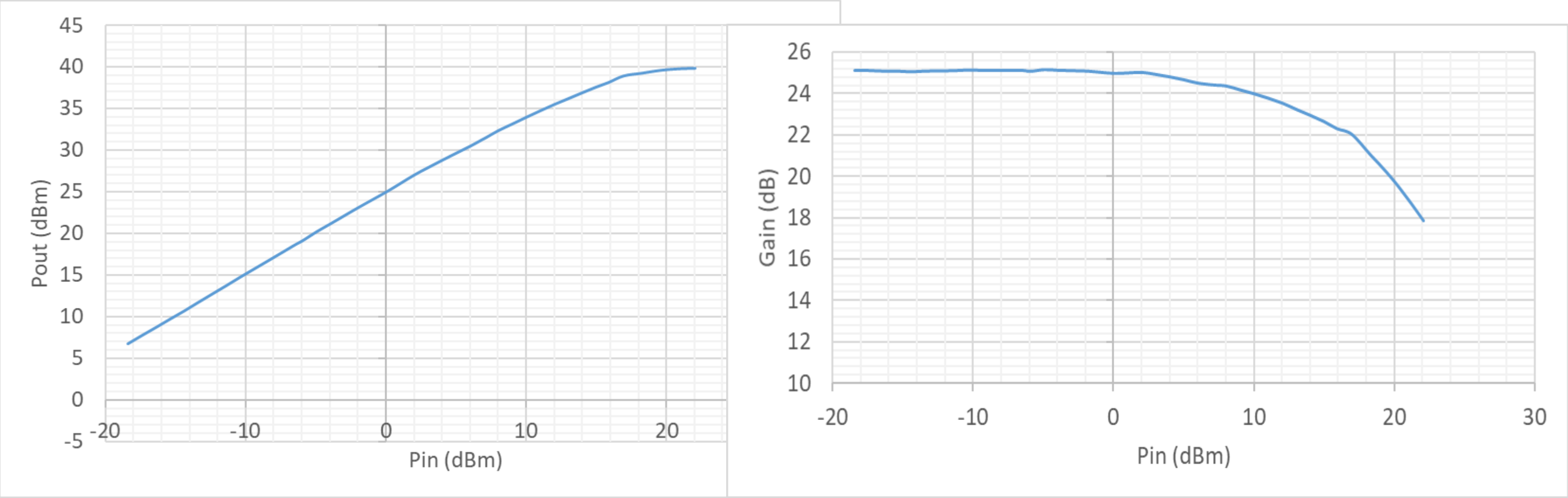

**CGY2650UH/C1 (GaN)**

GaN 30-33 GHz 10 W PA

CW measurments / Epoxy Glue




38.8 dBm / 20dB gain / 25.7 % PAE @ 29 GHz



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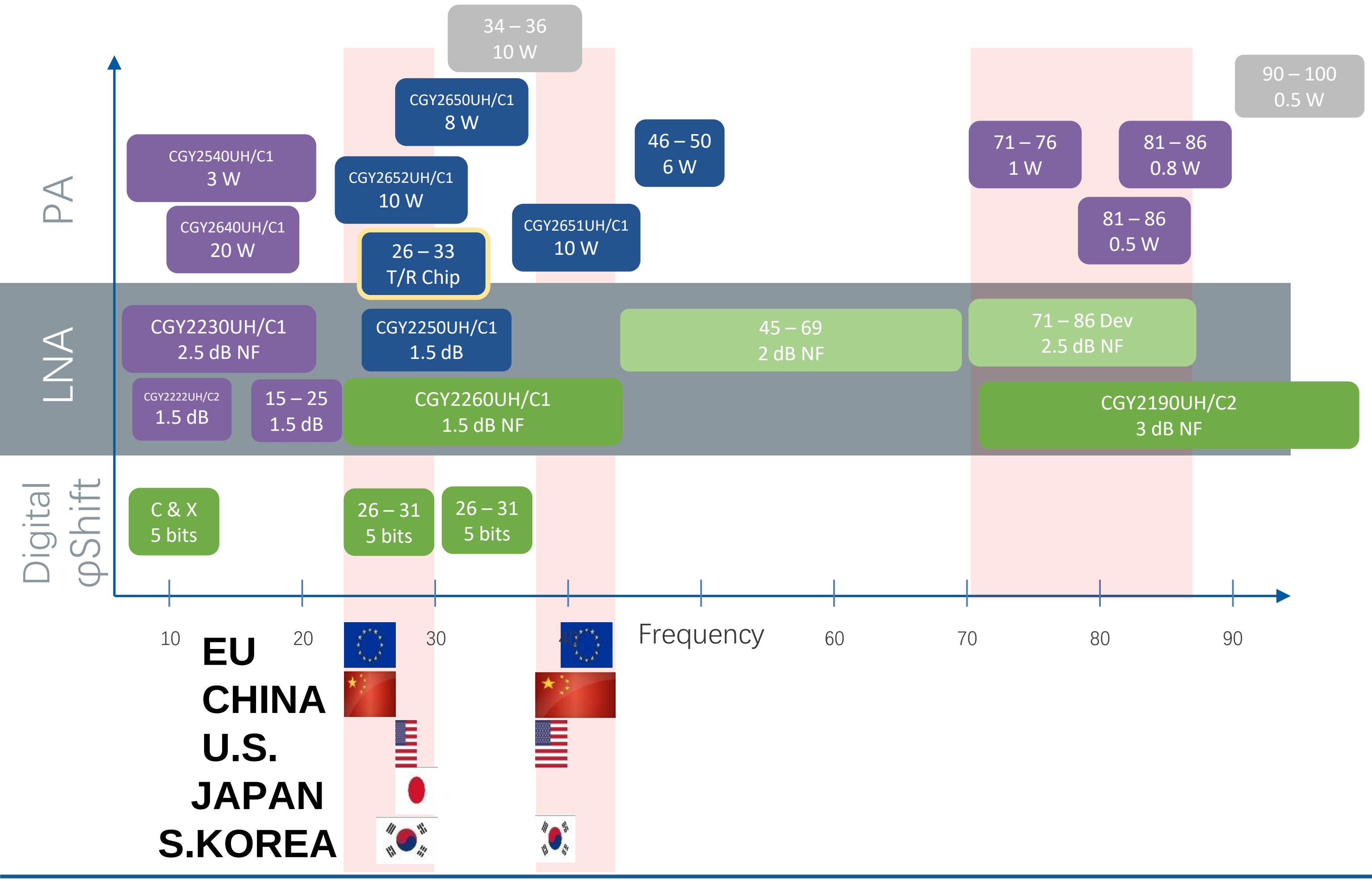
# mmW GaN/Si Product Roadmap

