A Light for Science

ESRF

G.Gautier
J.Jacob
M.Langlois
JM.Mercier

Status of High Power Solid State Amplifiers

Existing 352.2 MHz ESRF RF system

Courtesy J.Jacob

Existing Operation at 200 mA

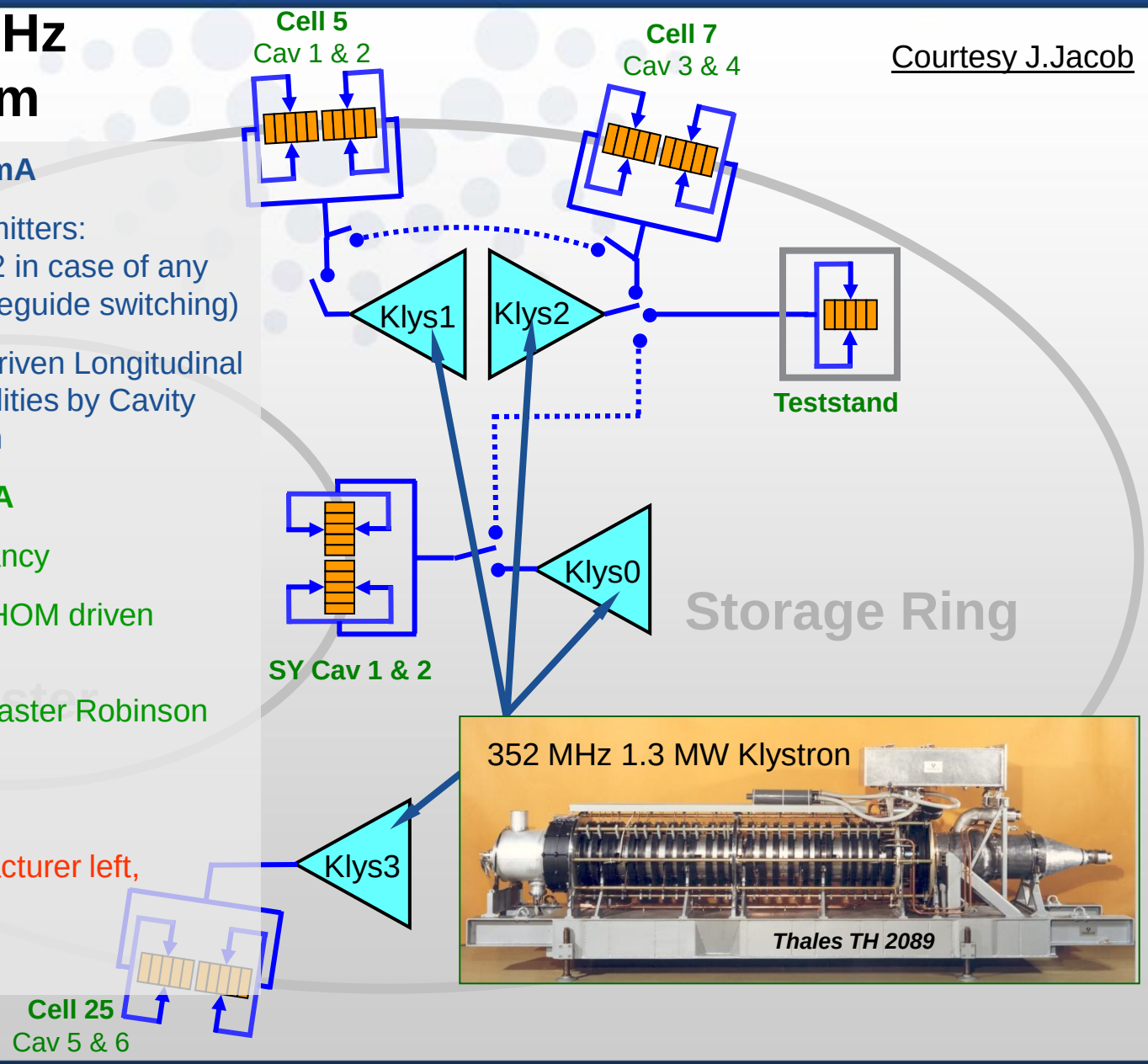
- 1.3 MW klystron transmitters: Redundancy with Klys2 in case of any transmitter failure (waveguide switching)
- Suppression of HOM driven Longitudinal Coupled Bunch Instabilities by Cavity Temperature regulation

Current upgrade to 300 mA

- No transmitter redundancy
- Need LFB to stabilize HOM driven instabilities
- Increased voltage to master Robinson Instability

