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High RF Power Solid State Amplifier Activities at SOLEIL

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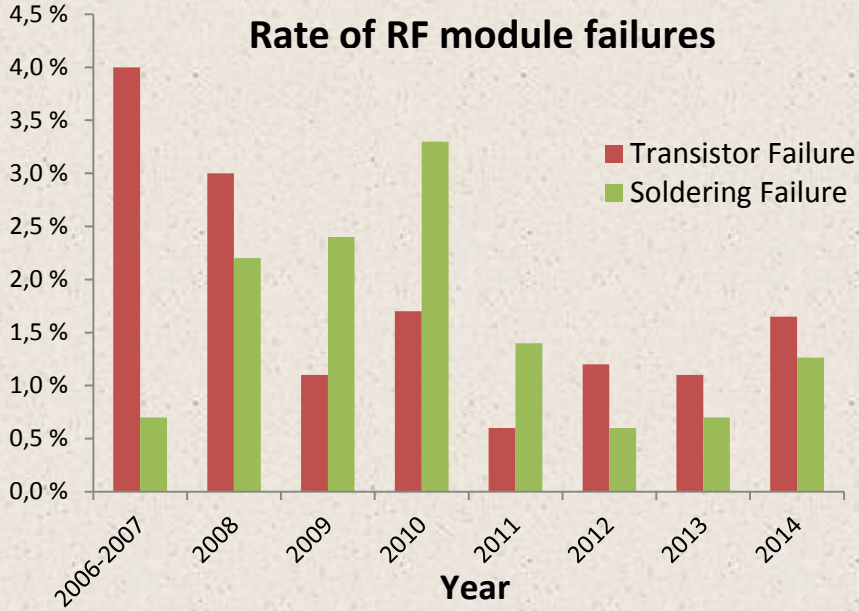
Experience with SSA in storage ring

- Storage ring SSA with Polyfet LR301 (LDMOS technology)
  - After more than 50,000 hours, only 5 beam losses due to the four 180kW amplifiers, MTBF > 1,5 year
  - The losses are essentially related to failures of the preamplifiers
  - Even if that is transparent for the operation, our original design presents some weakness
- Mean rate of module failures is around 3% per year



- Soldering degradations
- Weakness of LR301 transistor (developed in 2003 for the needs of SOLEIL)
- Difficulty with LR301 supply

- Maintenance: ~ 2 hours per scheduled shutdown to replace the damaged modules
- Annual cost: ~ 5 k€

- R&D for the upgrade of SR amplifiers to prevent this high rate of module failures

Reasons for the upgrade

- In 2008, arrival of the 6th generation LDMOS transistors (50V)
  - Better performance and reliability
    - Higher power (up to 1kW)
    - Higher gain (> 20dB à 352MHz)
    - Better efficiency
    - Improved ruggedness
    - Transistors supplied by large companies (NXP, Freescale, Infineon, etc…)
  - Economic attractiveness
    - Lower price (€/W) of new transistors
    - Better efficiency & higher gain => Large reduction in the electricity consumption
    - Re-use of the 3000 existing SOLEIL modules
    - Re-use of combination system & DC/DC converters
    - Upgrade cost is around 10% of SOLEIL amplifier's price
    - Compensation of the upgrade costs in 3 years
- After the evaluation of several transistors, choice of BLF574XR (2012) from NXP:
  - Mechanical dimensions close to LR301
  - Simple integration in SOLEIL module
  - Higher power density (500W CW)
  - Better ruggedness (XR version: eXtremely Rugged)

Reasons for the upgrade

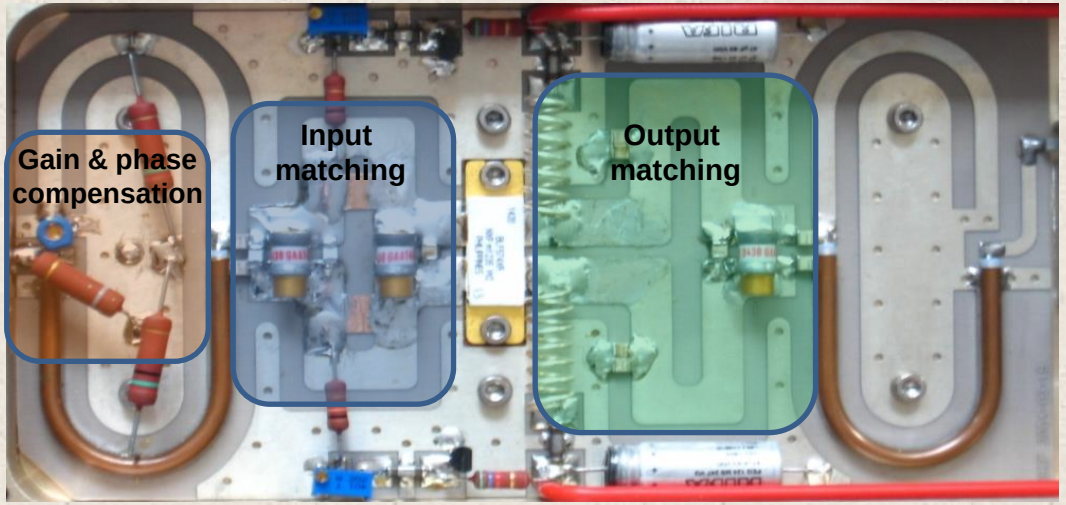
➢ **Comparison LR301 vs BLF574XR**

RF parameters	Polyfet LR301	NXP BLF574XR	Advantages of BLF574XR
Gain	13,7	20	Less drivers (+3,5% for overall efficiency)
Efficiency	62%	68%	Better efficiency (+4,5% for overall efficiency)
Output power	315W (350W tested)	330W (450W tested)	Bigger power margin
Gain dispersion	+/-0,8dB at Pnom	+/-0,2dB at Pnom	No sorting
Phase dispersion	+/-7,5° at Pnom	+/-5° at Pnom (+/-2,5° expected)	Better combining efficiency

➢ **Modifications of the SOLEIL module**

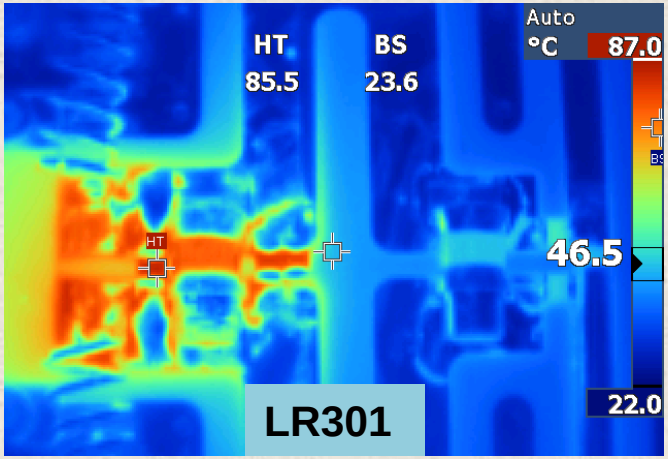
- Replacement of the transistor
- Changes of components for input and output matching
- Addition of a gain & phase compensation circuit

