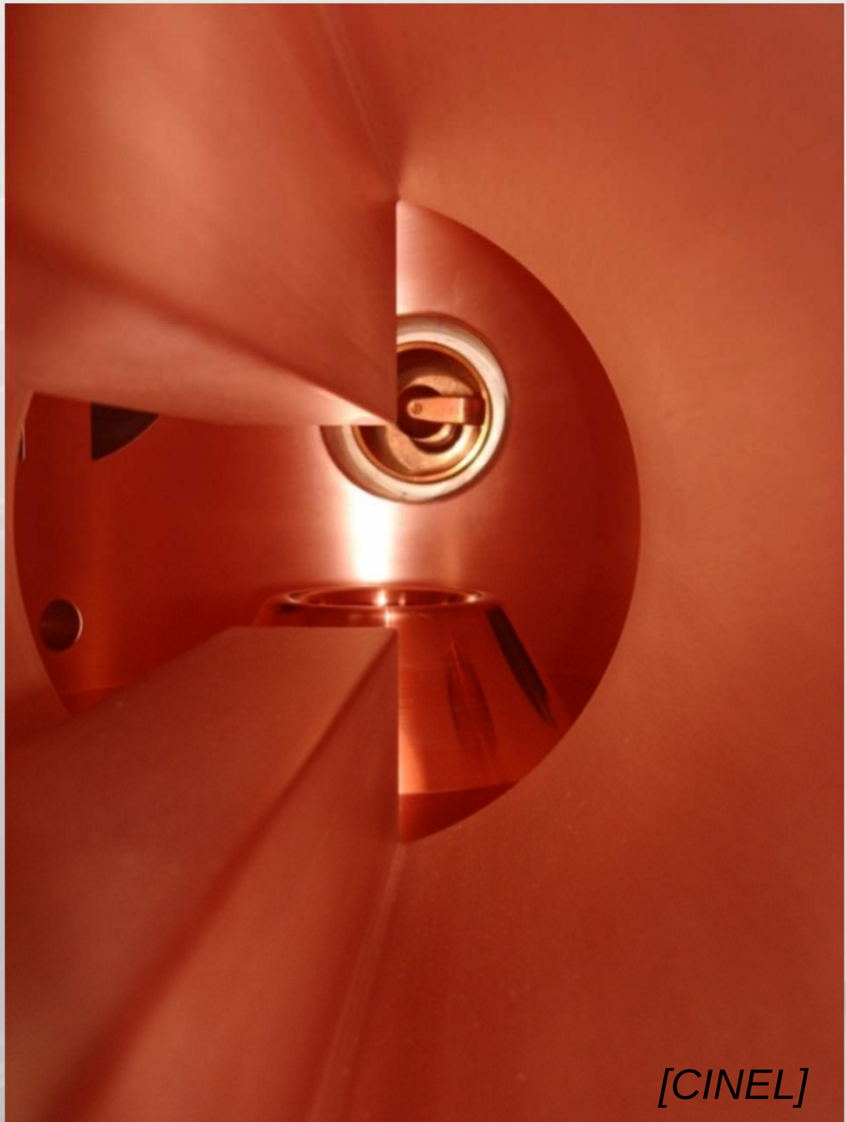


17th ESLS RF Meeting 2013

HZB – BESSY

18th – 19th September

Status of the ESRF RF upgrade

J. Jacob
J.-M. Mercier
V. Serrière
M. Langlois
G. Gautier

European Synchrotron Radiation Facility

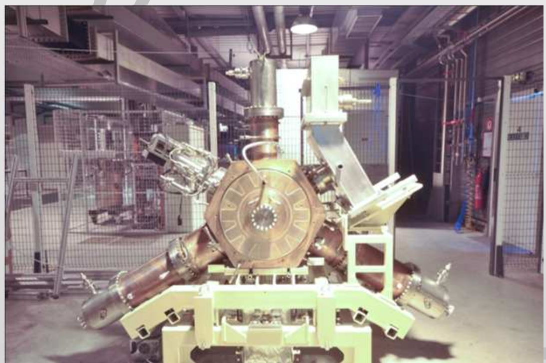
RF upgrade phase 1

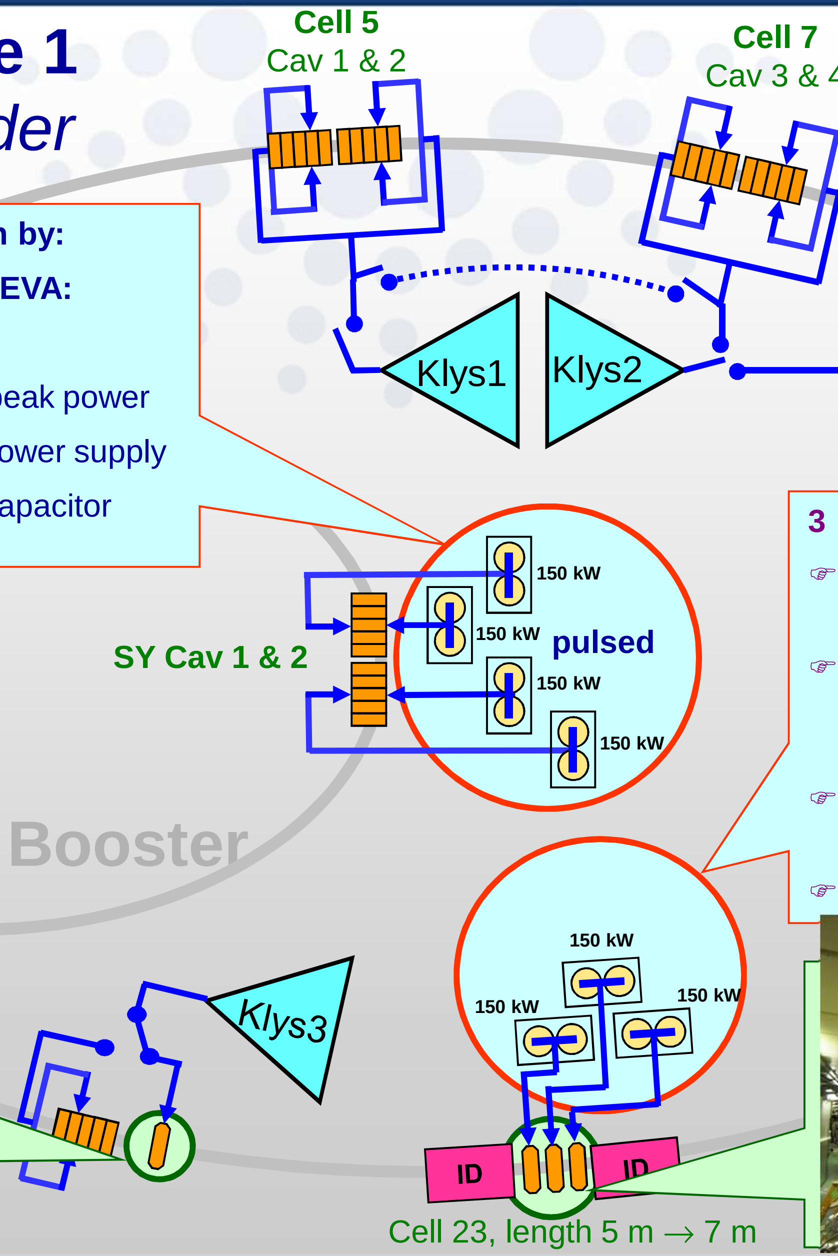
until 2015 - reminder

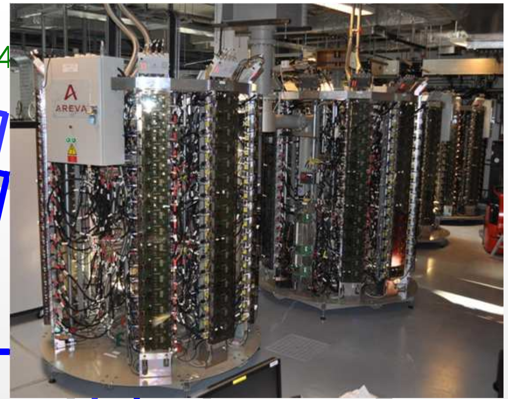
Replacement of Booster Klystron by:

4 X 150 kW SSAs from ELTA / AREVA:

- In operation since March 2012
- 10 Hz pulses / 30 % average/peak power
- 1 common 280 V dc / 400 kW power supply
- 3.2 F anti-flicker & smoothing capacitor banks





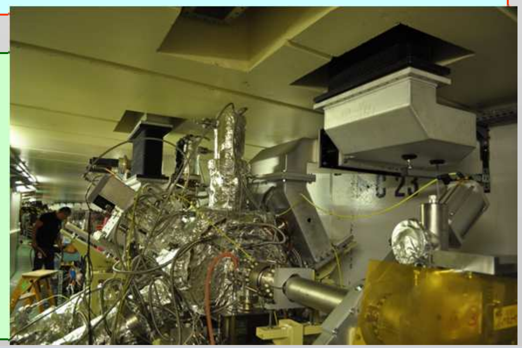


3 X 150 kW SSA from ELTA

- Powering 3 new HOM damped cavities on the storage ring
- 1st SSA to power 1 cavity since August 2013: commissioning under way
- 2nd SSA: delivered, connection to cavity end of the year
- 3rd SSA: March 2014

prototype HOM damped cavities …

- 2 cavities tested with beam on cell 25 with klystron transmitter TRA3:



ESRF upgrade phase 2: project for 2015-2019

Preliminary RF parameters		Existing ESRF	New ESRF lattice
Emittance	ε_x / ε_z	4000 pm / 4 pm	≈ 150 pm / 3 pm
Energy loss (incl. 0.5 MeV for ID's)	U	5.4 MeV/turn	3.6 MeV/turn
Same ID position ⇒ Δf_{rf} = + 150 kHz	f_{rf}	352.20 MHz	352.35 MHz