Long term

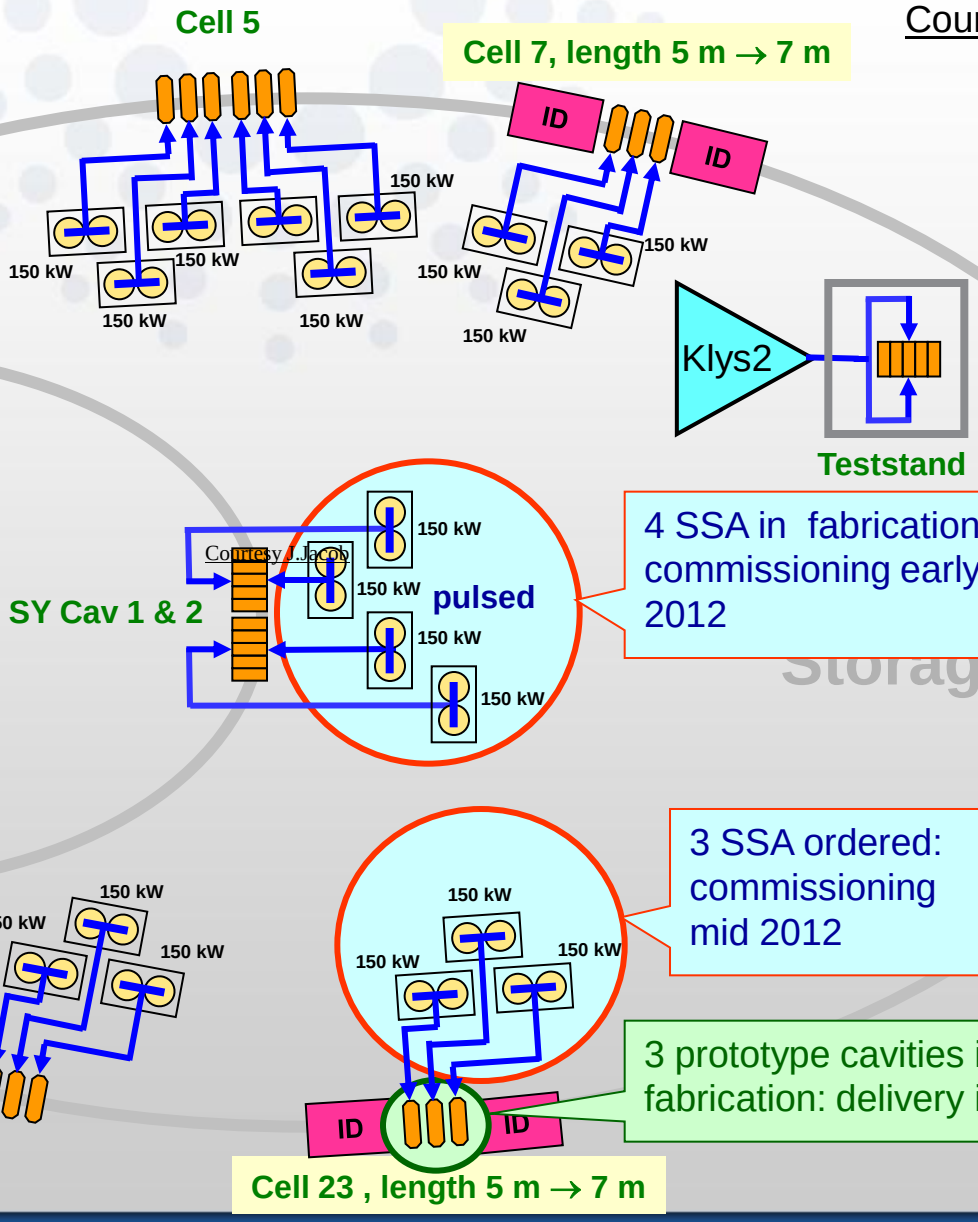
- Only 1 klystron manufacturer left, possible obsolescence



Courtesy J.Jacob

RF upgrade project:

- 18 new single cell HOM damped cavities
- 4 x 150 kW Solid State Amplifiers for the Booster
- 18 x 150 kW Solid State Amplifiers for the Storage Ring

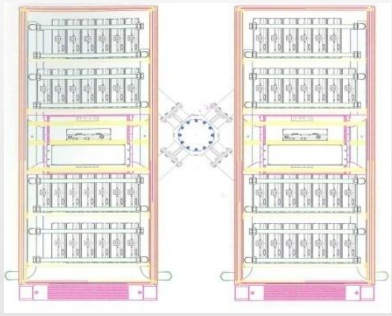


Pre-Qualification and Call For Tender (1)

