# Glob-Top of RF chips investigations during FaFr developments

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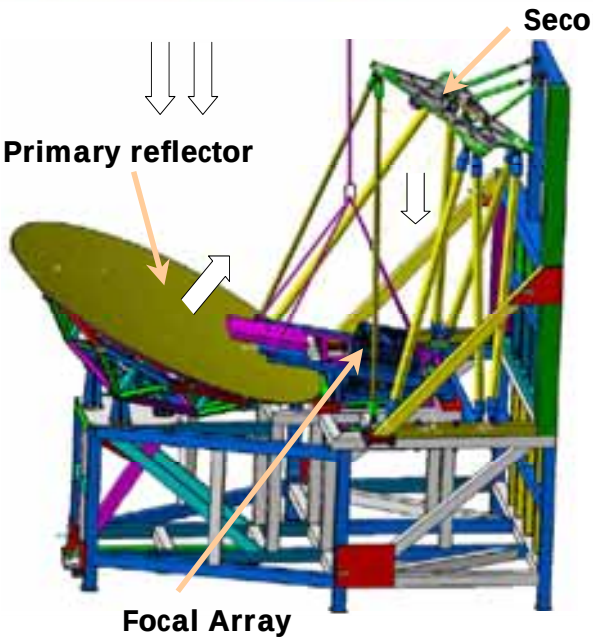
THALES



## outline

- Focal Array Fed Reflector antenna
- Low Noise Amplifier section
- LNA: technological description
- Processes and materials qualifications
- Glob top encapsulation
- Some electrical results
- Conclusion

# FAFR antenna : principle




Focal Array Fed Reflector antenna **description**

- radiating element of horn type
- ortho-mode transducer (OMT)
- band-pass filter (BPF)
- ***low noise amplifiers (LNA) with redundancy***
- beam forming network (BFN)

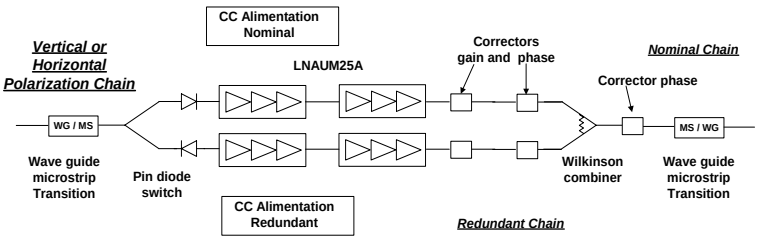




# Low noise amplifier section 1/3

## Active chain – Block diagram

- waveguide/µstrip transition
- pin-diode switch
- MMICs
- corrector (phase and gain)
- Wilkinson combiner
- corrector (phase)
- µstrip/waveguide transition

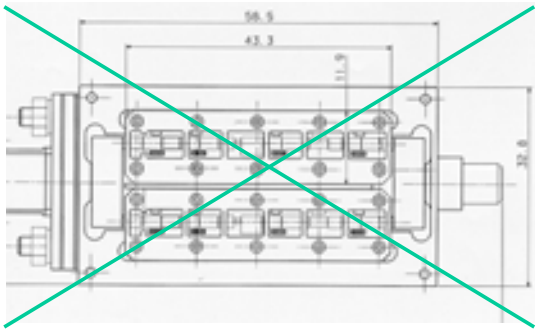



## 3 main challenges for the LNA module

- minimum size (sized to the antenna meshing @ 30GHz)
- optimize noise figure
- redundancy required