Longitudinal damping time	τ_s	3.4 ms	6.8 ms
Momentum compaction factor	α	$1.78\ 10^{-4}$	$8.42\ 10^{-5}$
Energy spread	σ_E/E	$1.06\ 10^{-3}$	$1.03\ 10^{-3}$
Nominal RF voltage	V_{acc}	8 MV	6 MV
⇒ RF Energy acceptance (incl. ID's)	$\Delta E/E$	2.9 %	4.3 %
Synchrotron frequency	f_s	1.86 kHz	1.15 kHz
$I_{threshold}$ for HOM driven instabilities (LCBI) *[for a given HOM]*	ratio	1 to 0.66 ⇒ HOM damped cavities MANDATORY for Phase 2	
Number of cavities	N_{cav}	5 (five-cell cav's ⇒ 25 cells)	14 (mono-cells, HOM free)
Cavity Coupling	β	4.4	3.7
Copper loss per cavity	P_{copper} / N_{cav}	47 kW	19 kW
RF power per cavity at I_{nom} = 200 mA	$P_{tot\text{-}200mA}$ / N_{cav}	266 kW	71 kW
Total RF power at 200 mA (w/o transmission losses)	$P_{tot\text{-}200mA}$	≈ 1.33 MW	≈ 1 MW

HOM damped cavities for upgrade phases 1 & 2

3 functional cavities in house from RI, CINEL and SDMS

12 additional cavities in procurement in the frame of phase 1 :

- proposals for the next cavities in house
- order presumably placed end October 2013
- delivery scheduled end 2015

----

15 cavities: 14 for the ring and 1 spare

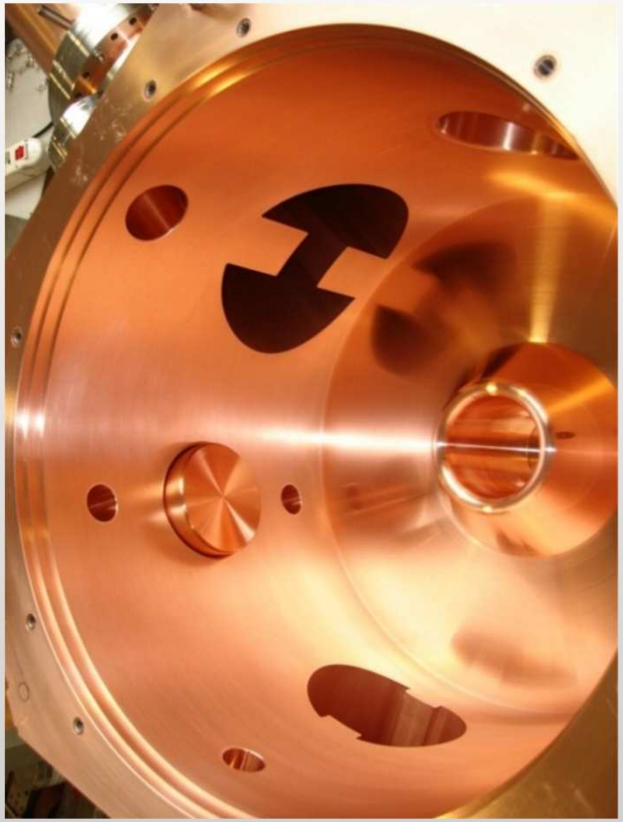
Phase 1 – well in progress

- Initially 200 mA → 300 mA
  ⇒ 18 HOM damped cavities
- 300 mA abandoned (thermal load for X-ray optics, bremsstrahlung, electricity cost, …)

