Recent Upgrades of the Soleil RF Systems & Contributions to Other Projects

ESLS-RF 2018

SOLEIL, 8-9 November 2018

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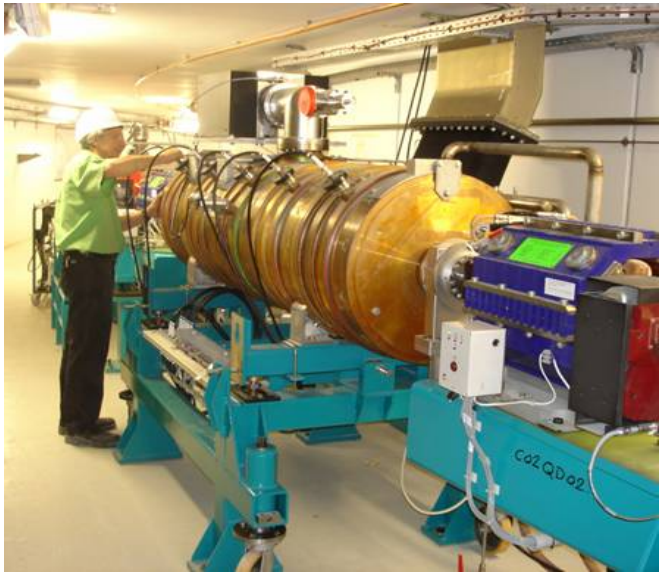
On Behalf of the RF & LINAC Group

ORIGINAL BOOSTER RF SYSTEM

- E_n : 100 MeV → 2.75 GeV (rep. 3 Hz) ; V_{RF} : 0.2 → 1 MV @ 352 MHz
- 1 x 5-cell Cu cavity (CERN LEP) → P_{tot} : 25 kW (P_{dis} : 20 kW, P_{beam} : 5 kW)
- 1 x solid state amplifier (SSA) → 35 kW CW @ 352 MHz (developed in house)



Cavity in the BO ring

BO RF room (amplifier with LLRF & control)

~ 75 000 running hours over 12 years and only 4 short downtimes in operation (< 10^{-4} overall)
of which a single *trip from the 35 kW SSA, due to a loose connection on a monitoring cable.*
~ 1 module failure / year, without impact on the operation, thanks to the modularity and redundancy.

RF Booster Upgrade

Booster RF system was originally designed for standard operation

And new low-*α* operating mode suffers from a low injection efficiency (15-20%) due to the long BO bunches

→ Heavy safety radiation constraints

→ Prevents more beam lines to join this operating mode

2nd RF station needed to increase V_{RF} from 1 MV up to 3 MV

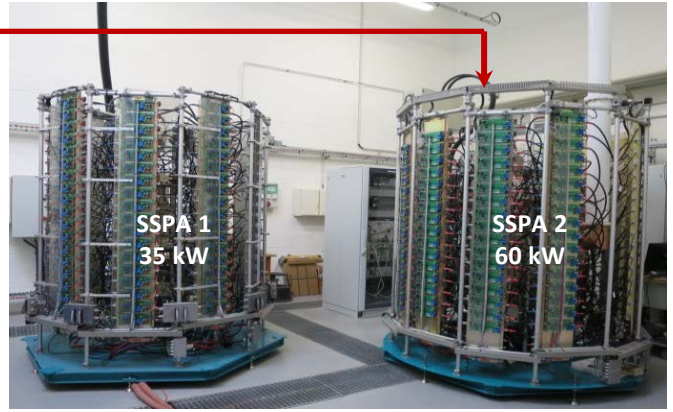
- Shorter bunch length → ***SR injection efficiency improved by a factor of ~ 2 in low-α operation***

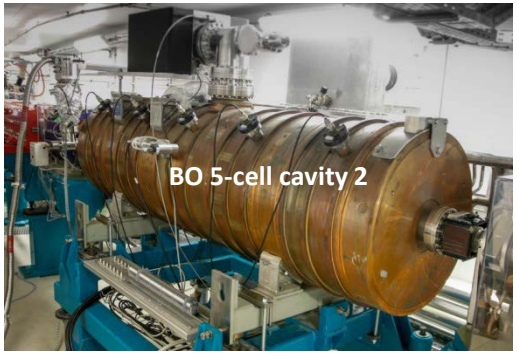
Upgrade plan :