# Hermetic vs non hermetic packaging

## Standard macro-hybrid design



**2 paths**

- 59mm × 33mm × 20mm
- weight : 100g

## Chip on Board design & glob top encapsulation

**4 paths**

- 54mm × 25.6mm × 9mm
- weight : 25g

**Introduction of the *Chip on Board* technology (glob top and related processes) for space applications**

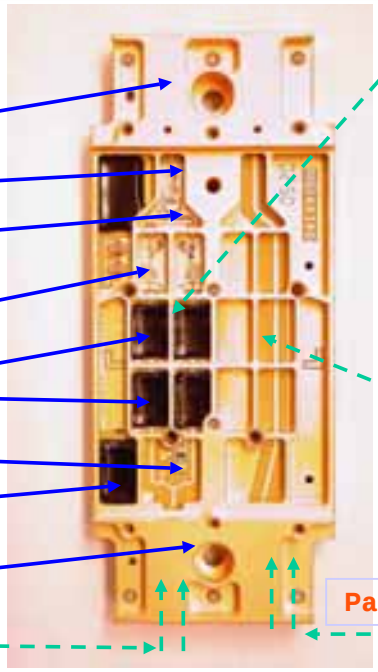




# Low noise amplifier section 2/3

## Bi-module LNA

- µstrip wave guide transition (output)
- Phase corrector (bimodules)
- Wilkinson combiner
- Gain et phase correctors (N/R ways)
- LNAUM25A MMICs
- Pin diode switch
- Constant current bias network
- Wave guide µstrip transition (input)



# Low noise amplifier section 3/3

## Main characteristics of a module

- 19dB gain @ 30GHz
- noise figure below 3.3dB at room temperature (can be improved)
- input/output return loss < -15dB
- redundancy
- electrical performance is reproducible, between every nominal and redundant paths
  - phase dispersion is below 15°pp
  - gain dispersion is below 1.5dBpp
- consumption : around 340mW
- dimension : 72.4mm x 30.1mm
- weight : 31.6 grams

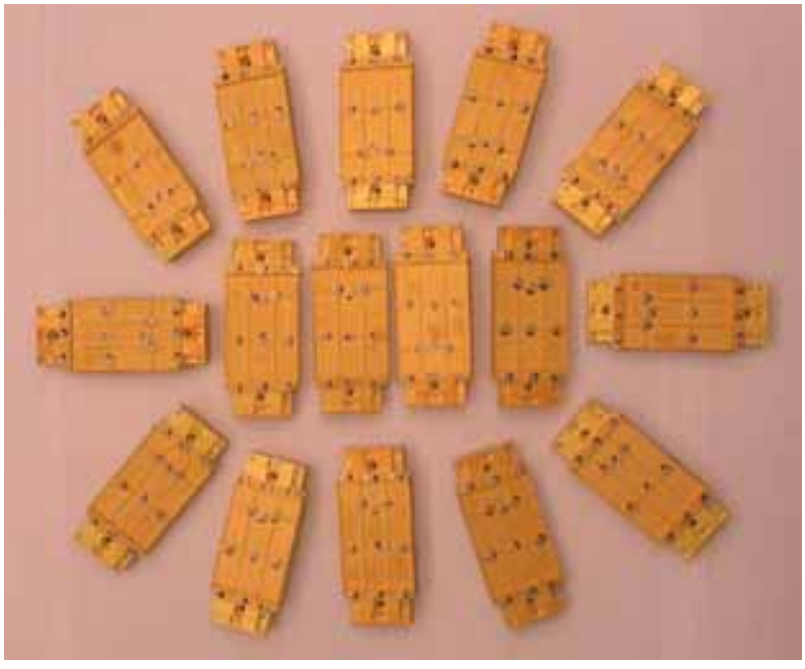




# LNAs before assembly

## About 20 modules manufactured on industrial facilities

## > 80 MMICs and 40 Si transistors encapsulated



# Technological description

- RO4003™ board assembled on an Aluminum structure
- GaAs MMIC devices, 0805 passives, alumina substrates, PIN diodes are then bonded on the board (glue and wire)
- actives devices (MMICs, Si transistor) encapsulated by glob top process
- an Aluminium lid finally gives the mechanical protection to the module
- DC supplies brought by a solderless connector (backside of the module)





# Processes and materials qualifications

## Introduction of new materials and processes for space applications :

- materials : RO4003™ as PCB, flexible adhesive, glob top encapsulant, CIN::APSE solder less connector
- processes : assembly of MMIC/alumina on PCB, wire-bonding on PCB, glob top dispensing

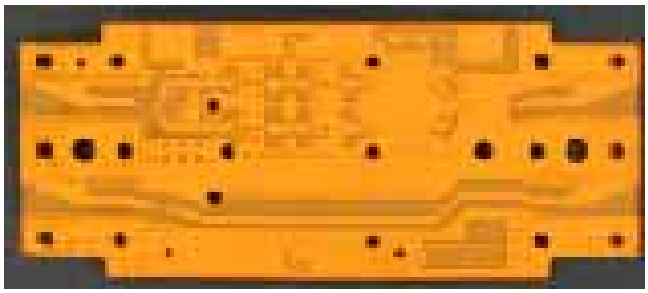
## This finally leads to :