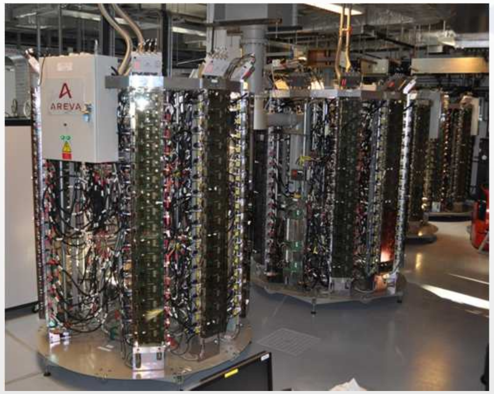
  ⇒ 14 HOM damped cavities + 2 five-cell cavities for **more stability** & more robust RF working points

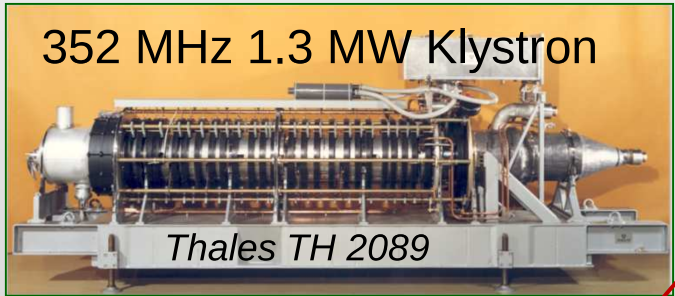
Phase 2 project (if OK from ESRF council end 2014):

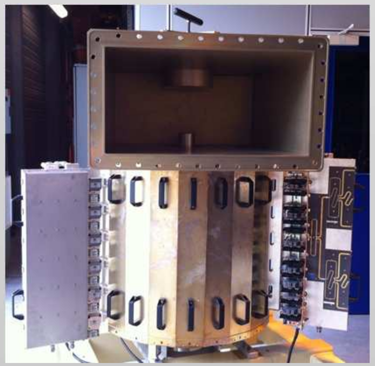
- Low emittance lattice
- 14 HOM damped cavities



Strategy – RF transmitters





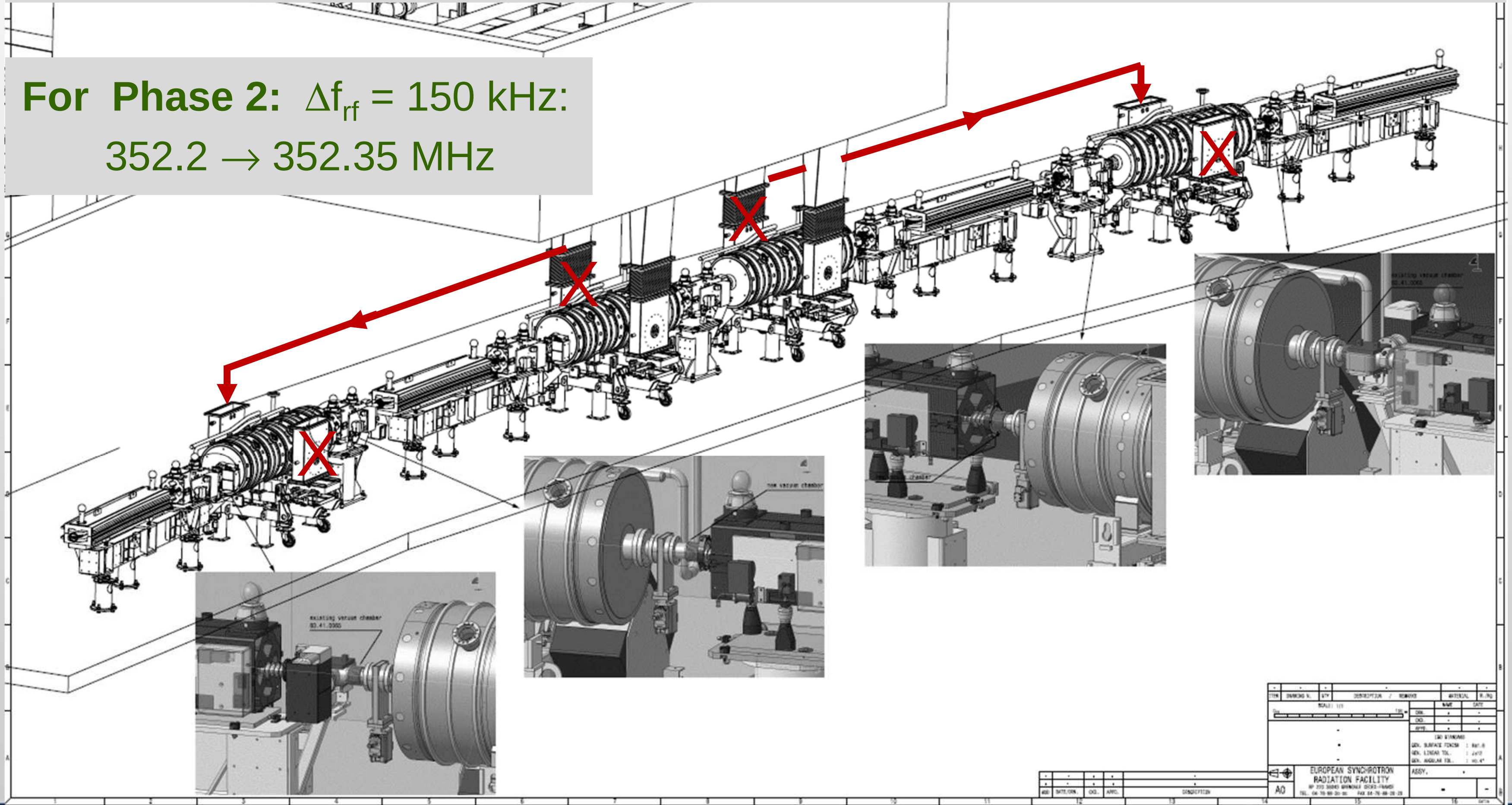


- 150 kW SOLEIL – ELTA SSAs with coaxial combiners:
  - 4 units on the booster (March 2012)
  - 3 units on the SR will (last one in operation from March 2014) to feed 3 new cavities
- Remaining HOM damped cavities could be started with power from existing klystron transmitters
- Ongoing in house development of SSAs
  - Successful test of first 12 kW prototype
    - ☞ Michel Langlois' talk
  - Next step: 75 … 100 kW prototype
- Gradual implementation of more SSAs envisaged in longer term