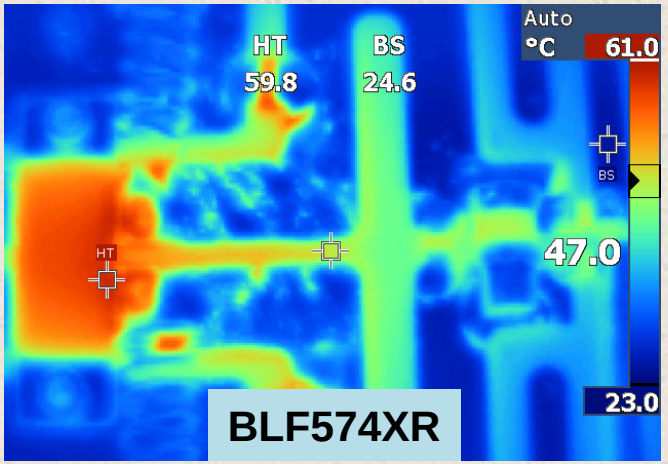
❖ **Modification time : ~ 1h/mod**
❖ **Cost of modifications: ~ 100€/mod**



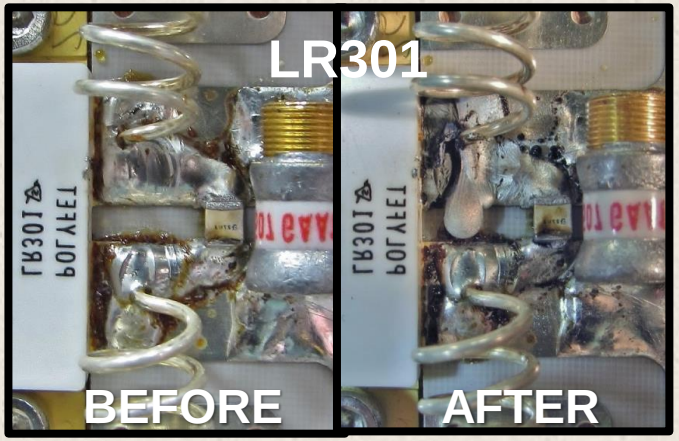
Reasons for the upgrade

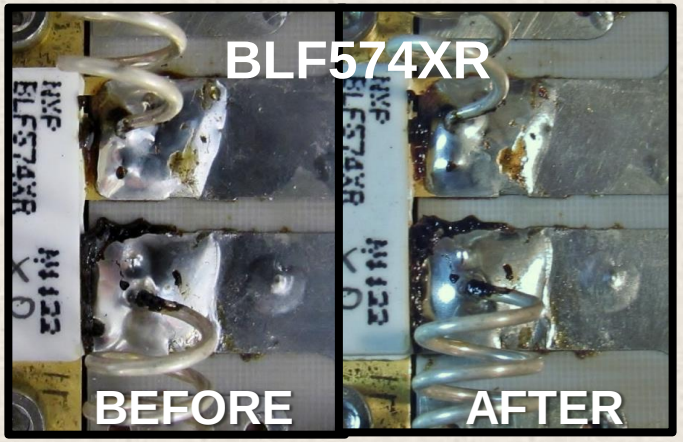
- Temperature measurement at 250W CW
  - Reduction of the transistor output lead temperature (LR301:77 ° C / BLF574XR:60 ° C)





- Endurance test of soldering on 16 modules (14 000 RF cycles)
  - Degradation on 2 of the 8 LR301 modules
  - No visible degradation on the BLF574XR modules





- Significant improvement but difficult to quantify the actual gain in lifetime

Strategy and schedule of the upgrade

- Test of a combination of 8 modules BLF574XR in 2011
  - Mounting and test of a 2.5 kW unit during 4.000h on dummy load
  - Insertion of these modules on SR amplifier and operation during one year without any problem

- Mid 2012, decision to launch the upgrade of the 4 SR amplifiers with the NXP BLF574XR
  - Subcontracting the module modifications to the H2DE company
  - Adjustment and measurements of the RF modules in house

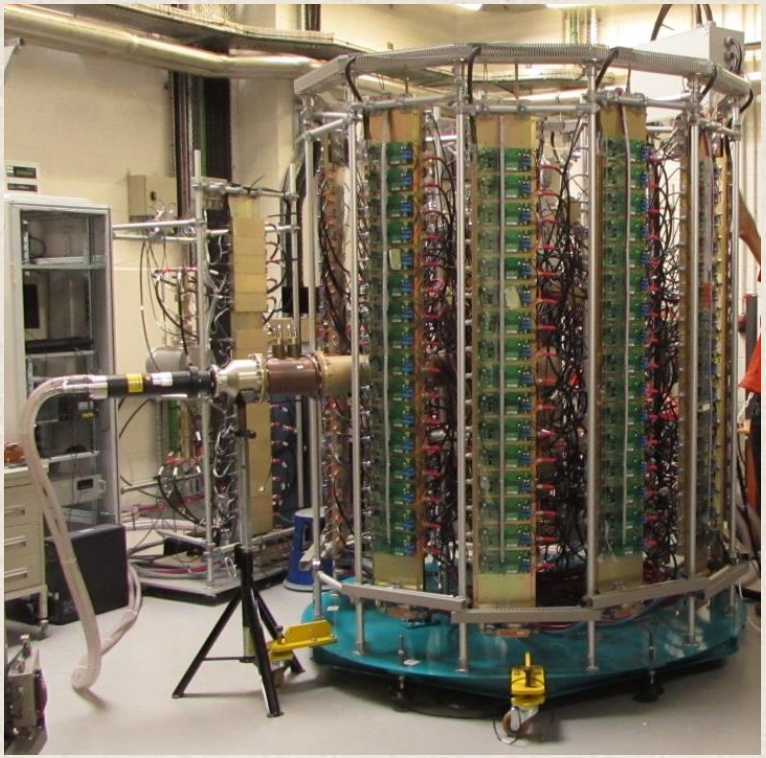
- In 2013, it was decided to replace all the 180 preamplifiers, the most critical part in terms of reliability