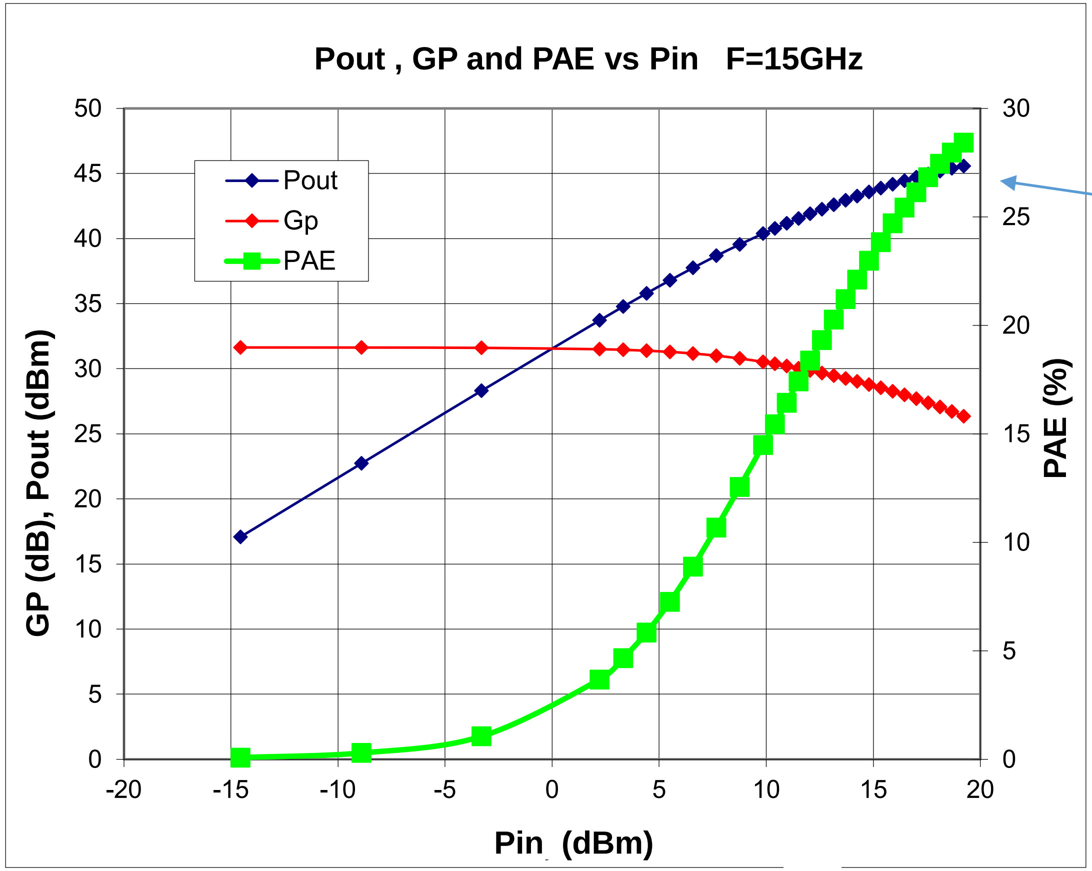



| | Status | Part nb | Frequency (GHz) | Pout / NF | Gain |
|---|---|---|---|---|---|
| GaN | TDL | | 34–36 | 43 | 22 |
| | | | 90–100 | 27 | 20 |
| | Dev | CGY2540UH | 0.5–20 | 35 | 22 |
| | | CGY2640UH | 13–17 | 44 | 32 |
| | | | 71–76 | 28 | 16 |
| | | | 81–86 | 26 | 14 |
| | Samp | CGY2652UH/C1 | 27–31 | 40 | 20 |
| | Prod | CGY2650UH/C1 | 30–34 | 39 | 22 |
| | | CGY2651UH/C1 | 37–43 | 40 | 20 |
| | | | 46–50 | 36 | 18 |
| GaN | Dev | CGY2230UH | 2–20 | 2.5 | 17 |
| | | | 8–12 | 1.5 | 20 |
| | | | 15–25 | 1.5 | 20 |
| | Prod | CGY2250UH/C1 | 26–34 | 1.6 | 20 |
| GaAs | Dev | | 45–69 | 2 | 20 |
| | | | 71–86 | 2.2 | 21 |
| | Prod | CGY2260UH/C1 | 25–43 | 1.5 | 24 |
| | | CGY2190UH/C2 | 75–110 | 3 | 23 |