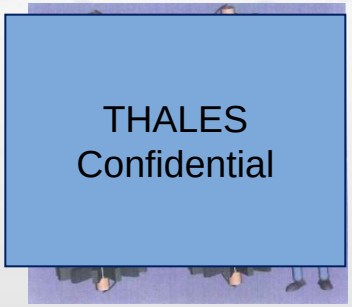
- Specification for the procurement of **7 SSA**
  - 4 SSA for the Booster + 3 SSA for the Storage Ring
  - Maximum Output Power **150 kW RF**
  - Frequency **352.2 MHz** – Bandwidth > **1MHz**
  - Basic Pallet - **300 W < Max Power < 1000 W**
  - **6th generation LDMOS** push-pull transistor recommended
  - **Maximum Spread** between pallets, in Gain 0.2 dB and Phase 5º
  - **Phase noise** < -70 dB
  - **Efficiency @ P1** **> 50%** in Pulsed mode, **> 55%** in CW
  - **Harmonic Content** : H2 < -36 dB, other harmonics < -60 dB
  - Remote Control **RS485** protocol ModBus/RTU **@ 1Mb/s**
  - **Reliability** - failure rate **< 0.7%** per year (< 2 transistors per SSA)

Pre-Qualification and Call For Tender (2)

- **July 2008** Pre-Qualification exercise launched with a **selection of 7 manufacturers.**



Racks



Rosaces

Towers

- **December 2008** Approval of ESRF upgrade program by the Council.

- **4 manufacturers are retained** for the Call For Tender (launched **January 2009**)
  - Cryoelectra (Germany) - *replied*
  - Elta (France) - *replied*
  - RES Ingenium (Italy) - *replied*
  - Thales (France) – *didn't reply*
- Possibility of 2 different contractors was considered
- Finally only one was **selected : ELTA,** who benefit from a technology transfer from SOLEIL