- Former spare cavity installed in one straight section the Bo ring and powered with 60 kW (V_{RF} = 1.8 MV)
- New 60 kW - 352 MHz SSPA, identical to a standard tower of our SR amplifiers (10 dissipaters of 16 modules, built from 160 RF modules of 400 W with BLF574XR transistors and their dc-dc converters made available by the SR SSPA refurbishment)
- SSPA and its associated LLRF & control (replica of the actual one) inside the Bo RF room
- Increase V_{RF} of the existing plant from 1 MV up to 1.2 MV → P_{RF} ~ 30 kW (P_{beam} ~ 0)

RF Booster Upgrade Status

- ✓ **60 kW CW SSPA completed (LDMOS BLF574XR)**
  With modules got back from the SR SSA refurbishment
- ✓ CAV-2 pre-conditioned @ 1.8 MV in November 2017 in a dedicated test-stand powered with the new 60 kW SSPA
- ✓ New cavity and SSPA installed in winter 2017-2018
- ✓ Commissioning began in January 2018
- ✓ Standard operation (1 MV) with CAV-2 inst. of CAV-1 since Feb 2018
- ✓ CAV-2 conditioned @ 1.8 MV, P_{RF}= 60 kW CW in end-February 2018
- ✓ **V_{RF} = 2.8 MV (2 cav.) successfully tested in low-α mode in June 2018**
  SR injection efficiency improved by a factor of 1.8 (35%)
- ✓ Beamline Radio Safety validation completed in September 2018
- ✓ **'Upgraded' Low-*α* operating mode proposed to users since October 2018 with V_{RF} = 3 MV (SR injection efficiency = 35%)**





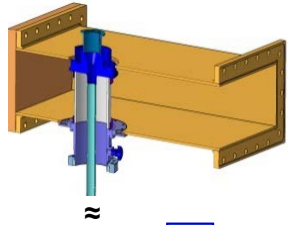
Additional benefits expected : power savings & redundancy in all the other operating modes

STORAGE RING RF SYSTEM

- **E_n = 2.75 GeV, ΔE = 1.2 MeV, I_b = 500 mA**
  → P_{RF} = 600 kW & V_{RF} : 3 - 4 MV @ 352 MHz
- 2 cryomodules (CM), each containing a pair of single-cell s.c. cavities (Nb/Cu)
- Each of the 4 cavities is powered with a 180 kW solid state amplifier SSA)
- Both CM's are supplied with LHe (4.2 K) from a single cryogenic plant

INPUT POWER COUPLER (IPC) UPGRADE

- **Original SOLEIL IPC is a LEP2 type antenna → 200 kW CW @ 352 MHz**
- **Problems of ceramic aging with LEP type IPC's at ESRF**
- ***300 kW / cav* → SOLEIL can store 500 mA using a single CM → redundancy**



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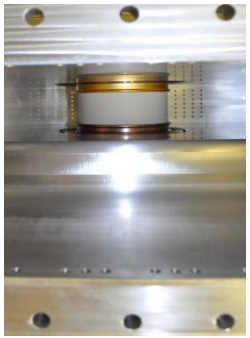
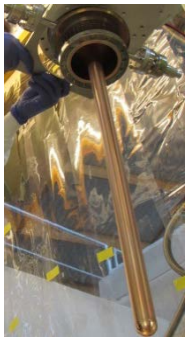
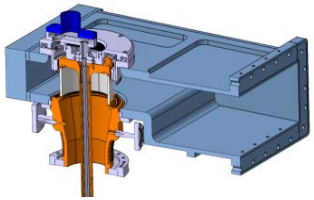
In 2011, collaboration agreement with CERN and ESRF → develop a new 352 MHz IPC version, based on the LHC design (400 MHz), capable of handling *up to 300 kW*.