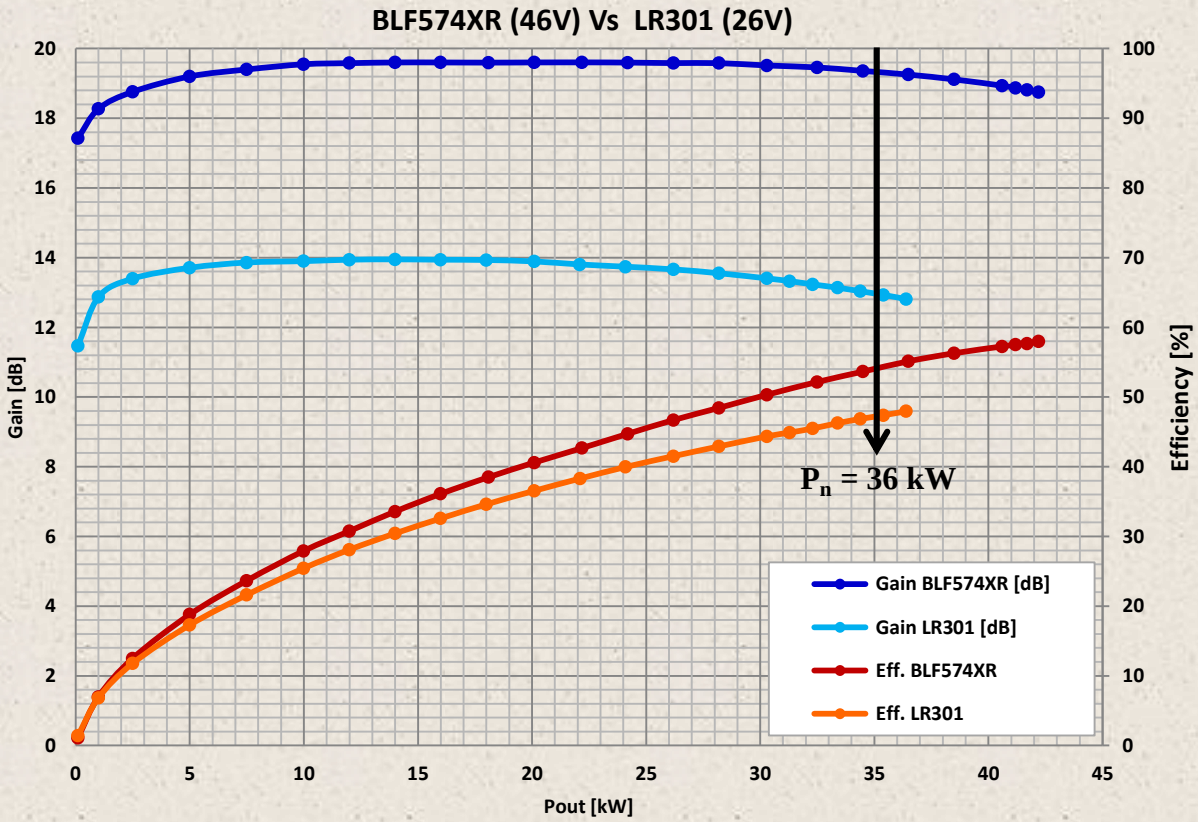
- No beam loss due to the SR amplifiers since more than 2 years after the installation of the BLF574XR modules

- Replacement of all modules of the last stage, more than 2800 modules to be performed
  - Realization of an additional 50kW tower in 2014 (investment of 50 k€)
  - Replacement of 1 to 2 towers per year, implemented during technical shutdowns

Performance of the upgraded 50kW tower

- July 2014, characterization and tests of the first 50kW tower on dummy load
- Efficiency optimisation of the SR amplifiers for actual 500mA operation
  - Required power : 140kW/amplifier; 36kW/tower
  - LR301 @ 26 V : G = 12.9 dB (1.1 dB comp), eff. = 48 %
  - BLF574XR @ 46 V : G = 19.3 dB (0.3 dB comp), eff. = 55 %

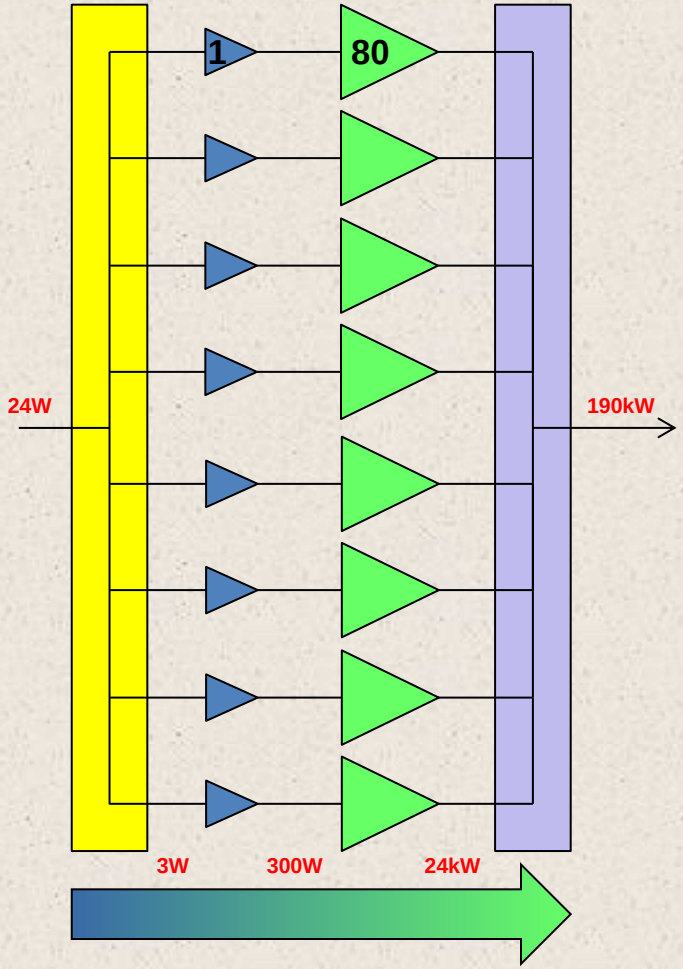




- Aug 2014, integration of this first tower on 180kW amplifier ➔cohabitation with 3 LR301 towers