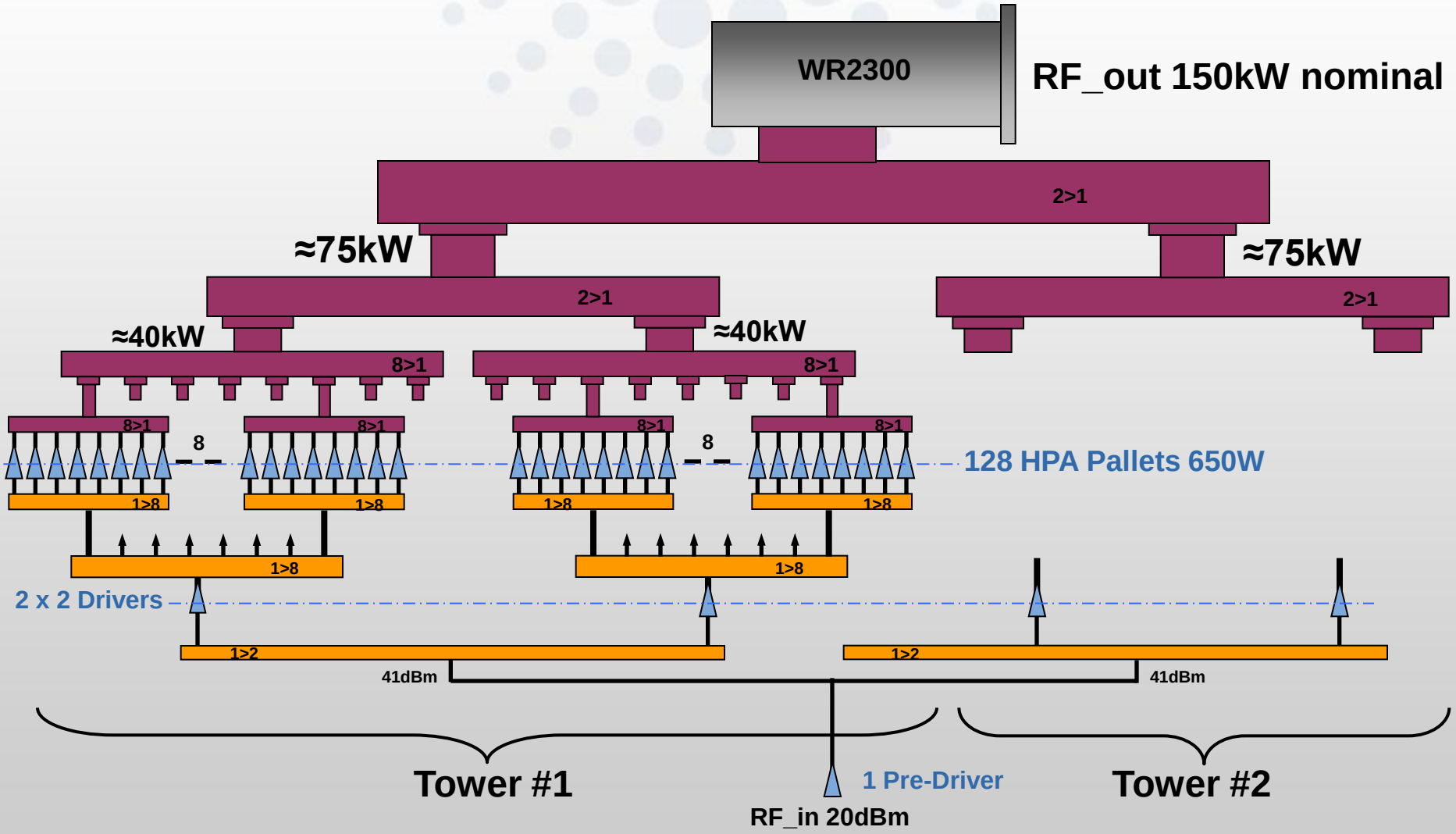
Technology Evolution during prospection

- **NXP** and **Freescale** very motivated in the development of new transistor – **LDMOS 6th generation**.
  - **LR301** (Polyfet) 30V 300W / 13 dB @ 352 MHz – customized for SOLEIL,
  - **BLF369** (NXP) 30V 500W / 18 dB η=60% @ 225 MHz,
  - **MRF6VP2600H** (Freescale) 50V 600W / 20 dB η=69% @ 352 MHz,
  - **BLF574** (NXP) 50V 500W / 26 dB η=70% @ 225 MHz,
  - **MRF6VP41KH** (Freescale) 50V 1000W / 20 dB η=70% @ 352 MHz,
  - **BLF578** (NXP) 50V 1000W / 20 dB η=74% (760W) @ 352 MHz,
- The 6th generation LDMOS transistor has allowed industry to offer High Power SSA at an acceptable cost.