**TDL = TO BE DEVELOPED LATER**

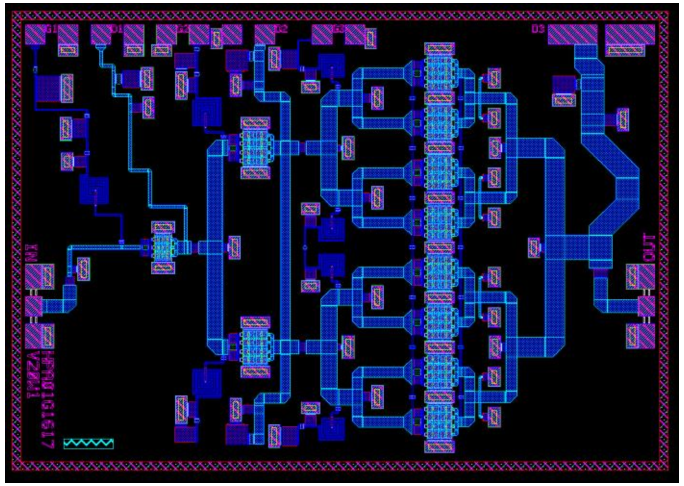
# Ku REALISATION

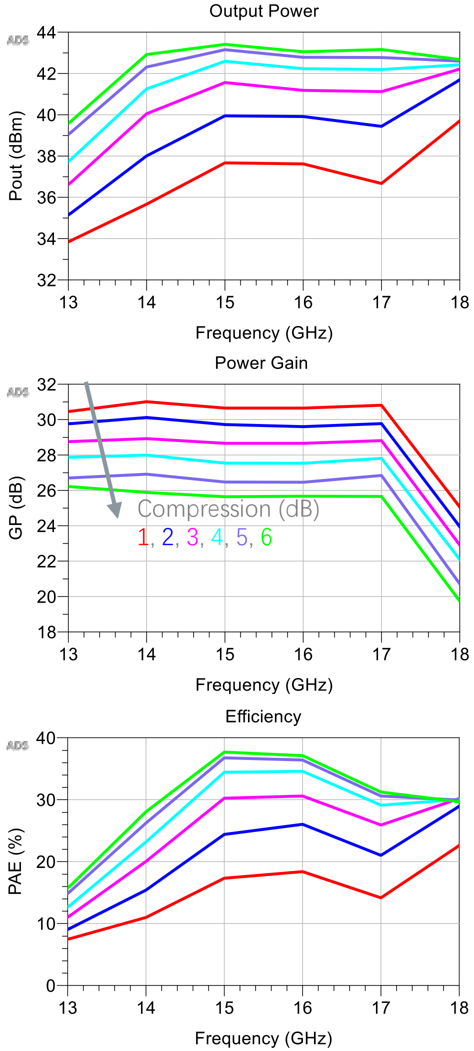
## CGY2640UH/C1 (GaN)




GaN 13-17 GHz 20 W PA

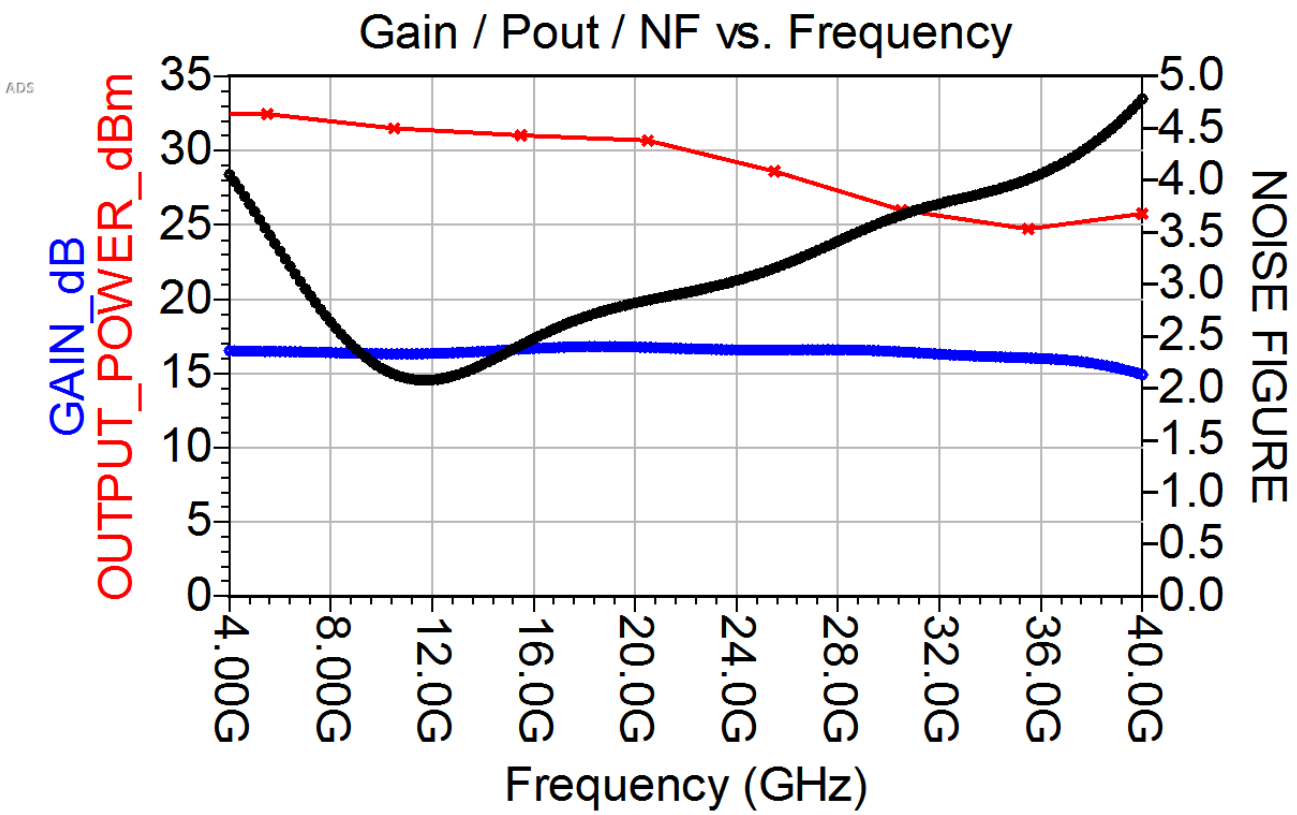
GaN 13-17 GHz 40 W PA

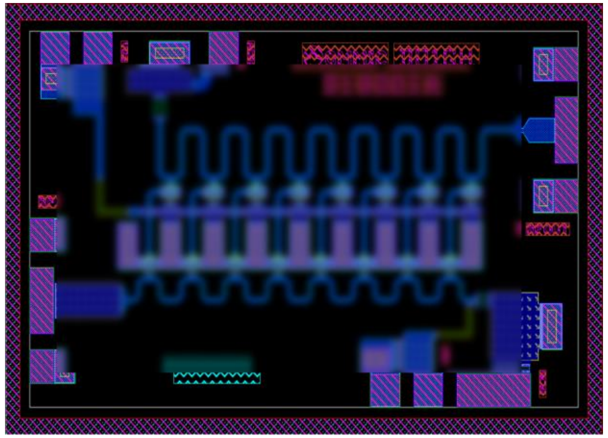




# TWA REALISATION

**CGY2550UH/C1 (GaN)**



1.3 x 2.1 mm²

18V Vd

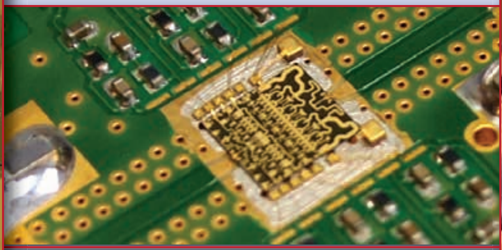
# APPENDIX

# OMMIC INFORMATION

# ACROYNMS, DEFINITIONS AND ABBREVIATIONS*

# FABS and LABS

## OMMIC Lets Expertise Do the Talking



Based close to open countryside on the outskirts of Paris, conversations at OMMIC are undertaken in French but for 35 years the company has endeavoured to speak its customers' language and use its background in III-V materials, design and processing to provide innovative solutions.