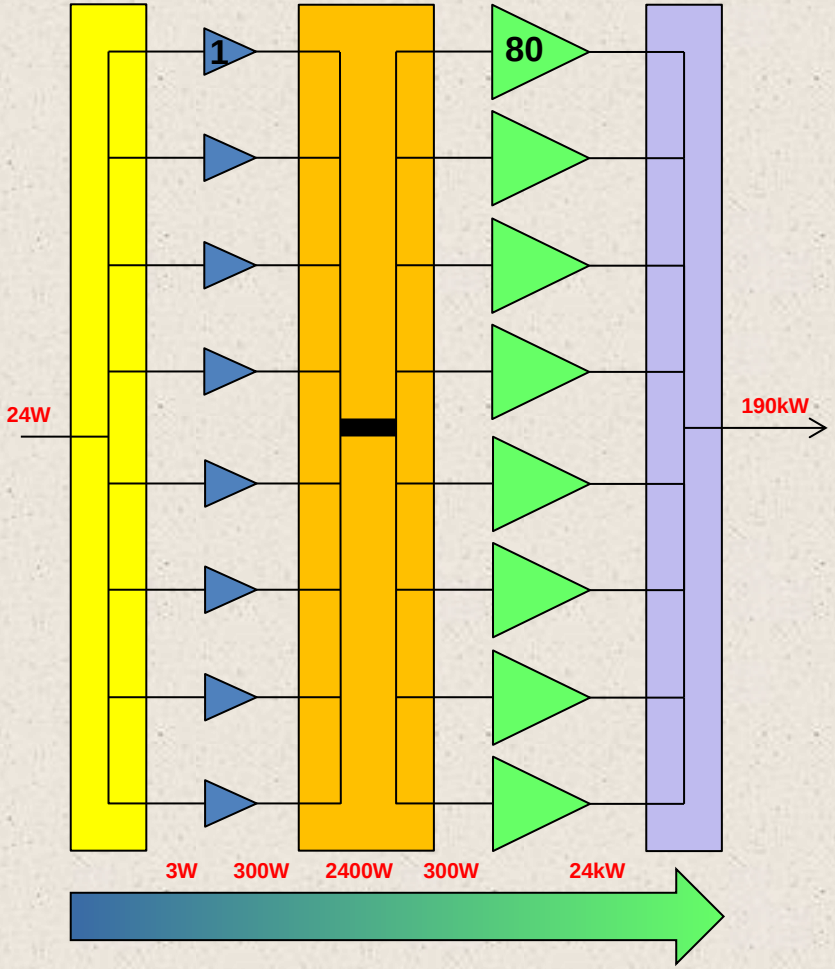
New layout of drivers

Actual solution



Maximum overall dispersion: 2 x (+/-0,2dB & +/-5 deg)
→ Minimum combination efficiency is 97,2%

New solution for SOLEIL upgrade



Maximum overall dispersion : +/-0,2dB & +/-5 deg
→ Minimum combination efficiency is 99,3%

- **Advantages: improved combination efficiency & immunity to driver failure (redundancy)**
- **Required «Combiner-Divider» under designing at SOLEIL**

Summary of SSA upgrade at SOLEIL

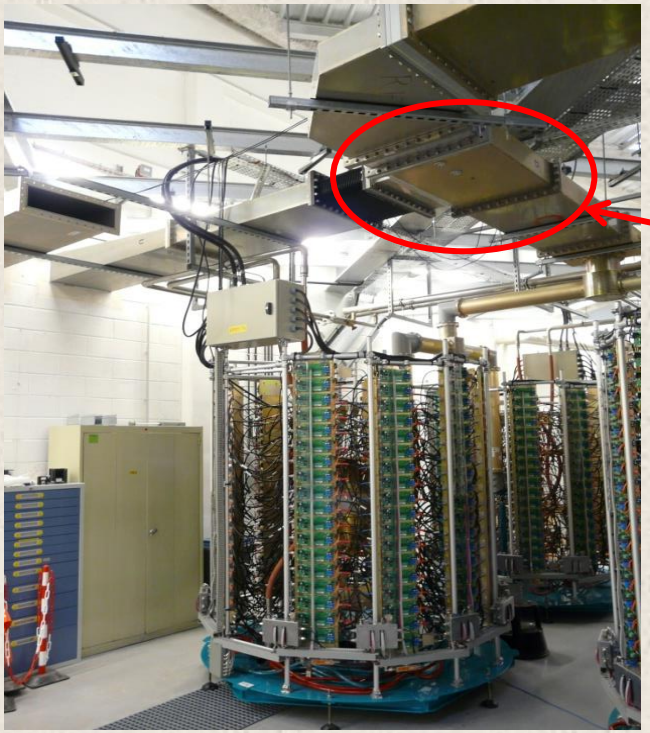
- **Important milestones**
  - **Complete replacement of the drivers has already proved its effectiveness in operation since 2013**
  - **Installation of the first tower BLF574XR => no failure after 1 year of operation**
  - **Progressive installation of the 15 other 50kW towers during about 10 years**
  - **Implementation of the new driver architecture in 2016**

- **This upgrade will make possible to obtain the same performance as the ESRF amplifiers, designed in 2010, with a low cost investment.**
  The reutilization of the RF modules, DC/DC converters and power combination system permits to maintain the upgrade cost around 10% of the amplifier price (~ 350k€)

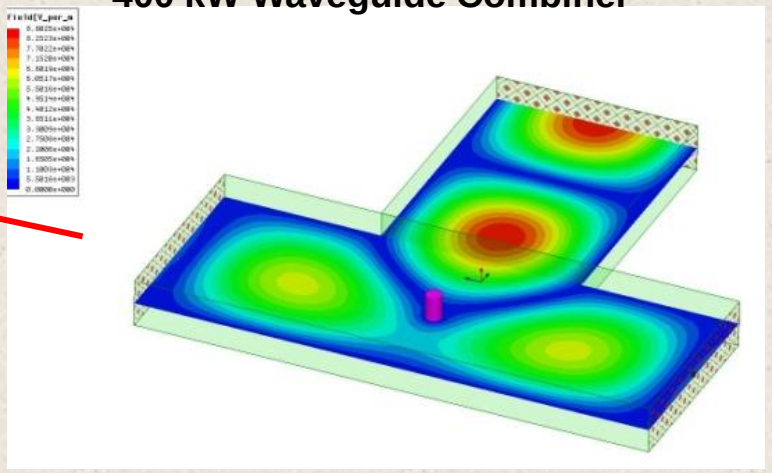
- **Capability of operating with 500mA in the storage ring with only 3 of 4 amplifiers**

Waveguide layout

- The will of SOLEIL to run at 500 mA using a single cryomodule
- In 2011, conclusion of a collaboration agreement with CERN and ESRF in order to develop a new 352 MHz IPC, based on the LHC design and capable of handling up to 300 kW (design by CERN and tested at ESRF)
- Due to the reflected power limitation of SSA (80kW), the combination of two 180kW ampliers is needed to provide 150kW CW full reflection (75kW CW reflected power/Amp)
- In 2013, design of 400 kW waveguide combiner and test up to 150kW in pulse and CW mode