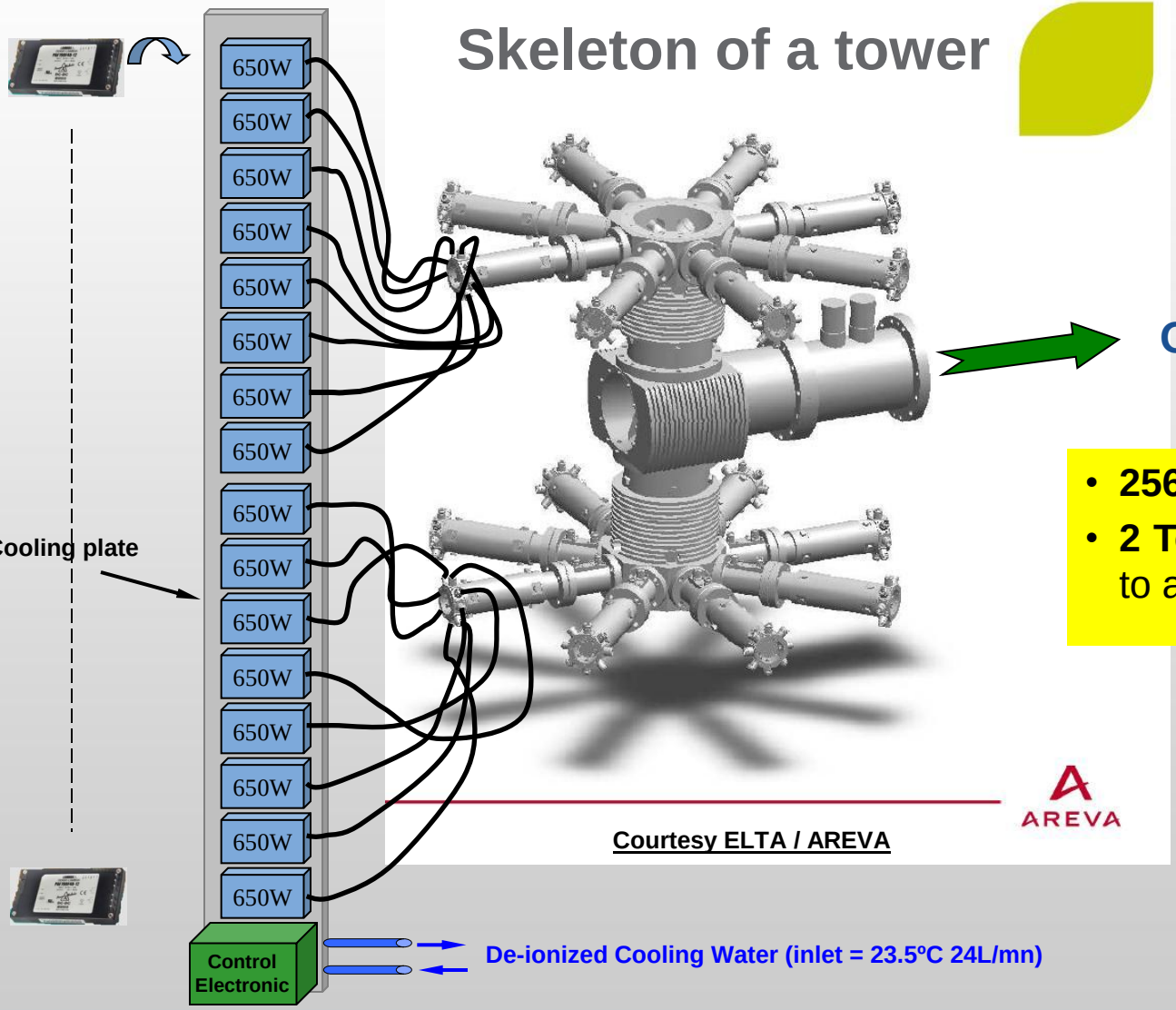
Contract

- Originally it was planned to build SSA with **3 towers**
- With the latest transistors, **2 towers** could be considered to sustain **150kW**
- Negotiations with **ELTA** started mid of June 2009, the contract has been **signed November 6th 2009**.
- Originally the supplier agreed to test a sequence of 3000 ON/OFF on the first tower. Finally, to avoid early aging of a complete tower, the test has been limited to a combination of 16 modules.

Solid State Amplifier – Architecture (1)



Solid State Amplifier – Architecture (2)



Skeleton of a tower

Courtesy ELTA / AREVA

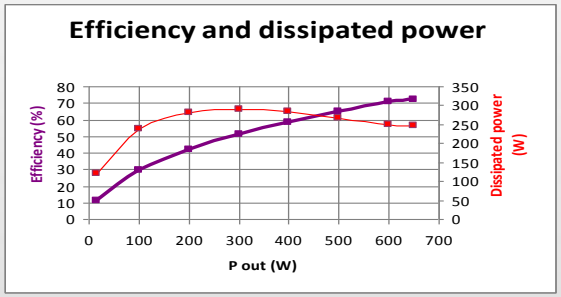
OUTPUT 75kW

- **256 RF modules** of 650W
- **2 Towers** combined together to achieve **150kW**

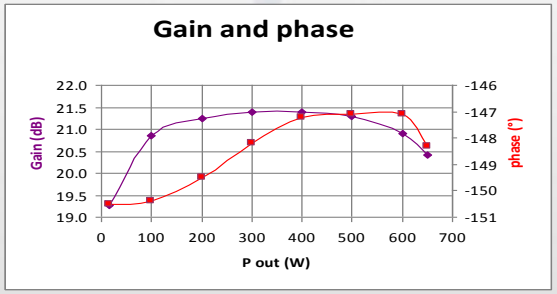
First Test (February 2010)


Michel Langlois

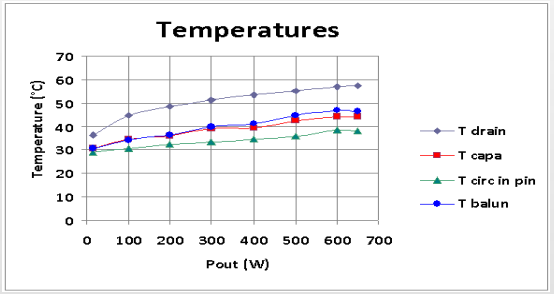
- **Milestone #1** - FAT of the first 650W module at SOLEIL.
- The test has given satisfactory results: All the measurements were controlled by ESRF and fit in with ELTA/SOLEIL measurements.