Founded in January 2000 by Philips, OMMIC is an independent SME that supplies MMIC circuits, foundry services and epitaxial wafers based on III-V (GaAs, GaN and InP) materials for telecommunication, space and defense applications.

OMMIC's portfolio of MMICs, includes LNAs from 5 to 160 GHz and power amplifiers from 8 to 46 GHz as well as corechips and control functions. Corechips are based on the integration in a single die of digital phase shifters, digital attenuators, LNAs, MPAs and switches for phased array antenna applications.

In 2015 OMMIC began providing fully plastic QFN corechips in C-Band to large radar companies and at the end of the year will release X-Band corechips packaged in plastic QFN offering better integration. The company also proposes a full solution for 94 GHz radar and passive imaging including a matched zero bias diode detector RTID.

OMMIC supplies InP, GaN and GaAs based MMIC circuits and services to the telecom, space and defense markets and MOCVD based epitaxial wafers to the commercial market. On-site epitaxy serves high-performance low-cost PHEMT, MHEMT and HBT epitaxial wafer supply to large volume GaAs fabs.

The company has three principal HEMT processes in full production and has been introducing other processes including MHEMT and HBT. These services enable cut-off frequencies as high as 400 GHz via the MHEMT technology. The latest processes include 100 nm GaN-on-silicon. Another newly released process is D025PHS which is a 250 nm PHEMT D mode, enabling high power from C to X-Band (12 W at 10 GHz).

OMMIC also supplies epitaxial wafers to the commercial market in 3, 4 and 6-inch formats using production MOVPE. This activity includes PHEMT containing up to 25 percent Indium in the GaInAs layer as well as HBT structures.

The company has an aggressive roadmap to develop and introduce advanced technologies based on III-V compounds. This means moving to shorter gate lengths, optimizing the channel Indium content for the PHEMT and MHEMT processes, smaller emitters and using antimonides for the InP DHBT.

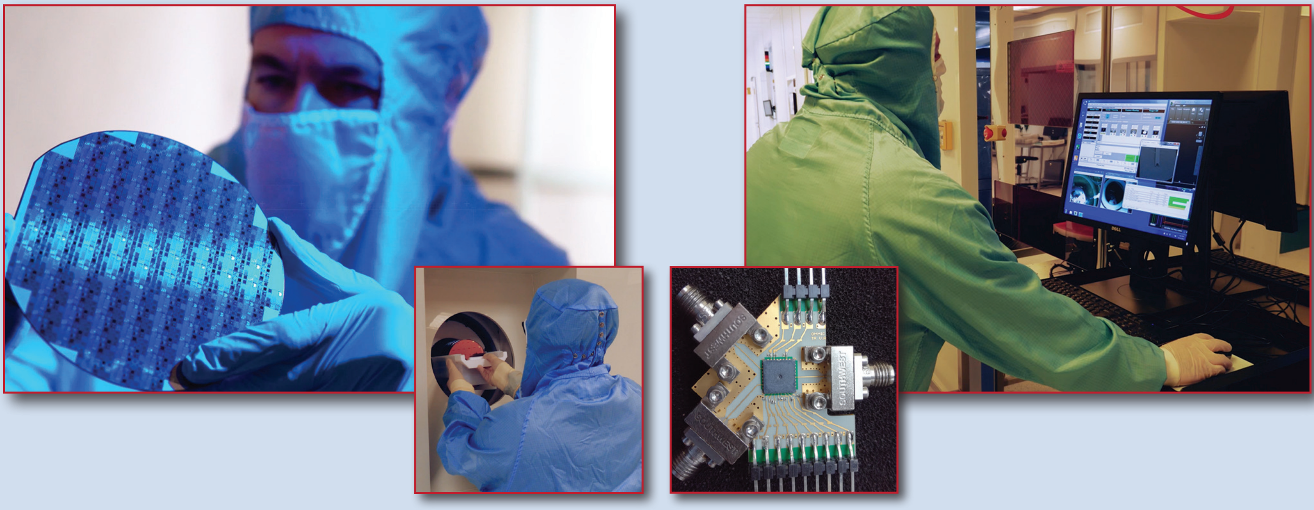
The short gate length technologies include 70 nm 70 percent In MHEMTs, soon to be followed by 40 nm with the D004IH process. With the 100 nm GaN/Si and D025PHS process OMMIC is targeting power applications from X to E-Band. The roadmap will lead to the development of sub 60 and 40 nm GaN/Si(C) to target greater power at W-Band and higher frequencies.

Currently, the company has started first runs of D01GH 100 nm GaN on Si and the first pizza mask (MPW) will be launched in June 2015. This process is not only dedicated to Ku to E-Band power amplifier design but also for robust LNAs. At the end of 2015 a Satcom HPA (27 to 32 GHz Psat>8 W) will be released using this 3.3 W/mm GaN process.

Clearly, OMMIC's activities are impressive in any language.

# FABS and LABS

## OMMIC Creates a First Designed to Last



In September 2017, OMMIC inaugurated the first European, 6-inch GaN production line and the world's first GaN-on-Si production line at its facility in Limeil-Brévannes, near Paris. After passing several qualification processes, the new line is scheduled to become fully operational by March 2018. This timing is critical: although 5G is still in development, it is expected to take off in 2019, with large-scale consumer adoption in 2020. With the new production line fully up and running in the second half of 2018, OMMIC will be in phase with the needs of the first 5G networks.

The inauguration of this significant semiconductor production line is the result of funds raised in June 2016 with the support of Bpifrance, BNP Paribas, Banque Populaire and Financière Victoire. This critical investment enabled the construction of a leading-edge factory for III-V semiconductors that will multiply OMMIC's annual production capacity by seven, with ambitious plans for that to increase 15-fold by 2020.

The initial recruitment of more than 35 technicians and engineers will be supplemented significantly in the future, not only to facilitate the deployment of the new line but to adapt to market demand. By recruiting new staff, the company is affirming its commitment to the continuation of its activities in Limeil-Brévannes and the revival and boosting of the French high-tech industry close to Paris, positioning itself as a French industrial flagship at the leading edge in the development of the European telecommunications market.

The construction of a new 1600 ft² clean room, with the advantage of easier maintenance, was accompanied by the renewal and upgrading of facilities and the purchase of 25 new machines, which will enable the company to improve yields and competitiveness. Thanks to this new production line, OMMIC will place itself as a leader in Europe to cover the needs of 5G antenna systems at 28 and 40 GHz, as well as continuing to serve and assist its current clients with more modern equipment. The company's processes can be used at frequencies above 15 GHz with output power that has not been reached before. Important for continuity, though, it will keep its current 3-inch line, which has been space qualified by the European Space Agency (ESA), for small volume markets and space products.