Projected booster RF upgrade for top up (phase 1): "4 five-cell cavities"

- 2 cav x 2 SSA/cav → 4 cav x 1 SSA/cav (empty space or 2 additional cav's)
- Nominal operation → half the RF power
- 4 x 150 kW SSAs: 7…8 MV max → 10 … 11 MV max
- 3 x 150 kW (1 missing SSA): still 7… 8 MV ☞ redundancy

For Phase 2: Δf_{rf} = 150 kHz:
352.2 → 352.35 MHz

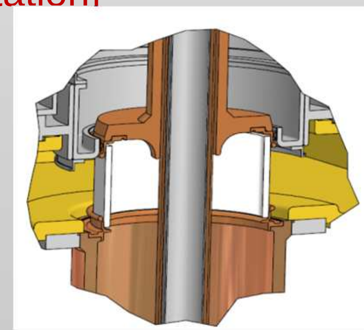


Other upgrade projects in the RF Group

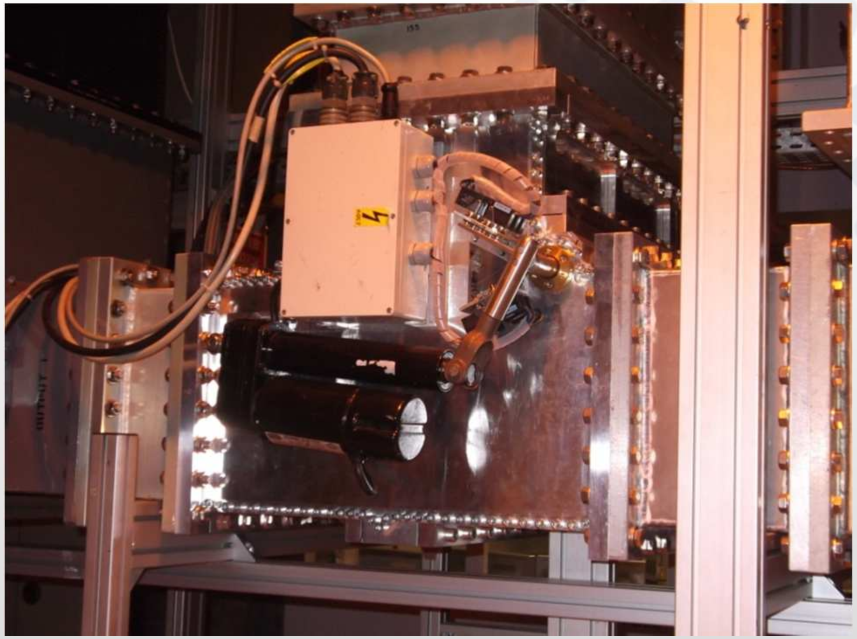
- Mostly for top up implementation/ phase 1, but needed also for new lattice/phase 2:
  - Linac refurbishment and upgrade for more redundancy: well under way:

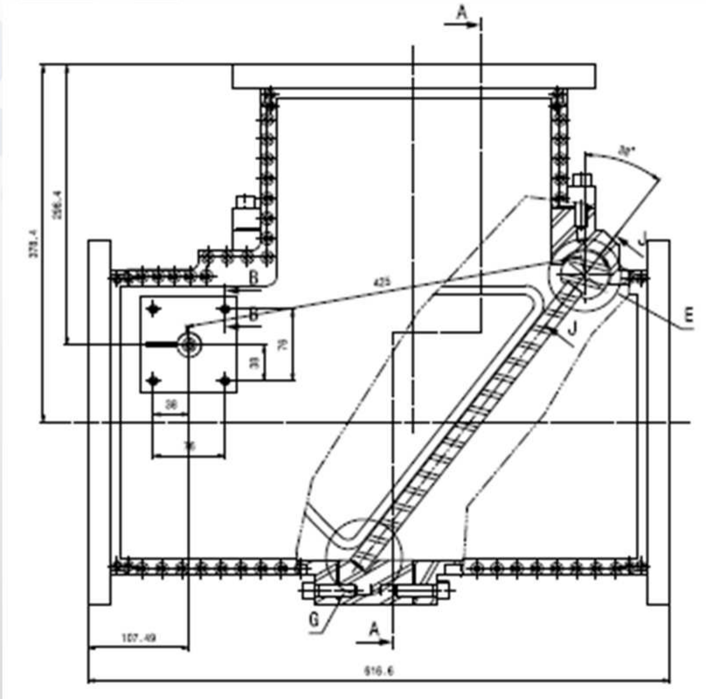
    … gun renewed a few years ago, spare buncher ordered, 3rd modulator in construction, power teststand in operation…
  - Injection/Extraction pulsed magnets – refurbishment and upgrade,

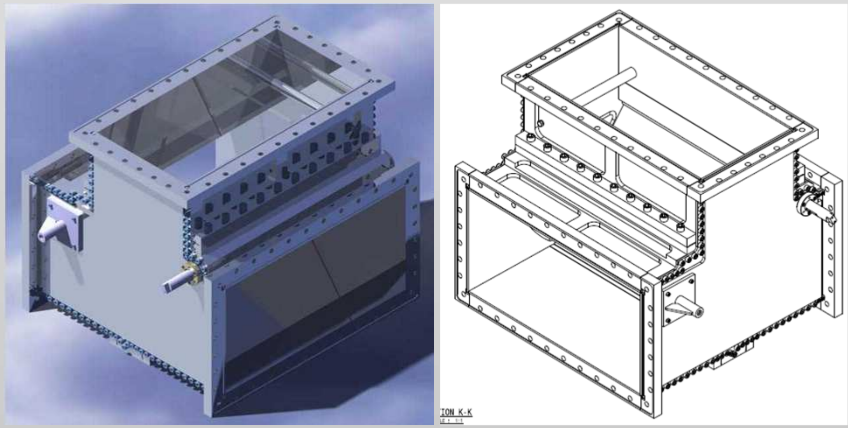
    … for instance project of fast booster injection kicker for high purity few bunch operation…
- Implementation of improved Arc detectors: probably of the CERN type combining 4 detectors to obtain better reliability and minimize false detections
- New coupler with LHC window - CERN / ESRF / SOLEIL collaboration:
  - 1st prototype for ESRF: reached 300 kW in CW in 2012, but arcing starting at the Cu collar, probably due to an initial impurity
  - Two more couplers for the ESRF expected this year
  - 2 couplers for SOLEIL: tested and conditioned to 280 kW at the ESRF in 2013, one of them successfully implemented at SOLEIL this summer [☞ see SOLEIL presentation]