400 kW Waveguide Combiner

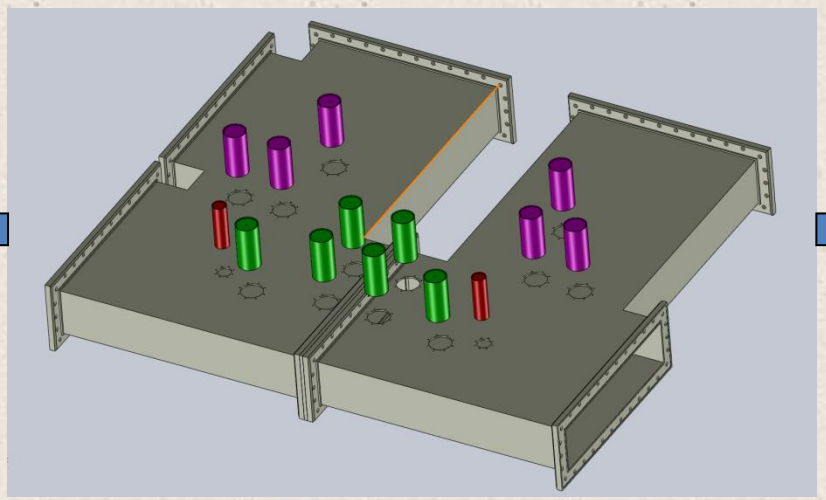


- Constraints:
  - Disassembling of the waveguide network for each combination
  - Duration of intervention: 4 hours

- Since 2013, the conditionning of IPCs was required several times
- Need for a simpler and faster solution ➔ Development of a low cost MagicSwitch

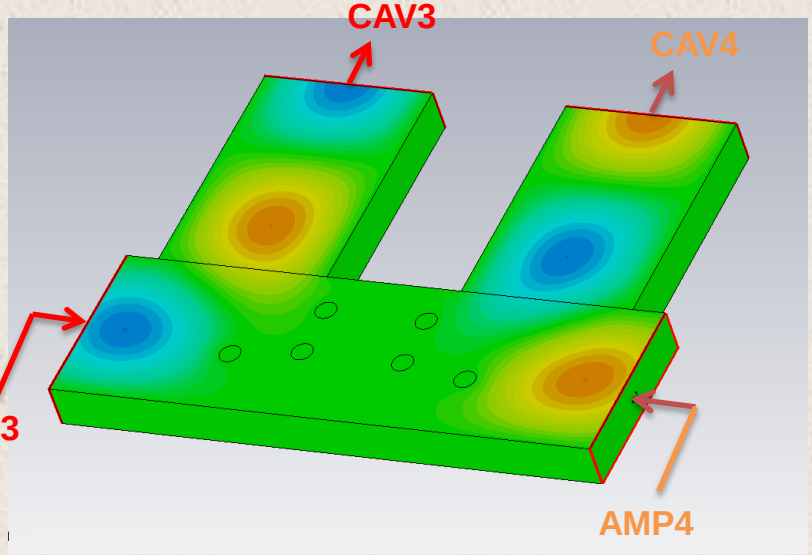
Principle & functions of MagicSwitch

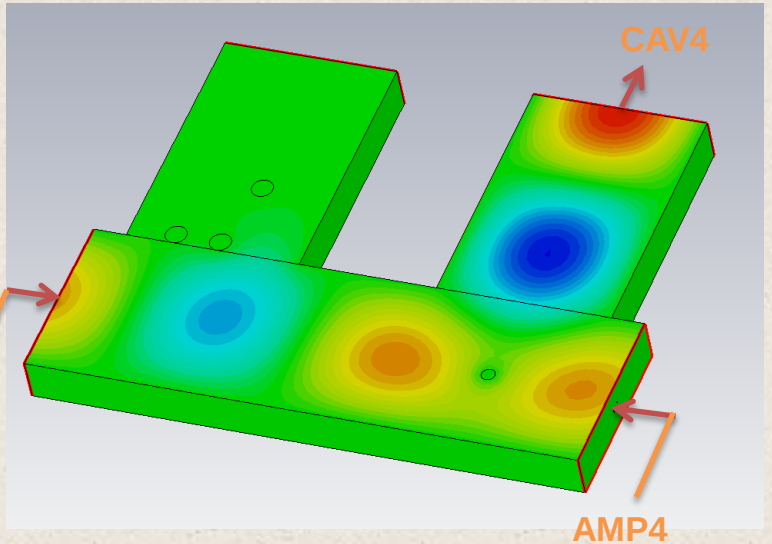
- **Principle of MagicSwitch**
  - **Change of the configuration with insertion of Al posts**