At the heart of OMMIC's success is the development of a very versatile and scalable GaN process. A single process design kit (PDK) contains all of the company's GaN processes: GaN-on-Si and GaN-on-SiC, with 100, 60 and, in the future, 40 nm gate lengths. With its GaN processes providing high gain, high output power, low noise and similar lag effect compared to traditional GaAs PHEMTs, the company predicts that its GaN technology will replace all GaAs PHEMT devices by around 2020. OMMIC first proffered this view at IMS2017, presenting the world's first GaN T/R chip that features a PA, LNA and SPDT switch on a single die, covering 25 to 36 GHz with a Pout of 4 W and 2.7 dB NF.

OMMIC is currently the fifth-ranked company for the manufacture of MMICs and identified the need for a facility that will help meet the growing market demand. With €14.5 million turnover in 2016 and a backlog of more than €20 million in 2017, this new capability will enable the company to move to its stated goal of becoming the third-largest GaN manufacturer by 2020, with sales over €100 million.

**www.ommic.com**

# BRIEF HISTORY

OMMIC has over 40 years of experience in III-V technology, from GaAs, InP to GaN technology, serving space, telecom, defense and consumer market with its state-of-the-art process.

PHILIPS

OMMIC innovating with III-V'S

**1972**

III/V SEMICONDUCTOR MATERIAL & MICROWAVE IC

Started to research in GaAs technology

**1979**

RTC - LIMEIL

Dedicated to 12GHz Satellite television reception

**1992**

PHILIPS MICROWAVE LIMEIL

Dedicated to cellular telecom application

**2000**

OMMIC

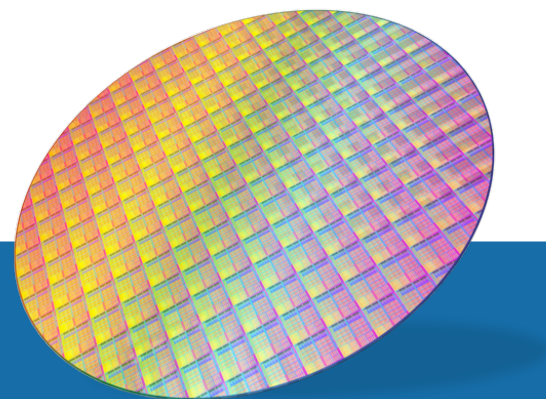
Independent company

# CORE MARKETS

OMMIC designs and manufactures integrated circuits based on III/V semiconductors (GaAs, InP, GaN) for microwave Tx/Rx Systems from 1 to 400 GHz, addressing ground-based telecom system (2G to 5G)


innovating with III-V'S

# MAIN ACTIVITES



## Foundry Service

OMMIC offers onsite epitaxy which serves high performance, low cost pHEMT, mHEMT & HBT wafer supply to large volume GaAs Fab.

## Custom Design

OMMIC also provides custom design MMIC services based on customer's specifications.

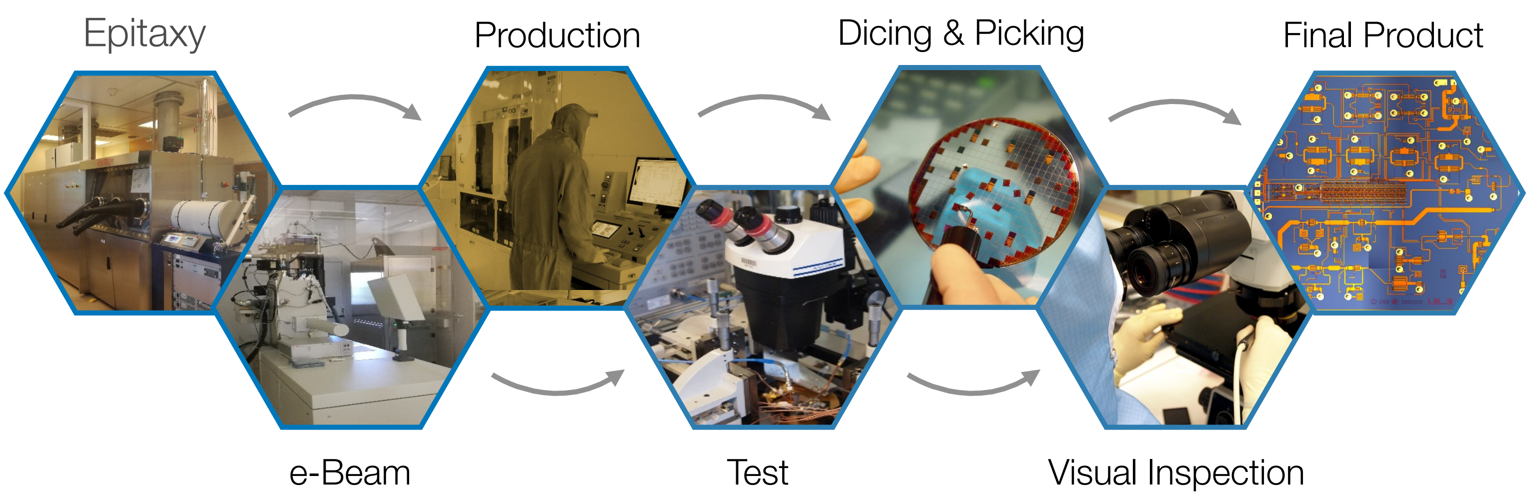
## Catalog Products

OMMIC offers standard catalog products including LNA, PA, WPA, Corechip from DC to 140 GHz.

innovating with III-V'S

# PRODUCTION FLOW

OMMIC offers fully open foundry service with its advanced processes available for customers, delivering the best performance product in the market.



# OMMIC ADVANTAGES

## Large Market

OMMIC's market opportunity is large, growing, and diverse. OMMIC chips address multiple markets, including SatCom, Radar, Space, and Cellular infrastructure for upcoming 5G.

## Technology Leadership

With over 40 years of III-V compounds experience including GaAs and InP, OMMIC is now as well a leader in GaN technology, which is expected to revolutionize Power Electronics and RF FEM market in near future.

## Potential for High Growth

Due to fast growing market like SatCom and cellular infrastructure for 5G, OMMIC is expecting a sustained growth in the next few decades.