352 MHz waveguide switch redesigned at the ESRF







- Successfully power tested (in CW at 1 MW through / 300 kW bent)
- Precision machining
- Only screwing, no weld distortion
- Parts sensitive to arcing can be exchanged: easily repairable

Lifetime in the new machine

- New lattice: in principle same operation modes as existing machine:

(preliminary)	Multibunch	16-bunches	4-bunches
Total current [mA]	200	90	40
Nb. Bunches	868	16	4
Bunch length [ps]	23	61	73
Lifetime [h]	12	2	1.5

☞ Will the new machine need harmonic cavities, e.g. Super3HC's ?

The ESRF Radio Frequency Group is seeking to recruit a:

Radio Frequency Engineer (m/f) for the Development and operation of Accelerating RF Cavities

permanent contract

You will contribute to the ESRF upgrade phase II that includes the construction of a new storage ring which aims at increasing the brilliance of the source by a factor up to 100. As an expert in the High power RF systems and RF measurement techniques, you will work on the accelerating cavities and their high power radio frequency feeders. Your duties will include:

- The follow up of procurement, the characterization, installation and commissioning of accelerating RF cavities and their ancillary equipment such as tuners and power couplers
- The design and 3D numerical field computations for accelerating cavities and waveguide components
- The participation in the design and prototyping of RF related components for the ESRF Phase II upgrade
- The operation follow up and maintenance of RF cavities, covering also instrumentation and control aspects
- The participation in beam physical studies covering the interaction with the accelerating cavities

As a member of the ASD, you will be required to contribute up to 15 % of your time to the operation of the accelerator complex on standby for the RF system and shift work for service to users.

http://www.esrf.fr/Jobs/english/recruitment-portal

Operation experience with booster SSAs in nominal operation on matched cavities

After 1.5 years / 1400 hours operation and some early debugging in spring 2012:

- Excellent reliability
- Most early failures: control hard & software, flow controllers, …
- Only 1 RF module and 1 DC/DC converter failure (without interruption of operation thanks to built in redundancy)
- 4 x Fuse blown on local controllers
- March 2013 shut down: 6 RF modules damaged by water supply leakage above one SSA (ESRF responsibility)
- Since then: a number of problems with the digital ESRF LLRF control system but all OK with the SSAs

Test results under specified extreme conditions (1)

- **Avoid overdrive conditions**
  - High peak drain voltage can damage the transistor [according to NXP]
  - Explains gain and efficiency degradation observed on first 75 kW under test at ESRF, according to ELTA *)
  - Taken into account by ELTA for the fabrication of the 2nd batch of 3 x 150 kW SSA for the ESRF storage ring:
    - No degradation observed after 3500 hours of fatigue test with 8 amplifier modules at maximum power *)
    - Paid with 1 to 2 % less efficiency of the RF modules and about 1 % less efficiency at nominal power for a complete SSA

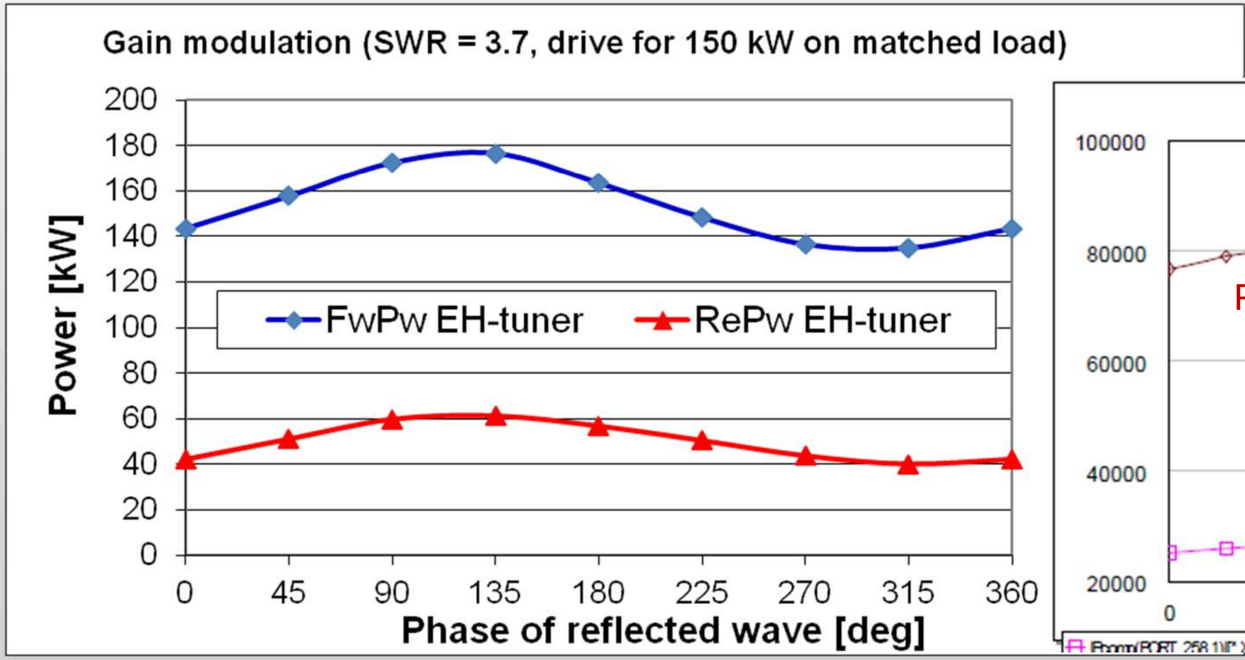
- **Short pulses (20 μs)**
  - Transient gain increase up to ≈1.3 dB
  - Risk of overdrive