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Six IPC's were built at CERN and then RF conditioned in the ESRF test-stand up to 300 kW in transmission and 200 kW in full reflection, using a copper cavity from CERN

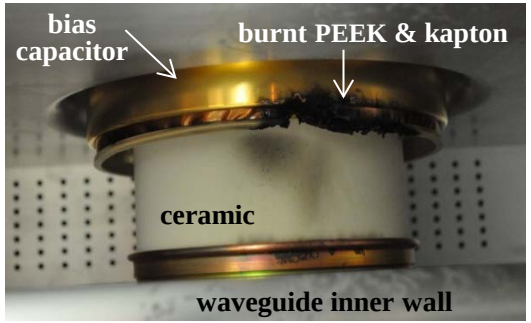
The IPC's were mounted on the CM's, *in situ*, without removing out of the ring, using a hood with laminar air flow, enclosed within a plastic tent and with slight N_2 gas overpressure inside the cavity

" Clean room " built on top of the CM !

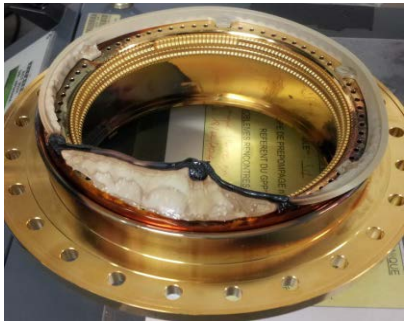
IPC UPGRADE

STATUS :

- High voltage DC bias capacitor implemented to overcome multipacting issues at P~110 kW
- Initial dimensional error → bias capacitor damage by overheating



During pre-condition tests at ESRF


During operation at SOLEIL

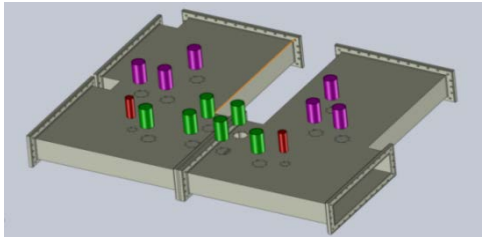
- Bias capacitor design corrected and re-implemented
- ***All 4 power couplers upgraded (200 kW → 300 kW)***
  Last one in January 2017
- All of them tested up to 270 kW CW with beam
- Overheating issues on IPC-4 about to be solved thanks to a new bias capacitor design in operation since end-October 2018

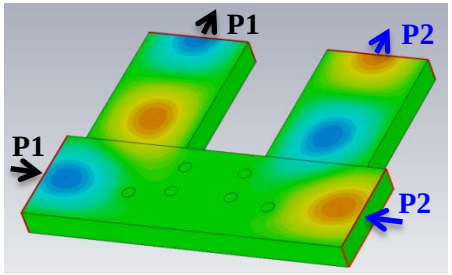
TOWARD STORING 500 MA USING A SINGLE CM

Modification of the waveguide network to combine the power from two amplifiers into one cavity

→ *Possibility of storing the full beam current using a single CM*

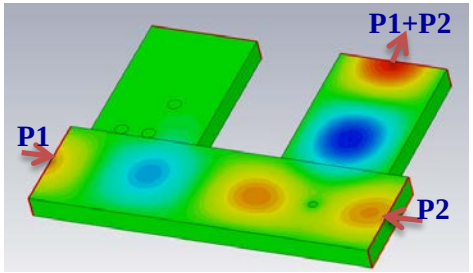
→ « **Magic Switch** »