Efficiency 72.4% @ P1 650W



Gain 20.5dB @ P1
Max. Phase Shift 3.4º



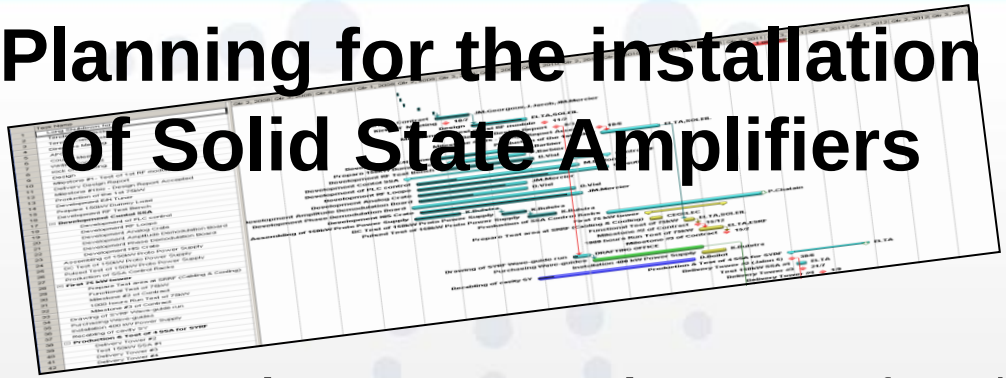
Measured with fiber-optic method, confirmed by infrared method.
$Rth_{junction/case}$ = 0.14 K/W
☞**$Temp._{junction} \approx 110ºC$**
☞**Electromigration**
- **MTF 50% = 2,000yrs**
- **TTF 0.1% = 1,000yrs**

- **Other Tests:**
  - Harmonic spurious (< -60dB) - Non harmonic gain ($G_{nh} < G_{352MHz}$)
  - Reflected power capability in full reflection all phases:
    - Full power during 20µS
    - Half power during 1 hour
  - Test of the circulator,
  - Unconditional stability for I_{DQ} variation – **K>3**

Almost all the measurements are compliant to ESRF specification

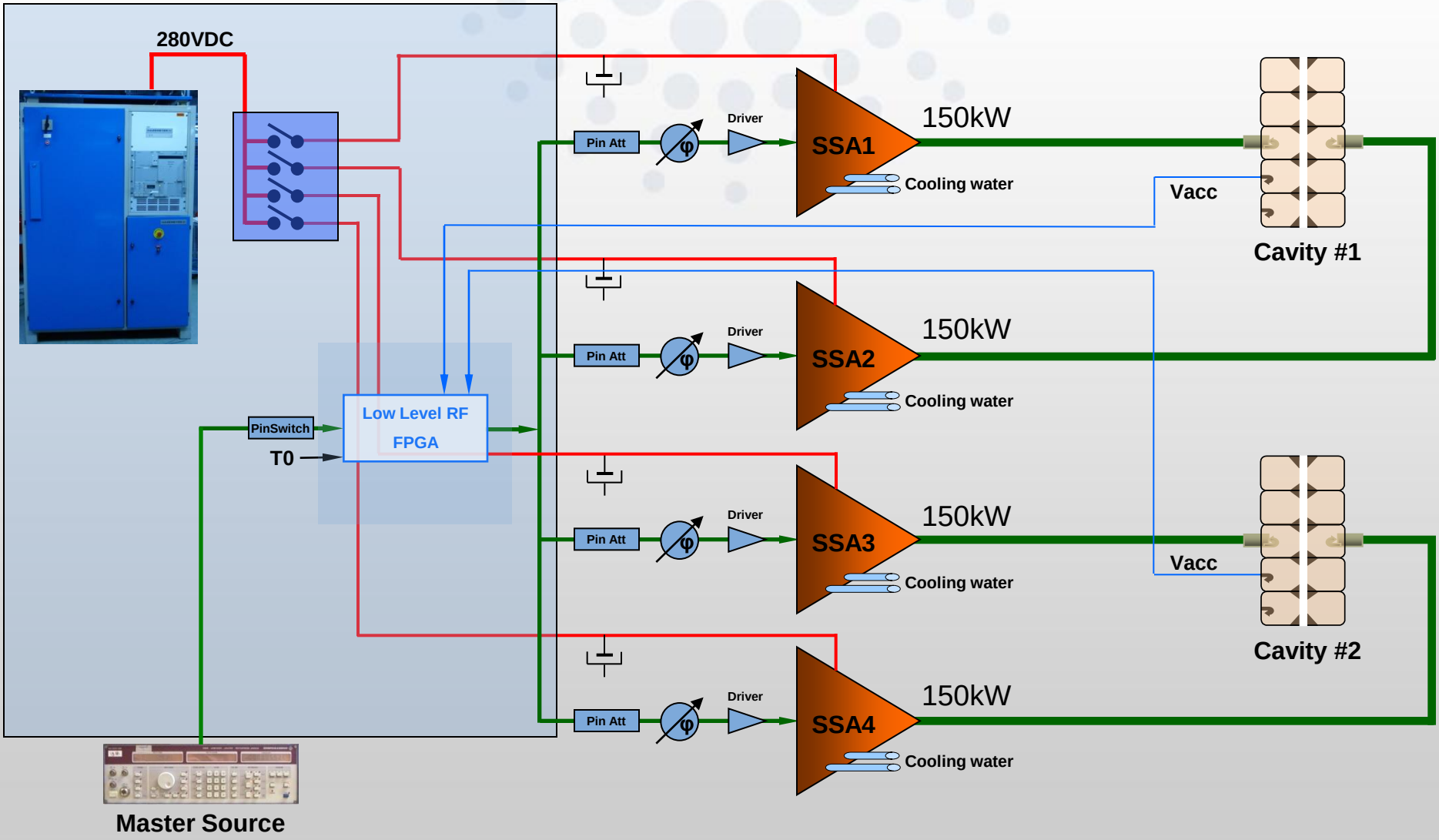
Mismatch test for VSWR = 3.7
220W reflection at 650W for the worst phase the module **power is reduced** by 10%.
It is also true for VSWR = 2.1
ESRF has accepted this non compliance with the spec.