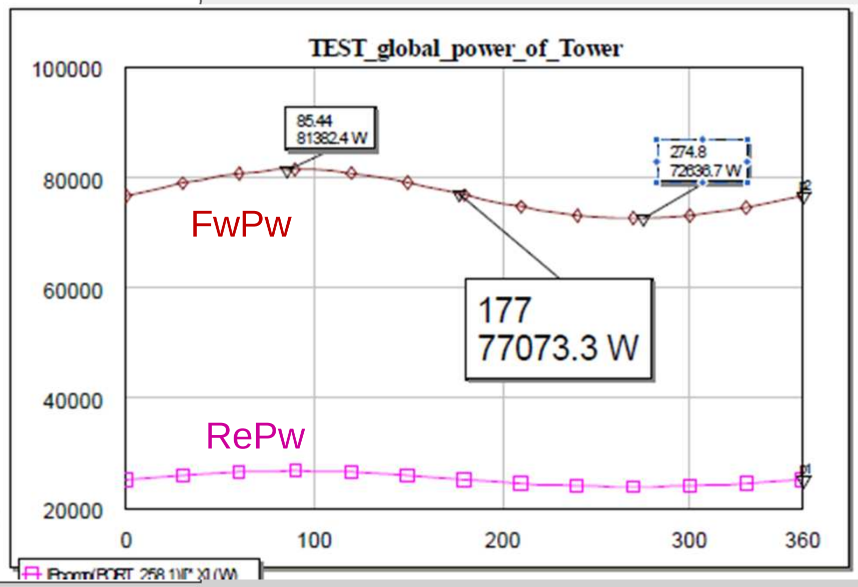
  ⇒ Overdrive protection needs to be adjusted carefully

* [J.-P. Abadie & A. Cauhepe, ELTA / AREVA]

Test results under specified extreme conditions (2)

- **SWR = 3.7** → P_{refl} / P_{fwd} = 50 kW / 150 kW, all phases (☞ EH – tuner)
  - ✓ Reflected power well absorbed by circulator loads on RF modules
  - ➢ But: gain modulation with phase of high power EH-tuner, intrinsic to coaxial combiner tree (non directive) ⇒ overdrive at certain phases!





Measurement on 5th SSA during SAT at ESRF for constant drive giving 150 kW on matched load [ELTA, ESRF, 10 June 2013] ☞ ± 20 kW on FwPw

Computation for a 77 kW tower driven by ideal constant power RF modules [A. Cauhepe, ELTA] ☞ ± 4.5 kW on FwPw

Test results under specified extreme conditions (3)

- **Operation with up to 6 RF modules OFF (tested in 2011 on batch1)**
  - On matched load: 150 kW obtained without problem (slightly higher drive) OK
  - But with SWR = 3.7 (RePw = 50 kW) → Arcing at output of passive modules!
    - → **Up to 1700 W reverse power** on the circulator loads of passive modules
    - → Destruction of load circuit, arcing propagating along cable towards combiner

Solutions for batch 1 on the booster:

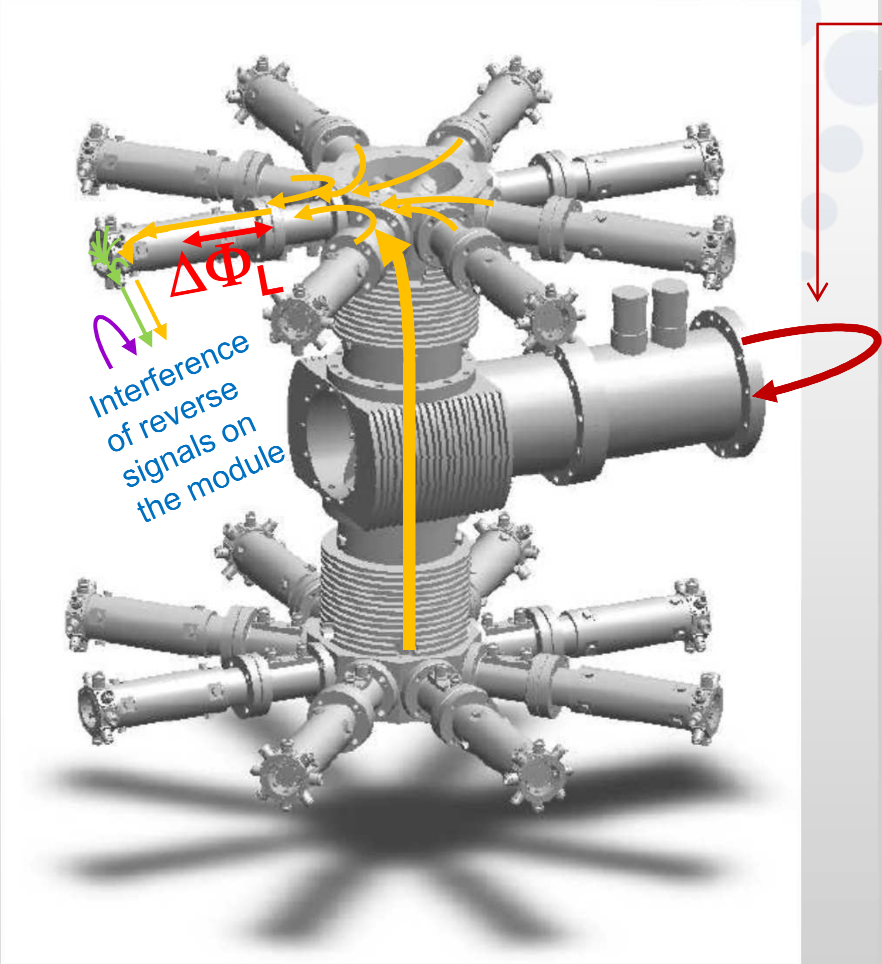
- Booster in pulsed operation → no overheating → OK !