- qualification of the RO4003C™ printed circuit board, substrate well dedicated for microwave design and component assembly
- qualification of the assembly of passive/active components on the substrate
- qualification of 25µm thermo-sonic wire bonding on PCB
- qualification of the glob top encapsulation of active devices
- qualification of the solder-less CIN::APSE® interconnection

# Printed circuit board qualification 1/3

## RO4003C™ substrate selected :

- double sided printed circuit board based on a glass reinforced hydrocarbon/ceramic thermoset
- Ni/Au plating (for wire bonding)
- low loss material which can be fabricated using standard epoxy/glass (FR4) processes
- dimension 72mm x 30mm, 0.3mm thickness
- +/-15µm line /space etching tolerance







# Printed circuit board qualification 2/3

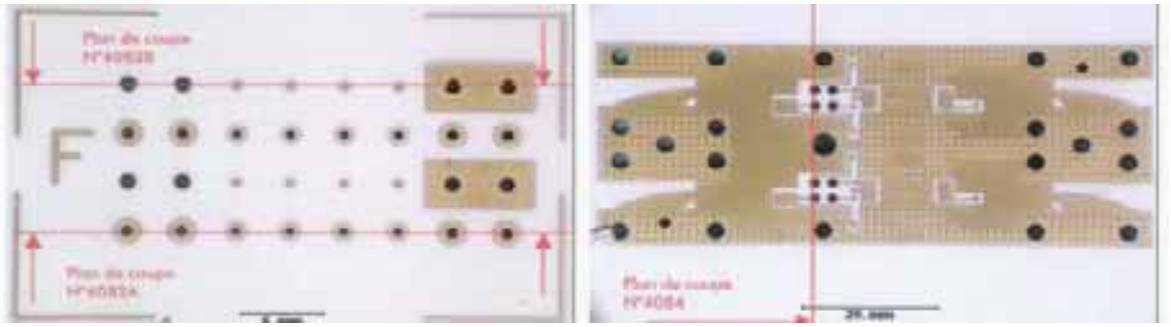
## Reliability tests done under ECSS-Q-70-10A

- life test for 1000h at 125°C
- 500 thermal cycles [-55°C, +125°C] according to MIL Std 883 method 1010 cond. B
- humidity test for 10 days at 40°C and 93%HR

## After all these tests, we can notice :

- no degradation after visual inspection on the surface metallization and the via holes (cross-sections done on test-samples coming from the three test files)
- no degradation on the metallization adherence (with values above 8N/cm after these tests)
- no electrical deviation about the isolation resistance, the breakdown voltage and the interconnection resistance

# Printed circuit board qualification 3/3



**PCB evaluation board**

**cross sections (line, via hole)**





# Assembly of devices 1/2

## Another challenge : assembly of materials with mixed CTE !

- MMIC, alumina, SMT devices (CTE≈6-7ppm)
- PCB (CTE≈15-20ppm)

➔ *Introduction of a flexible adhesive in respect with*

- use on automatic dispensing equipment
- extractable ionic content and out-gassing characteristics in agreement with MIL Std 833 Method 5011

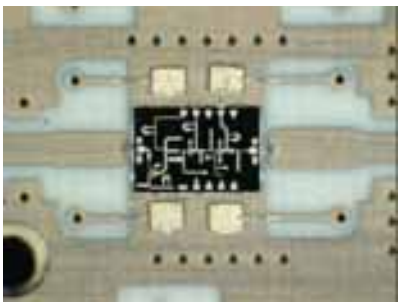
## Selection of a standard reference from E&C SP

- 77-83% (by weight) silver content
- excellent outgassing characteristics & ionic content results (32ppm Chloride ion, 33ppm Ammonium ion, <10ppm for Sodium, Fluoride Nitrate ions)

# Assembly of devices 2/2

## Reliability test done

- 500 thermal cycles [-55°C, +125°C] according to MIL Std 883 method 1010 cond. B
- components assembled for this process : alumina substrates (8.3mm x 5.6mm), GaAs MMIC (3mm x 2mm), 0805 SMD capacitors



## Results

- no cracks or delaminating effect after visual inspection and on cross-sections done on the joint of the epoxy glue, before and after the reliability test
- value of different components strength on the board substrate with the new adhesive after shear test is above 2-4 x times above MIL Std 883 Method 2019.5