Normal operation

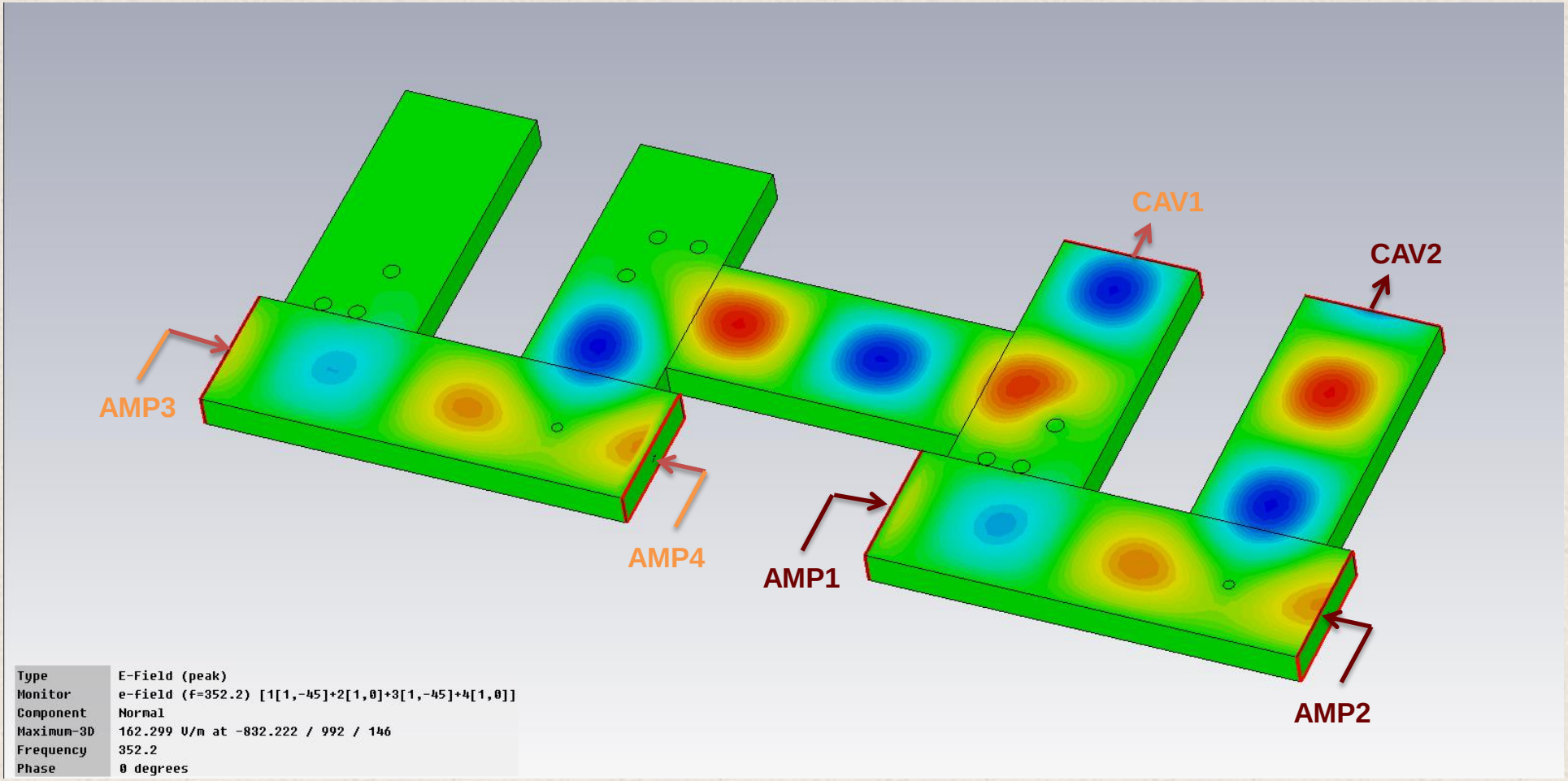
Cavity conditionning





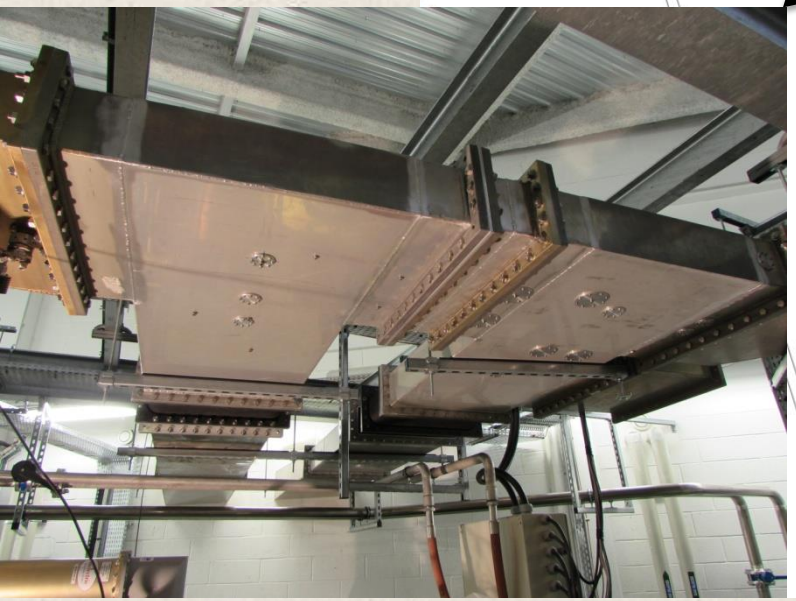
Principle & functions of the MagicSwitch

- **Operations with a single cryomodule**



- **Conditionning of 2 cavities simultaneously,150kW CW full reflection per cavity**
- **Operation at 500mA with a single cryomodule, 300kW per cavity**

Future waveguide layout



- Installation of a first MagicSwitch on the cryomodule n°2 in December 2014
- Installation of the second MagicSwitch on the cryomodule n°1 in mid 2016
- Waveguide connection between the 2 MagicSwitches in the end of 2016

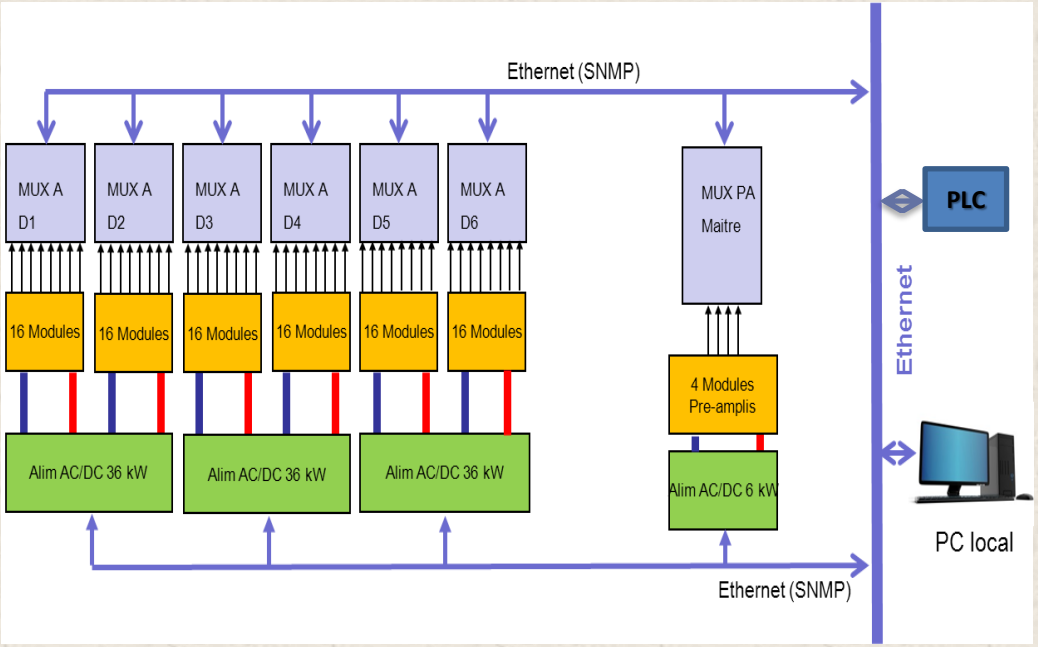
New approach of the amplifiers

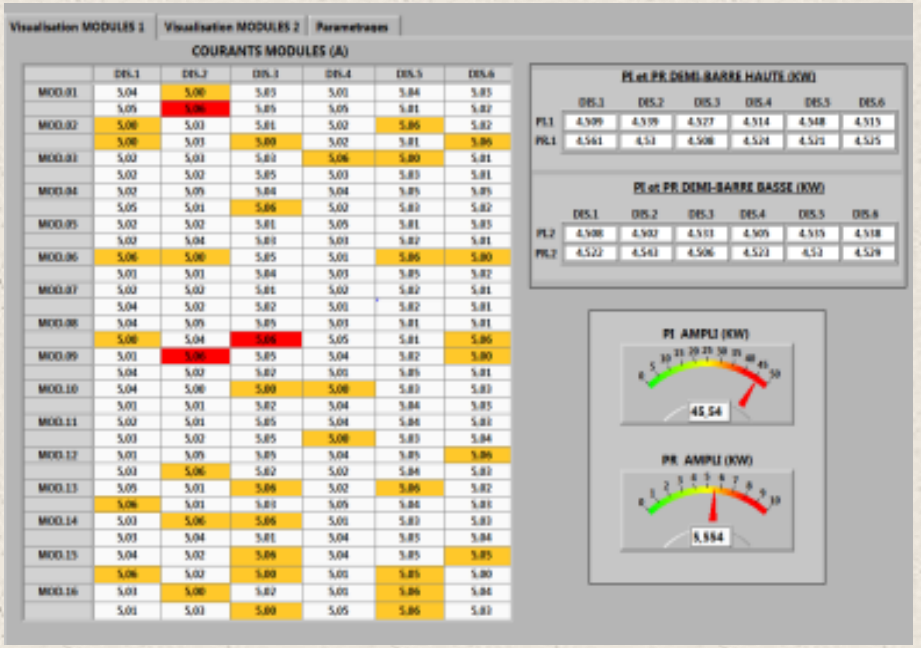
- **Use of rackable AC/DC power supplies**
  - **Avantages: Efficiency, Price, Maintenance, Modularity, Control system**
  - **Disadvantages: Air-cooling, Difficult integration in SOLEIL towers**