Solutions for batch 2 for the storage ring:

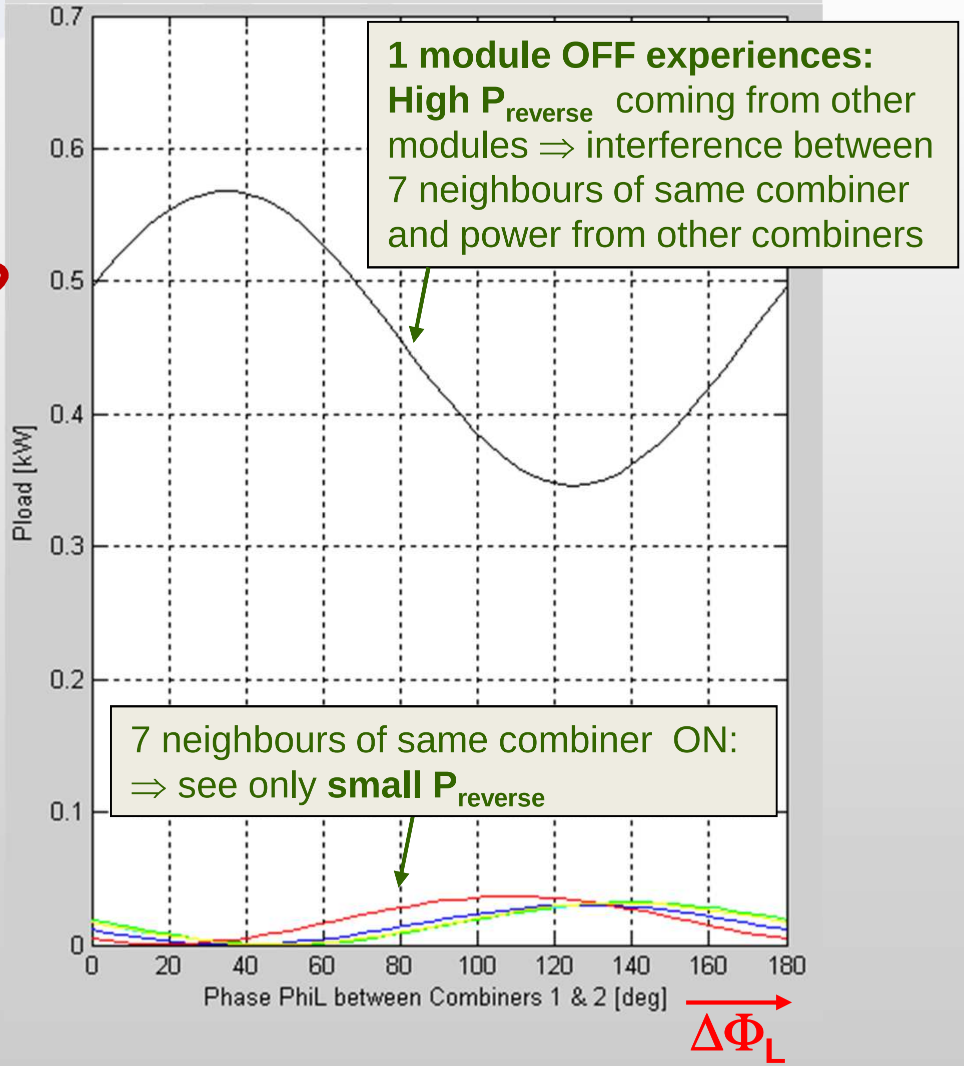
1. 150 kW power circulator and load at SSA output	not retained by ELTA
2. Replace 800 W loads by 1200 W loads (also for booster spares)	implemented on batch 2
3. Optimum phase between 1st (6kW) and 2nd (50 kW) combiners	implemented on batch 2
4. Additional interlock: $P_{reverse}$ < 3.5 kW at output of 1st x8-combiner	implemented on batch 2
5. Flame retardant RF cables between RF modules and 1st combiner	implemented on batch 2