# Wire bonding of devices 1/2

## Connection of the devices to the soft substrate

- 25µm gold wire thermo-sonic process on automatic and manual die bonder
- tightly manage the loop to reduce the inductance impact @ 30GHz

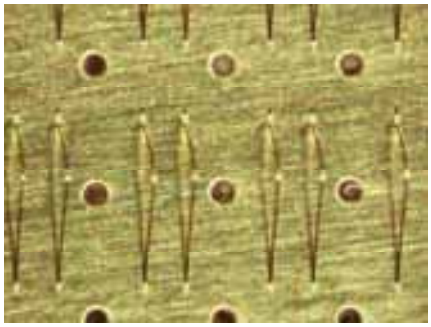
## Reliability test : storage at 175°C

- intermediate status after 15 days / final step at 31 days
- 50 shear tests done at each step
- criteria on failure modes and on "mean value of bond pull at 4x the standard deviation" :
  - before ageing : better than 3g
  - after ageing : better than 2.5g
  - criteria much more restrictive than MIL Std 883

# Wire bonding of devices 2/2

## Results obtained

- on a manual die-bonder, mean pull test value
  - before ageing : 8.3g
  - at mid-term : 7.2g
  - after ageing : 7.2g
  - standard deviation : around 1g
- on an automatic die-bonder, mean pull test value
  - before ageing : 6.94g
  - at mid-term : 6.71g
  - after ageing : 7.07g
  - standard deviation : around 0.6g







# Solderless connection 1/2

## Connection of the RF board to a flex for DC supplies :

- CIN::APSE® solution
- plunger-button assembly : the contact construction consists of 508µm randomly wound wire (button) and an additional brass element (plunger) to achieve the required height
- whole contact installed into a customized plastic insulator

## Reliability tests done for the process qualification :

- mechanical tests : sine vibrations + random vibrations + 500 thermal cycles [-55°C, +125°C]
- life-test for 1000 hours at 125°C
- humidity test for 6 days at 60°C/95%HR
- prior to the tests, an assembly/disassembly procedure 5 times to stress each connector

# Solderless connection 2/2

**After all these tests, we can notice the following results :**

- the isolation resistance is better than $25x10^3$Mohms
- the contact resistance evolution is better than 2% after the mechanical test, 1.5% after the life-test and 3.7% after the humidity test

**No electrical breakdown with a very precise monitoring continuity after 10 thermal cycles [-55°C, +125°C] (slope of 2°C/mn)**





# Glob top encapsulation 1/8

**Glob top technology : application of an encapsulant to protect components from environmental & mechanical damage**

- so old : developed in the 60's, very familiar for consumer applications such as mobile, automotive, …
- but now ready for space and microwave applications :
  - current encapsulants have very low outgassing (ECSS-Q-70-02A) & ionic content values (MIL Std 883 method 5011)
  - dam & fill process : required for a good mechanical accuracy of dispensing