OMMIC STANDARD PRODUCT SHORT FORM LINK

OMMIC WEB SITE LINK

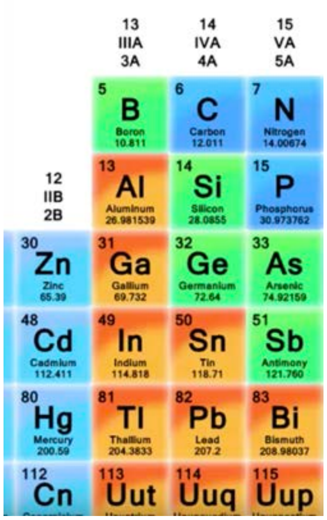
## 2019 OMMIC 3” MULTI-PROJECT WAFER RUN

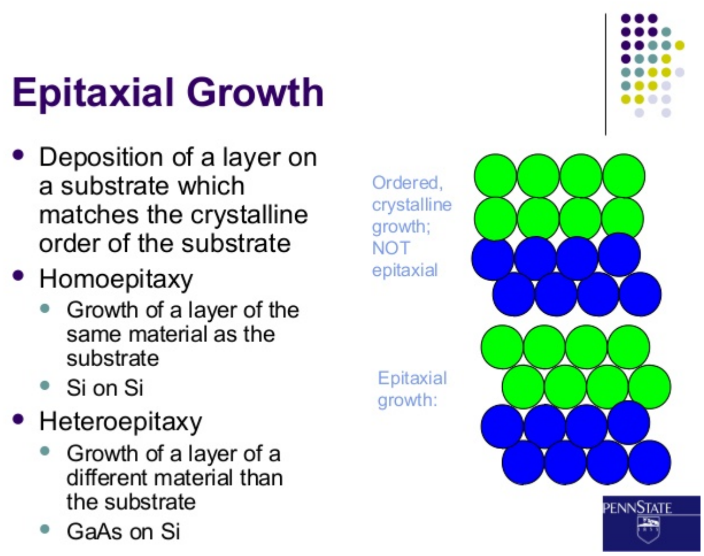
| ED02AH | D01PH | D01MH | D007IH | D01GH | DH15IB |
|---|---|---|---|---|---|
| 3 SEPT | 10 SEPT | 3 SEPT | 28 JUNE<br>31 OCT | 13 Aug<br>29 NOV | 16 OCT |

## ACROYNMS, DEFINITIONS AND ABBREVIATIONS*

**GaN - Gallium Nitride**

**III-V Semiconductors-** refers to periodic element table below also called a compound semiconductor is a semiconductor composed of elements from two or more different groups of the periodic table. For example -one element from column III, and one from column V, of the Periodic Table -- the so-called compound III-V semiconductors, such as GaAs, InP and GaN. (See figure below)




**Epitaxy** (see figure above) refers to the deposition of a crystalline overlayer on a crystalline substrate.

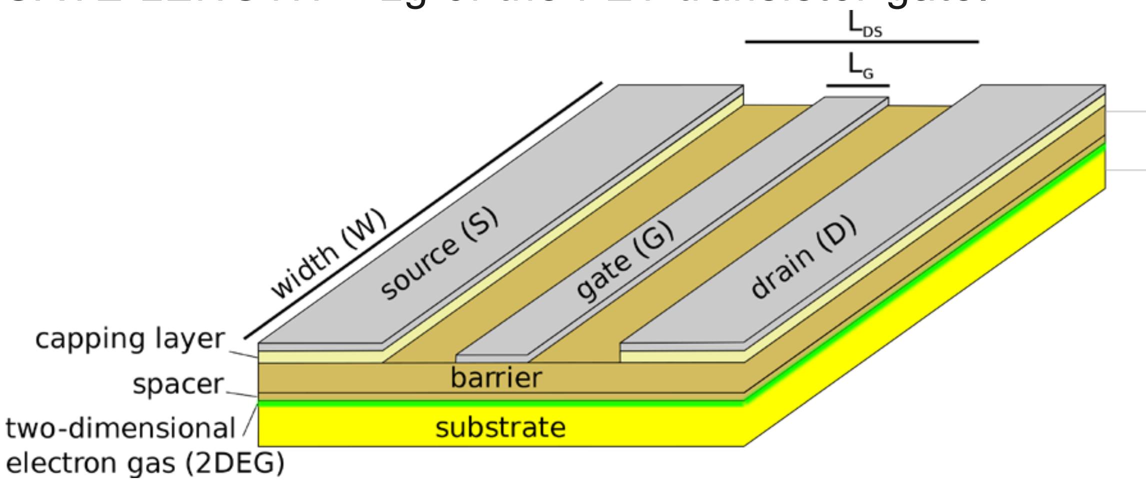
The overlayer is called an epitaxial film or epitaxial layer. The term *epitaxy* comes from the Greek roots *epi* (ἐπί), meaning "above", and *taxis* (τάξις), meaning "an ordered manner". It can be translated as "arranging upon".

## IN SITU PASSIVATION

Passivation of the active GaN material surface after epi .

PW =Power density Power is a measure of power divided by transistors size. In the case of FETs it is expressed in watts/mm. In olden times GaAs MESFETs struggled to achieve power densities beyond 1 watt/mm. Soon we will see in production GaN transistors with more than 10W/mm power density.

## GATE LENGTH = Lg of the FET transistor gate.




## PA= Power Amplifier

# Power-added efficiency (PAE)

Power added efficiency is similar to drain efficiency, but it takes into account the RF power that is added to the device at its input, in the numerator. PAE is the most-accepted figure-of-merit to use to compare single devices. It is better to chose the highest PAE rather than the highest drain efficiency, grasshopper...

$$\eta_{power-added} = P.A.E. = \frac{P_{RFout} - P_{RFin}}{P_{DC}} = \frac{P_{RFout} - P_{RFin}}{V_{DC} \times I_{DC}}$$

Note that PAE is often applied to amplifiers as a figure of merit, as well as devices.

In a theoretical sense, an amplifier with infinite gain will have power added efficiency equal to drain efficiency. For a real amplifier, PAE will always be less than drain efficiency, but once you get to 30 dB gain or so, the two quantities become very close in value because input power will be less than 0.1% of output power (30 dB gain is 1000 in linear scale). You can express PAE in terms of drain efficiency, you will get:

$$\eta_{power-added} = \eta_{drain} \frac{G-1}{G}$$

For an amplifier with 30 dB gain, PAE and drain efficiency differ by just 0.1 percent (999/1000).