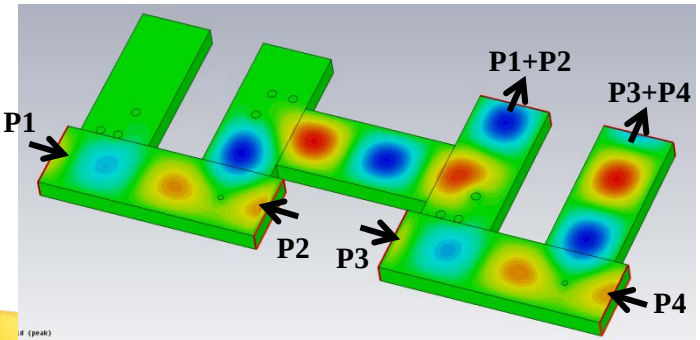




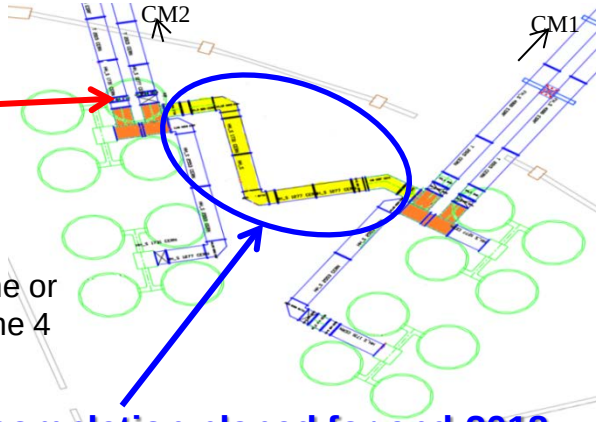
OR

depending on the post configuration





Connecting 2 Magic Switches



Waveguide network layout to power one or the other CM with 300 kW / cav from the 4 SSPA's, combined by pairs

➢ **The 2 Magic Switches implemented and waveguide distribution completion planed for end-2018**

180 kW SSPA's Refurbishement

Since 2013, on going refurbishment

- **LR301 replacement by 6th generation BLF574XR** (V_d = 50V instead of 30V *with better performances*)
  - More robust transistor and lower thermal stress → longer lifetime → less maintenance
    → failure of a single « new » transistor (~ 5 years of operation)
  - +7 dB transistor gain → 160 modules & their dc PS are got back for the new BO SSA
  - P_{mod} increased : 315 W → 450 W
  - Electrical power savings (efficiency : 50 % → 60%) compensate the investment cost in < 3 years
- **Modification of the 2.5 kW combiners** (welded → screwed connections) to increase their power capability
- 9 towers already refurbished (~ 2000 modules) → rate of 5 towers a year until 2020 with SOLEIL and external resources

Storage Ring RF upgrade Status

Present : Now we can store **450 mA with 3 running SSPA's or 500 mA with 3 running cavities**

In 2020 (end of refurbishment) : Possibility to store 500 mA with 3 running SSPA's / cavities or 450 mA with a single cryomodule, combining 2 SSPA's per cavity

CONTRIBUTIONS TO OTHER PROJECTS

500 MHz SSPA for ThomX(1) & SESAME(2)

(1) *ThomX : Compton X-ray source under construction in Orsay, France*
(2) *SESAME : Jordan Synchrotron light source*

ThomX 50 kW SSPA
(6 x 16 RF modules + 3 x 15 PS)

- Fully modular 50V power supplies
  230 V_{ac} / 50 V_{dc} converters, in 2 kW units, 96% efficiency, with voltage remote control for efficiency optimization
- Change from the tower to cabinet assembly, better suited with the new power supplies.
- Control upgrade → stand-alone, self-protected and more modular (1 µcontroler per dissipater)

SESAME 80 kW SSPA
(10 x 16 RF modules + 5 x 16 PS)

- ✓ For SESAME SR : 4 x 80 kW SSPA → 1st one built by SOLEIL as a demonstrator
  → 3 others on the same model by SigmaPhi Electronics (SPE), SOLEIL licensee since 2014
  Status : all in operation (first pair since end 2016 and 2nd one since May 2017)
- ✓ The ThomX 50 kW SSPA is also completed ; it shall be soon installed and commissioned on site

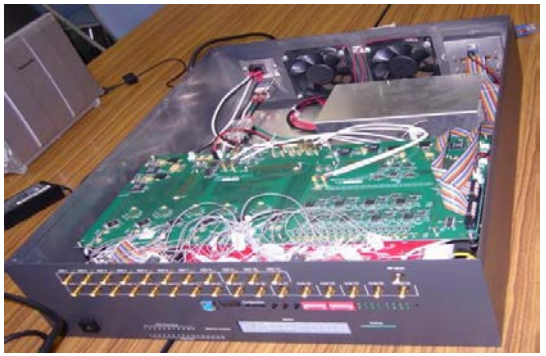
ADDITIONAL RF CONTRIBUTION TO THOMX

500 MHz SR RF system (cavity, LLRF, TFB)

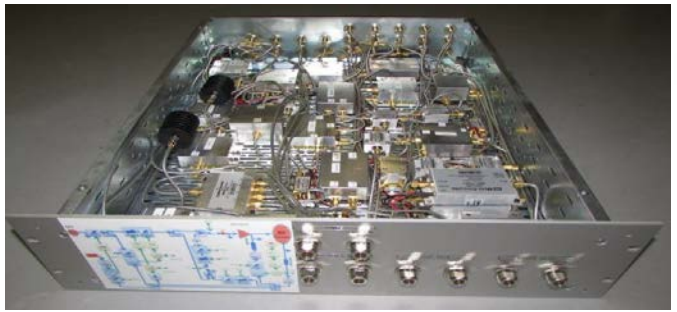
ThomX ELETTRA type cavity

Cooling rack for HOM temperature tuning

FPGA - based TFB acting on a 4 plates stripline (x, y)