dam process fill process

# Glob top encapsulation 2/8

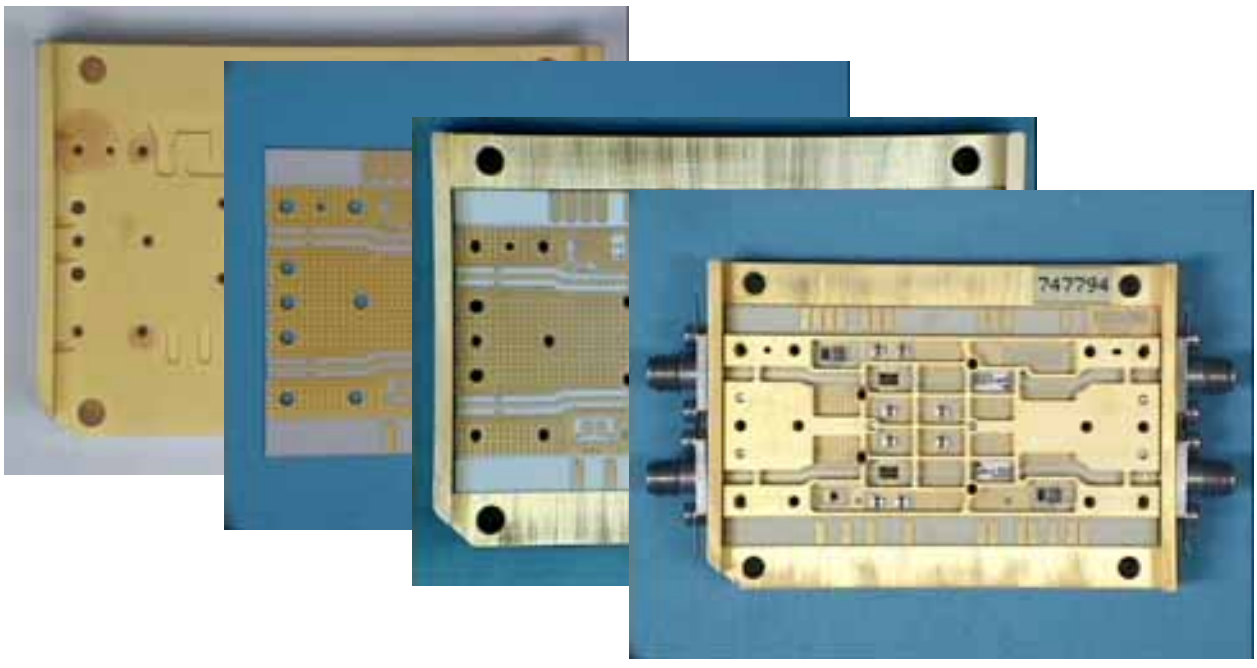
**Development of a dedicated module for the qualification of the glob top technology :**

- same size as the LNA module
- same assembly structure
- same components, same materials, same processes (all previously presented) used
- definition of a test-plan to evaluate the reliability of active devices (GaAs MMIC, Si transistor) encapsulated by glob top dispensing



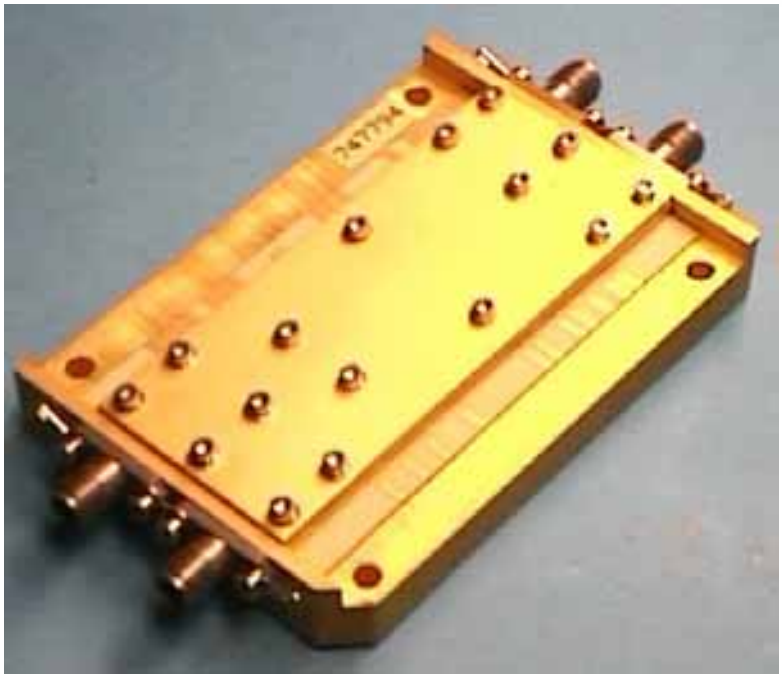


# Glob top encapsulation 3/8



# Glob top encapsulation 4/8

## Glob top technology qualification module







# Glob top encapsulation 5/8

## Reliability test plan for this packaging solution

- radiation test : full 3D finite elements simulation to give the cumulated dose effect at the equipment/component level
- mechanical tests : one module stressed to the combination of random vibrations and up to 500 thermal cycles (according to MIL Std 883 Method 1010 condition B)
- thermal cycles : 500 cycles [-55°C, +125°C] with intermediate steps at 200 and 350 cycles, test applied on 6 modules
- humidity test : storage at 85°C/85%HR for 1000 hours under reverse biasing conditions, test applied on 6 modules
- life test : test is applied on 8 samples, storage at 125°C for 2000 hours under nominal biasing conditions for half of the samples and reverse biasing conditions for half of the samples