The maximum possible power-added efficiency of a device always decreases with frequency. This is because the natural tendency for maximum gain of an active device to decrease with frequency.

## LNA LOW NOISE AMPLIFIER

## NOISE FIGURE

*Noise factor* is a measure of how the the signal to noise ratio is degraded by a device:

F=noise factor=$(S_{in}/N_{in})/(S_{out}/N_{out})$

Where $S_{in}$ is the signal level at the input
$N_{in}$ is the noise level at the input,
$S_{out}$ is the signal level at the output
and $N_{out}$ is the noise level at the output.

The noise factor of a device is specified with noise from a noise source at room temperature ($N_{in}$=KT), where K is Boltzman's constantand T is approximately room temperature in Kelvin; KT is somewhere around -174 dBm/Hz. Depending on where devices are positioned in an amplification chain, the individual noise factors will have different effects on the overall noise, according to Friis (see below). Thanks for clarifying this, Andreas!

Signal to noise ratio always worsens from input to output due to entropy or one of those other depressing laws of the universe; as the S/N ratio at output is less than S/N ratio at input, noise factor is always greater than unity.

*Noise figure* is the noise factor, expressed in decibels:

NF (decibels)=noise figure =10*log(F)

## CW CONTINUOUS WAVE (100% DUTY CYCLE)

## GaAs PHEMT

GaAs PHEMT was the second MMIC technology to be perfected, in the 1990s. Breakdown voltages of PHEMT up to 16 volts make high-power/high efficiency amps possible, and noise figure of tenths of a dB at X-band means great LNAs, and made the DISH network possible, you lucky dogs!

PHEMT stands for pseudomorphic high electron mobility transistor. "Pseudomorphic" implies that the semiconductor is not just GaAs, perhaps AlGaAs/InGaAs/GaAs or some other secret recipe of 11 herbs and spices. Here's some further info on the the use of pseudomorphic in this context (sent in by some M101 fans!)

*Actually, "pseudomorphic" means that the hetero layers are thin enough not to keep their own crystal lattice structure, but assume the structure (lattice constants especially) of surrounding material (lots of stress is involved),*

*If you look at a two dimensional cross section of the layer, you'll see that while it assumes the lattice constant of the bulk structure in the X direction, it tries to keep its original lattice constant in the vertical direction. This layer is indeed strained. For a GaAs pHEMT, indium is added to improve mobility and form a quantum well. Indium wants to growth the lattice and the typical range for useful thicknesses would be 10-25% on GaAs. You can also do strain compensation with the Schottky or cap layer.*

The purist nerds of semiconductors often capitalize "PHEMT" as pHEMT. To them we offer this advice: get over it, or we will beat you up like we used to do on the playground, remember?

| **Advantages** |
|---|
| Useful through Q-band, especially if thinned to 2 mils and individual source vias are used<br>Excellent power and efficiency (greater than 60% PAE)<br>Breakdown 12 volts at best, typical operate at 5-6 volts<br>Channel temperatures up to 150C possible |

## GaAs MHEMT

Recent work on metamorphic MHEMT has made premium InP HEMT performance possible (amps up at 100 GHz) at the same price as "regular" GaAs PHEMT. You can get noise figure and fmax equal to indium phosphide by using MHEMT, if you use a reputable foundry and indium content is high. You can actually exceed InP RF performance with indium content greater than 55%! The down side to all that indium is reduced operating voltage.
MHEMT stands for metamorphic high-electron mobility transistor. The channel material is InGaAs. "Metamorphic" implies that the lattice structure of GaAs is buffered using epitaxial layers to gradually transform the lattice constant so it lines up with InGaAs. InGaAs is normally grown on InP, which is expensive and fragile compared to GaAs. "Metamorphic" is changing the lattice constant by bond breaking as opposed to "pseudomorphic" which means just straining the heck out of it!

| **Advantages** | **Disadvantages** |
|---|---|
| Extremely low noise figure<br>Incredibly high fmax (more than 100 GHz)<br>Extremely low on-resistance, makes great switches, but not as good as PIN diodes<br>Channel temperatures up to 150C possible | Breakdown voltage much lower than PHEMT<br>Low operating voltage (1 to 2 volts)<br>Positive and negative voltage typically needed (VGS and VDS) |

MIMO (multiple input, multiple output) is an antenna technology for wireless communications in which multiple antennas are **used at** both the source (transmitter) and the destination (receiver). The antennas at each end of the communications circuit are combined to minimize errors and optimize data speed.

MASSIVE MIMO >64 antenna elements

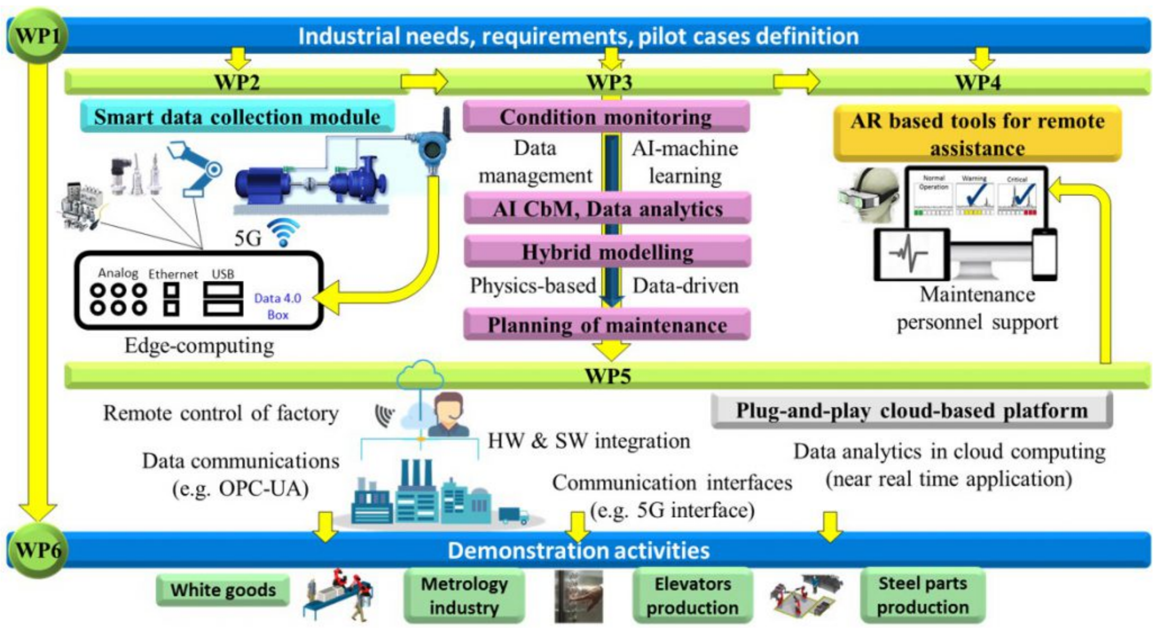
KU BAND = The Ku band (Kurtz-under band) is primarily used for satellite communications, particularly for editing and broadcasting satellite television. This band is split into multiple segments broken down into geographical regions, as the ITU (International Telecommunication Union) determines.