Planning for the installation of Solid State Amplifiers



- **January 2011** - **Empty the Booster Xmitter room** from klystron system. Booster cavities will be powered by RF backup station (TRA #2)
- **February 2011** - **Prepare the room** with the new waveguide run, water piping …
- **March 2011** - Installation of the **400kVA AC/DC converter**.
- **April 2011** - Test of the AC/DC converter connected on water load.
- **July 2011** - Commissioning of the **first 150kW SSA**.
- **January 2012** - Commissioning of the **four 150kW SSA** on the booster cavities.
- **August 2012** - Commissioning of the **three 150kW SSA** on the new Storage Ring RF section.

New Booster RF - General Layout



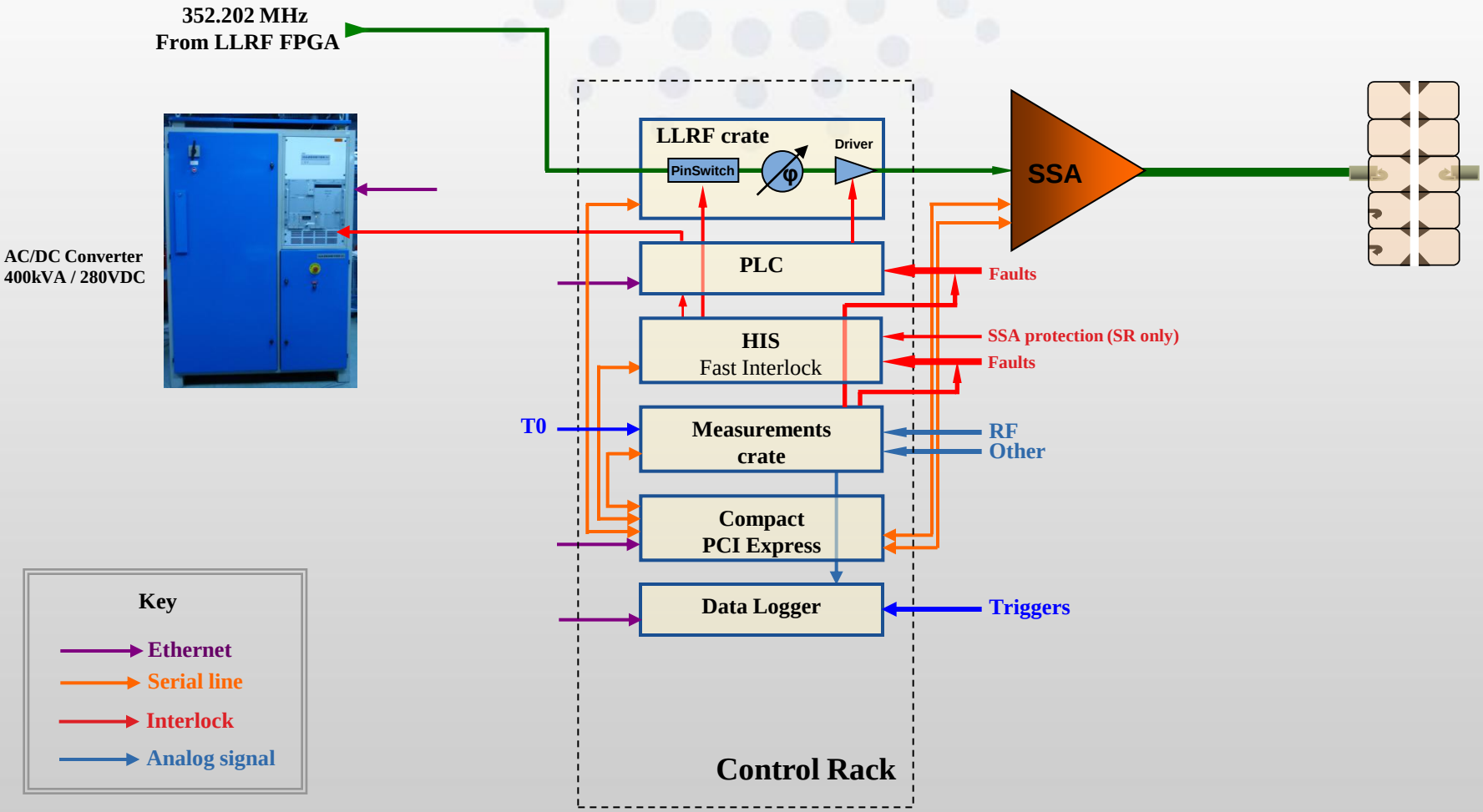
New Booster RF – Low Level RF


Georges Gautier


RF 352.202 MHz

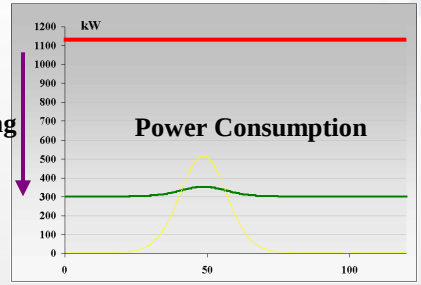
USB
A-low
A-high
Cosφ Sinφ
cw
Pulse
A*Cosφ
A
A*Sinφ
Iset
Qset
+
-
Controller PI + Low-pass
Controller PI + low-pass
DAC 14bits
DAC 14bits
I
Q
Modulator Hittite HMC 497 LP4E
Att
G = 35dB Max power 37dBm
Splitter 6 dB
SSA #1
SSA #2
SSA #3
SSA #4
Cavity #1
Cavity #2
Down conversion From 10MHz to 0 Σ
ADC 12bit Sampling 80MHz
ADC 12bit Sampling 80MHz
Analog down conversion IF 10MHz
Analog down conversion IF 10MHz
10MHz
RF 362.202 MHz
Synchro T0
FPGA
Heron-IO2 / Hunt Engineering