# Glob top encapsulation 6/8

**For humidity test (and life-test partially), reverse biasing condition with $V_{DS}$=0V and $V_{GS}$<0**

- to exhibit surface effects
- and not remove humidity on active area due to thermal dissipation (for humidity test)

**Prior to these tests, all samples were also subjected to :**

- screening tests : standard of hybrids manufacturing
  - 10 thermal cycles [-55°C, +125°C]
  - 5 mechanical shocks
  - burn-in 240h @ 125°C
- pre-conditioning tests : standard tests according to JESD22-A113C + 10 vacuum cycles [-30°C, +60°C]




# Glob top encapsulation 7/8

**Radiation results**

- Design considerations
  - geostationary mission with electrons, trapped and solar flare protons and bremsstrahlung as radation components
  - radiation design lifetime : 18 years
- Results :

| Parts | Design Dose (krad) | Total Deposited Dose (krad) with glob top | Total Deposited Dose (krad) without glob top |
|---|---|---|---|
| 2N2907A | 70 | 68 | 127 |
| MMIC | 300 | 268 | 362 |

**Glob top encapsulation has a positive impact on the radiation shielding**

# Glob top encapsulation 8/8

## Thermal cycles test file

- modules tested up to 500 cycles [-55°C, +125°C] : no degradation on [S] parameters & static parameters

## Mechanical, life test and humidity test files :

- mechanical file closed
- life test file closed (DPA done)
- thermal shocks file closed
- humidity test file: some electrical analysis TBD (relative to general reliability understanding of component)

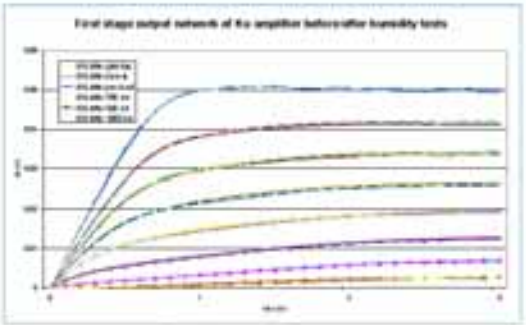




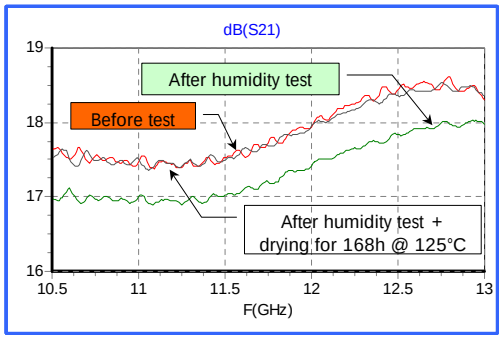
# some electrical results

## humidity test file

- no variation were observed on the static parameters up to 1000 hours with reverse biasing at 85°C/85%RH
- 1dB losses maximum on the gain noticed at the end of the test. But after 168 hours @ 125°C, all the gain characteristics were nominal on all modules. Some humidity were finally confined on the board and/or the dam & fill materials and removed after drying. The integrity of the active devices is safe



Static parameters




**Gain before/after drying step**

# Conclusion 1/2

**Current packaging technologies for space applications are based on ceramic/metallic hermetic solutions**

**A trade-off for the LNA section of a FAFR antenna shows "*Chip on Board*" solution is 2x more integrated and 4x lighter than current hermetic solutions**

**Great improvement in organic materials (encapsulant, PCB, …) allows to use them for microwave space applications**

**This leads to the :**

- design of the LNA section of a FAFR antenna
- qualification of Chip on Board solution and related materials and processes : RO4003$^{TM}$ board, assembly, wire bonding, solder less connection, glob top encapsulation





# Conclusion 2/2

**All qualifications related to PCB, assembly of mixed materials in CTE, wire-bonding and solder less connection give very good results**

**Reliability tests on the glob top encapsulation :**

- no problem on the microwave line
- a defect identified on the LF alumina substrate (large alumina + die) due to specific configuration on the qualification module (under analysis)

**The introduction of this packaging concept offers finally a great opportunity for the size and weight reduction of space equipment**

**This impact has to be analysed on**

- other microwave products like receiver, down/up converter, …
- other semi-conductor (GaAs, SiC, GaN, ....) process foundries

# Acknowledgement

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cnes

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for their support





# and now, any question ?

thanks for your attention