The Ku band is a portion of the electromagnetic spectrum in the microwave range of frequencies ranging from 11.7 to 12.7GHz. (downlink frequencies) and 14 to 14.5GHz (uplink frequencies).

T/R = TRANSMIT /RECEIVE

# SERENA

The project SERENA (gan-on-**S**ilicon **E**fficient mm-wave eu**R**opean syst**E**m i**N**tegration pl**A**tform) will develop a system architecture and technology platform by using an integrated approach.
Further, SERENA will combine advancements in hybrid analogue/digital mm-wave beam-steering system architectures with a completely European based semiconductor supply chain. Finally, the project team will foster an inter-disciplinary design approach with a strong emphasis on multi-physics simulations and predictive co-design to show the unique capabilities of the SERENA technology.

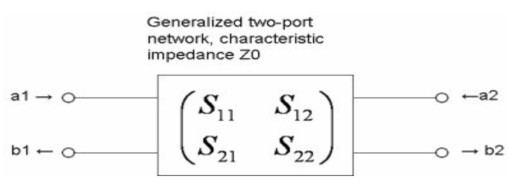



# TWA - TRAVELING WAVE AMPLIFIER or

**Distributed amplifiers** are circuit designs that incorporate transmission line theory into traditional amplifier design to obtain a larger gain-bandwidth product than is realizable by conventional circuits. **SEE FIGURE NEXT PAGE**

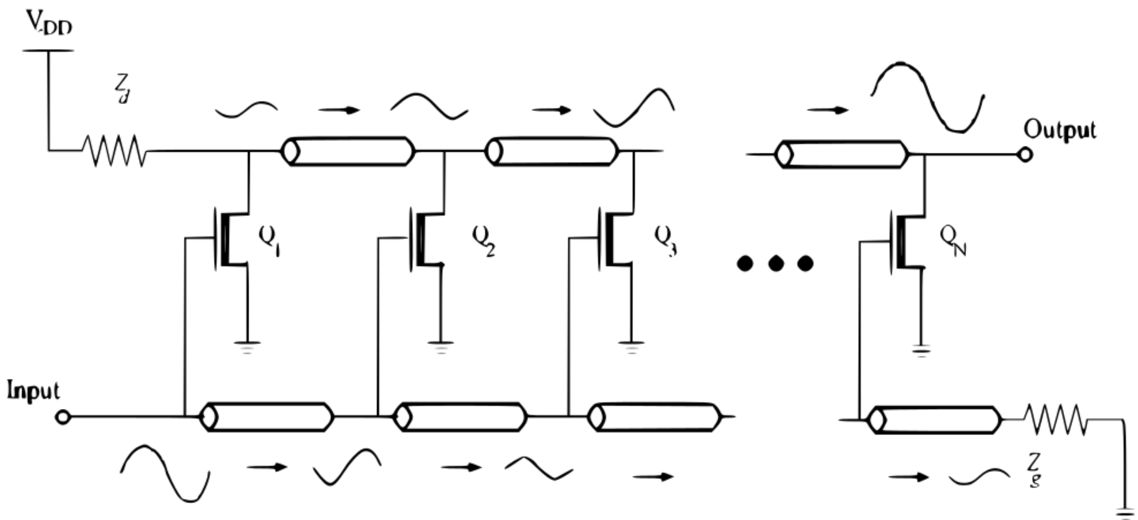
### S PARAMETERS

Let's examine a two-port network. The signal at a port, say port 1, can be thought of as the superposition to two waves traveling in opposite directions. By convention each port is shown as two nodes so as to give a name and value to these opposite direction waves. The variable $a_i$ represents a wave incident to port i and the variable $b_j$ represent a wave reflected from port j. Don't get all hung up on how two signals can occur at the same node! The magnitude of the $a_i$ and $b_j$ variables can be thought of as voltage-like variables, normalized using a specified reference impedance. This is very convenient since the square of these magnitudes are then equal to the power level of the waves. Remember, S-parameters don't mean much unless you know the value of the reference impedance (it's frequently called $Z_0$).




If we assume that each port is terminated in the reference impedance $Z_0$, we can define the four S-parameters of the 2-port as:

$$S_{11} = b1/a1$$
$$S_{12} = b1/a2$$
$$S_{21} = b2/a1$$
$$S_{22} = b2/a2$$



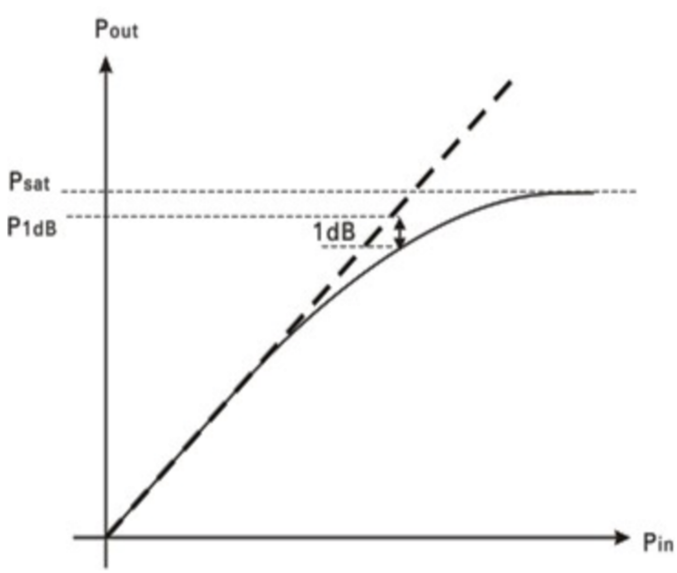

N-stage traveling-wave amplifier

*Information from Wikipedia and Microwaves 101

linkfor youtube video on 5G

$P_{1dB}$ is the output power when the amplifier is at the 1 dB compression point.
$P_{sat}$ is the output power when the amplifier is saturated.

Please refer to the diagram below for a clearer picture.



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