Specifications of 2kW module	
Input voltage	90-275 V AC
Efficiency	>95%
Ripple pp(mV)	30 (measured)
Voltage range	43V-57,5V DC
MTBF	422246h

Specifications of controller SC200	
Physical Interface	Ethernet, USB, RS232
Protocol	SNMP, HTTP, MODBUS TCP
Measurement	Voltage, Current , Temperature
Display	LCD 160x 128 Pixel

- **New control system and monitoring of the amplifiers**

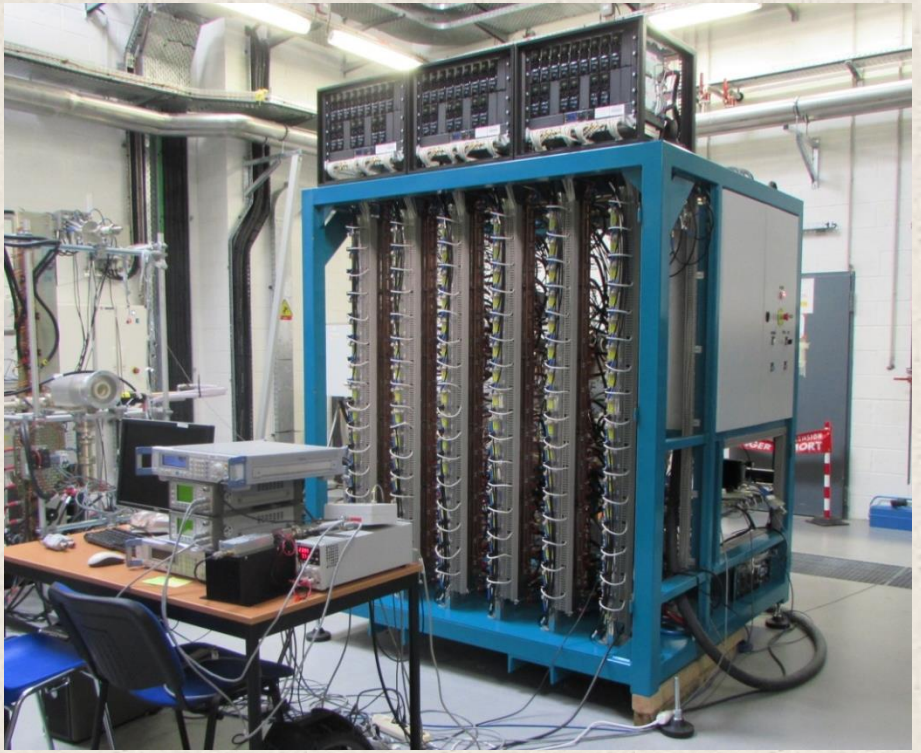




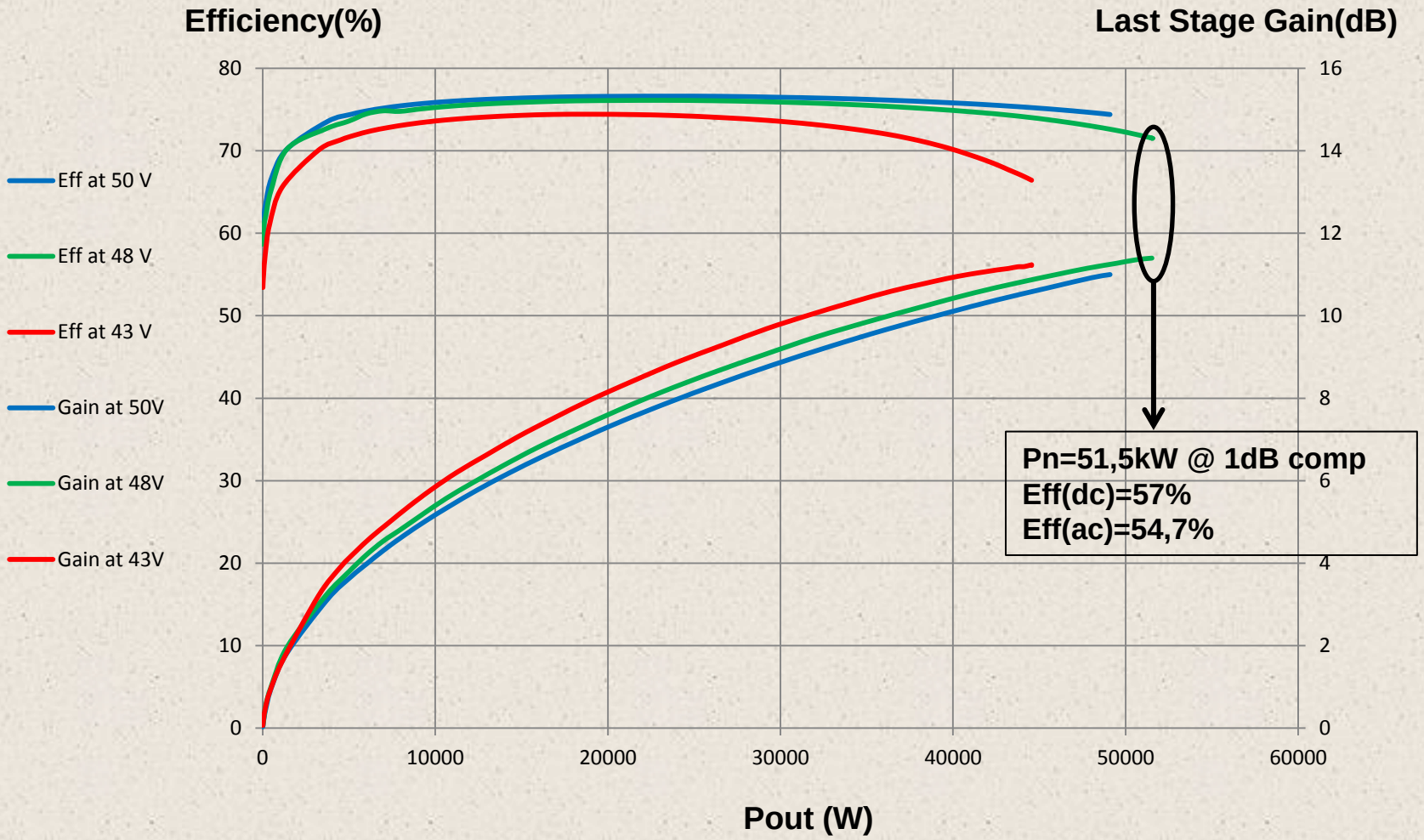
50kW amplifier for ThomX

- **ThomX Amplifier: 50kW @ 500MHz**
  - **Based on 530 W modules ➔ 96 amplifier modules are mounted on 6 dissipaters**