New Booster RF – Control



Powering the Solid State Amplifier

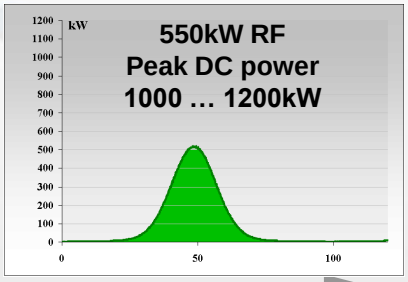

JF.Bouteille JK Bulstra
Power Supply Support

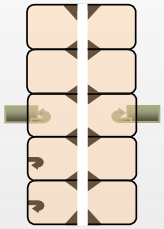


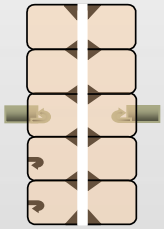
Power saving

Klystron

SSA



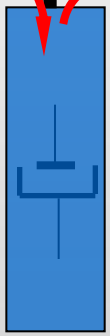




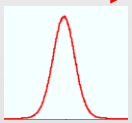
Mains 400VAC

Constant current

280VDC



Anti-flicker
4 x 750mF



4 SSA 150kW RF each

2 booster cavities
x 2 couplers

4 Drivers, 1W each

352.2MHz pulsed @ 10Hz

Conclusion

- **SOLEIL was the pioneer**, ESRF makes the second step in this adventure of highest power SSA.
- **Substantial Energy Saving** in the booster**,** thanks to SSA**.**
- No more High Voltage.
- **Reliability** enhancement, compared to klystrons, is expected.
- ESRF large scale application promotes the Industrialization of High Power SSA.
- 3 HOM damped cavities powered by **3 SSAs** should be installed on the **Storage Ring**. **Commissioning planned end of 2012.**

Acknowledgements

- **SOLEIL** - P.Marchand, R.Lopes, T.Ruan and F.Ribeiro for their collaboration.

- **ELTA/AREVA** – D.Pinet, JP.Abadie, A.Cauhepe and C.Mathias.

- **ESRF** – All my colleagues of the **RF group**
  JF.Bouteille and K.Bulstra of the Power Supply Support group

Thank you for your attention