⇒ Delivery of batch 2 delayed by 1 to 1.5 years

Adjustment of phase between 1st and 2nd 8x-Combiner stages



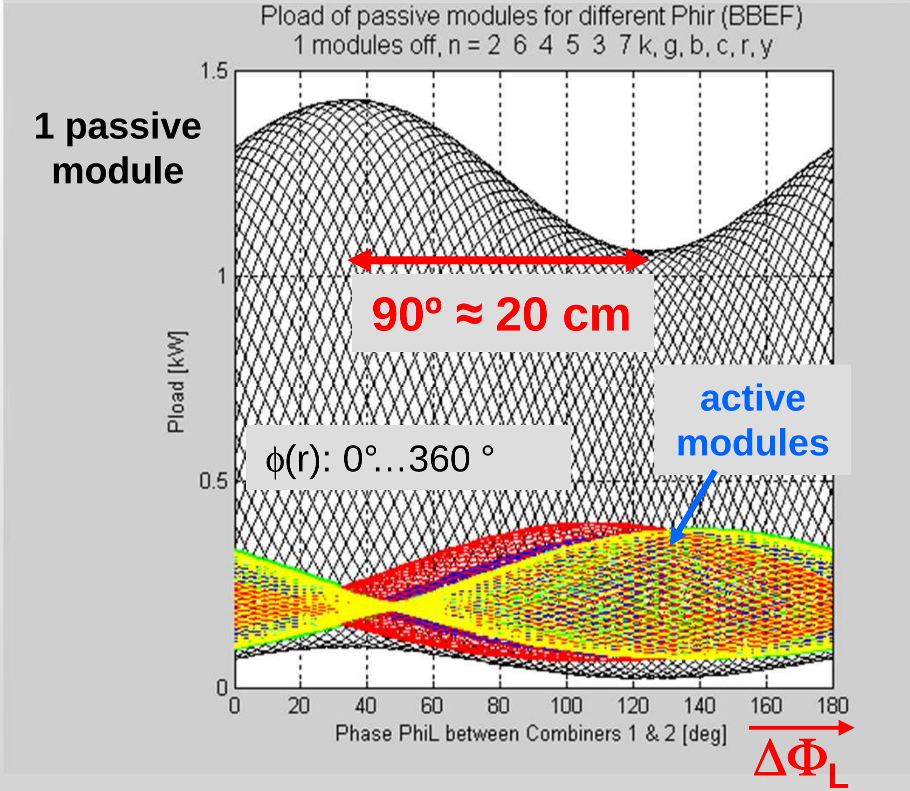
SSA matched: r = 0

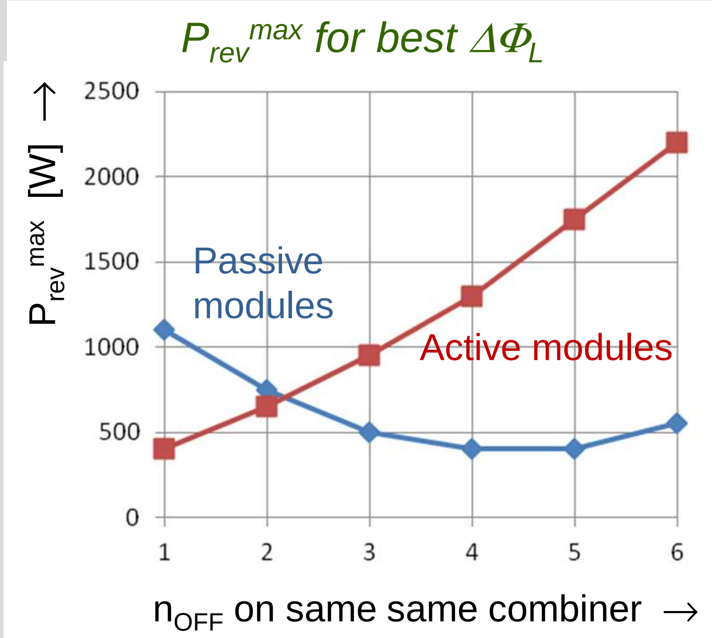


☞ $\Delta\Phi_L$: proposed by SOLEIL

Adjustment of phase between 1st and 2nd 8x-Combiner stages

Additional interference with reflection for mismatched operation: $|r| = 1/\sqrt{3}$ *(ESRF spec)*

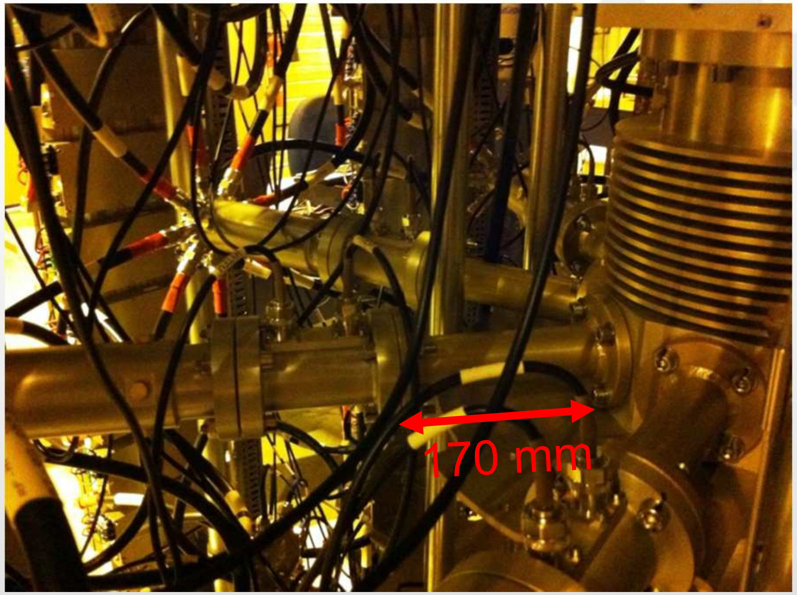


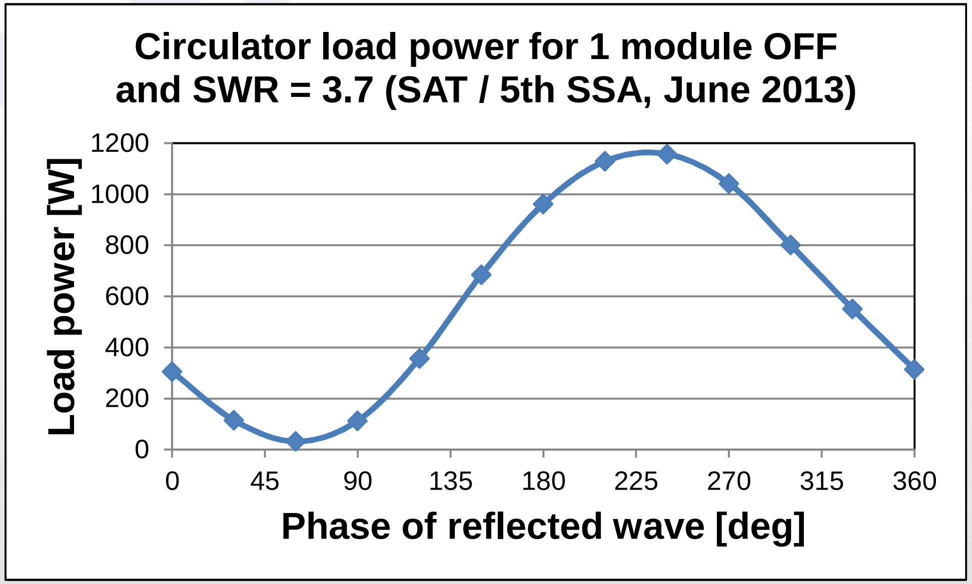


☞ Not more than 3 modules OFF on the same combiner !

- 1 module OFF: depending on $\Delta\Phi_L$ the circulator load receives
  - P_{rev}^{max} = 1400 W for worst $\Delta\Phi_L$
  - P_{rev}^{max} = 1100 W for best $\Delta\Phi_L$
- Active modules receive the remaining power: maximum of 400 W for best $\Delta\Phi_L$

Successful test of 1st improved SSA of batch 2





- **Efficiency still well above spec:**

  η ≈ 58 % at 150 kW

  η ≈ 48 % at 100 kW

- **P_{refl} / P_{fwd} = 50 kW / 150 kW:**
  - Acceptable limitation to 145 kW by overdrive for some load phases
  - Successful test with 1 and 6 modules OFF -> no damage on circulator loads !

- **Full reflection:**

  Specified P_{refl} / P_{fwd} = 80 kW / 80 kW not reached due to 3 kW interlock on 6 kW combiner arms

  ⇒Instead P_{refl} / P_{fwd} = 60 kW / 60 kW successfully tested and accepted, as being operationally sufficient

- **Drawback:** more heating of prolonged 1-5/8" lines in mismatched conditions → to be followed up

SR – Cell 23: HOM damped cavity + 150 kW SSA

- Commissioning just started
- Modulation of the 280 V DC voltage at 600 Hz: under investigation with ESRF PS-Group
- Difficulty to perform cavity conditioning with 20 μs pulses:
  - Undershoot of 280 V DC supply
  - Strong transient reflections from high Q cavity
  - No circulator → Interlock protection at 50 kW reflection


Thank you !!