- **Milestones**
  - **Oct. 2014: Finalization of the amplifier design with the cabinet integration**
  - **Jan. 2015: Complete delivery of main components**
  - **Feb 2015: Mounting with the assistance of SESAME colleagues**
  - **March 2015: First tests on dummy load up to 52kW CW**
  - **April 2015: All measurements achieved (pulse & CW, with full reflection and VSWR of 2.5:1)**



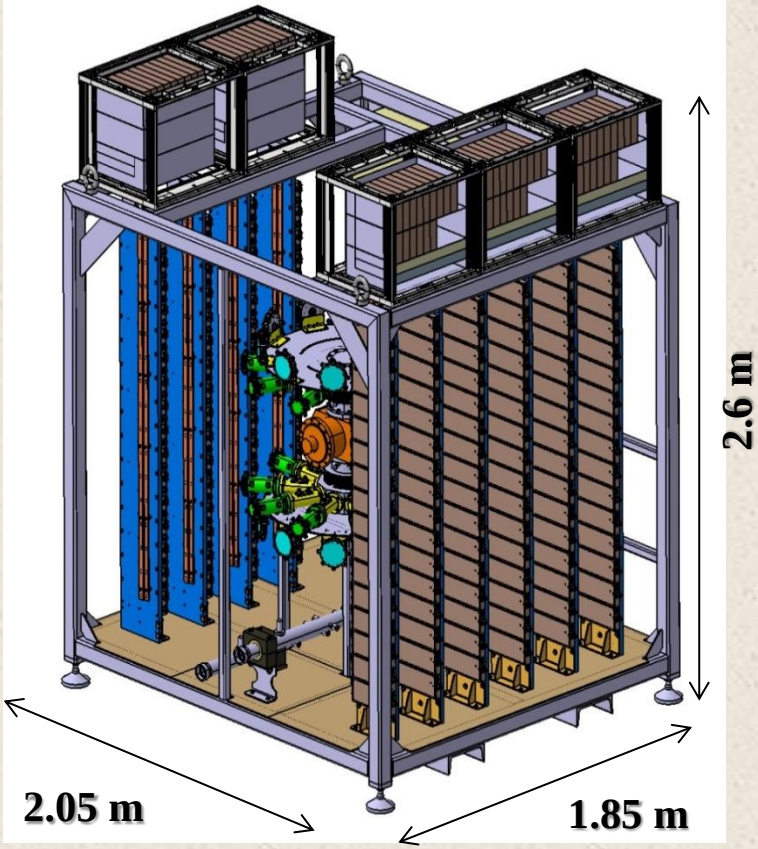
Results of ThomX amplifier



80kW amplifier for SESAME

- Four 80kW amplifiers at 500MHz are needed for the SESAME storage ring

- Within the context of collaboration between SESAME and SOLEIL, a first 80 kW amplifier is designed and built at SOLEIL
- This amplifier consists in a combination of 160 modules, which can provide 550W each; it will be built and tested by SOLEIL and SESAME RF teams at SOLEIL
- SOLEIL has concluded an agreement of transfer of know-how on SSA with SIGMAPHIELECTRONICS (SPE), which will build the 3 other amplifiers for SESAME after the validation of the first one (demonstrator)



- Schedule
  - Industrialization by SPE with SOLEIL support
  - Mounting & FAT at SOLEIL of the first amplifier in November 2015
  - Mounting & FAT at SPE of the 2nd amplifier scheduled for December 2015
  - SAT at SESAME of the first two amplifiers in winter 2016
  - Supply of the 2 last amplifiers by SPE in mid 2016

R&D with 1.3GHz amplifiers

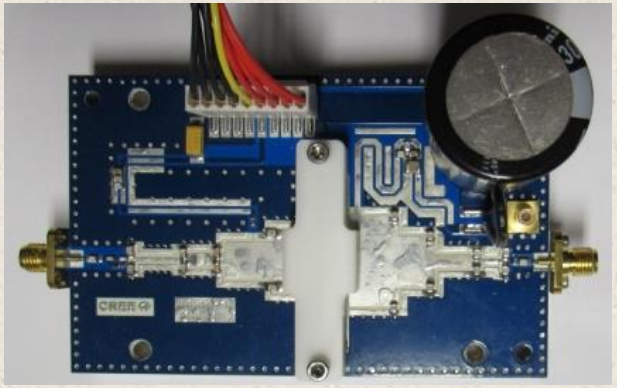
- For LUNEX5 : several 20kW amplifiers @ 1.3 GHz are needed

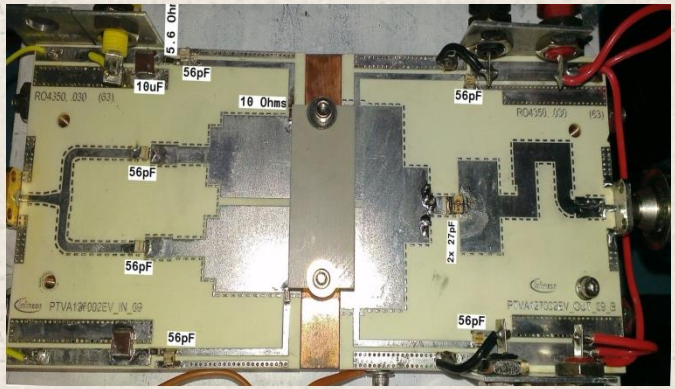
- In June 2015, funding of the LUCRECE project
  → R&D on complete 1.3 GHz RF plant (Amplifier, LLRF, SC cavity) for CW operation

- Decision to develop a 20 kW SSA with 400W CW modules, better optimized than 200W ones, actually in use

- Comparative analysis of transistors capable of producing 400W CW at 1.3 GHz

- Preliminary measurements of transistors with demoboards





  - GaN Single-ended transistor tested : Pout = 425W CW @ 57% eff.
  - LDMOS Push-Pull transistor under testing (Pout =641W @ 56% eff., 32 ms pulse width)

- Other 1.3 GHz component samples, like 500W circulator & 1500W stripline load, have to be tested

Thanks for your attention