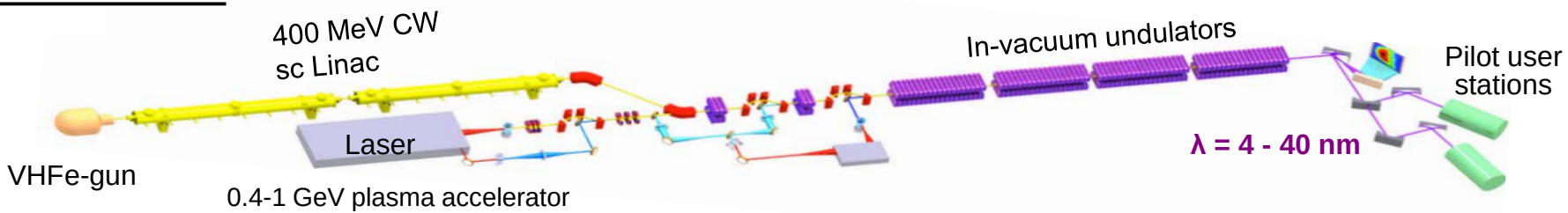
LLRF: conventional « slow » phase, amplitude and tuning loops + LFB = fast bunch phase feedback acting through the main cavity



- Installation & commissioning → 2018 – 2019

LUCRECE/LUNEX5 PROJECT

LUNEX5 Context



Phase 1 : based on a 400 MeV CW sc Linac → explore advanced FEL techniques and applications
Phase 2 : additional laser wakefield (or plasma) accelerator will be assessed in view of FEL applications

- **Collaboration between SOLEIL and CEA-SACM for the 400 MeV conventional LINAC (phase 1)**
  - *2 x 200 MeV E-XFEL cryomodules of 12 m upgraded for CW operation*
  - *One RF power amplifier for each cavity → 16 x 16 kW @ 1.3 GHz (not the most economical but the best way for achieving the required cavity field stability)*
  - *LLRF system (0.01° in phase and 10^{-4} in amplitude) with its associated synchronization part*

- **R&D on a VHF (176 MHz) photocathode e-gun for LUNEX5 → 2 x 60 kW SSPA's**
  To be launched soon

LUCRECE PROJECT

OBJECTIVE : First step in the RF R&D for **LUNEX5** project, LUCRECE aims at developping a **complete RF elementary cell (cavity, power source, LLRF and control) adapted to CW operation** to be used for ERLs or fs multi-user FEL at high repetition rate

DETAILS (2016-2021) :

- A 1.3 GHz - 20 kW CW SSPA, using GaN transistors *[SOLEIL, SPE]*
- A 1.3 GHz CW TESLA-shaped cavity *[CEA, SOLEIL]*
- A 20 kW CW input power coupler *[CNRS-LAL, THALES, SOLEIL]*
- A digital LLRF system (10^{-4}, 0.01°), based on FPGA + CPLD + µC *[SOLEIL, CNRS-LAL]*
- Cryomodule mechanical studies *[CEA, ALSYOM, SOLEIL]*

→ Integrated tests at 2 K and 1.8 K in horizontal cryostat CryHoLab at CEA

Status :

- **Cavity about to be ordered**
- **400 W GaN SSA module shall be completed at end-2018**
- **20 kW FPC fabrication kick-off in 1st quarter 2019**
- **LLRF components qualified → R. Sreedharan's talk**

RF timetable :

- *2019 : Preliminary RF system design → **P. Marchand's talk***
- ***2020 : CDR for DLSR** (Phase 1)*
- *2020-2022 : Main RF system design finalization*
- ***2022 : TDR***
- *2022-2025 : Equipment procurement and machine reconstruction*
- ***2026 : Restart of user operation***

❖ *In a second step : **VSR** (Phase 2)?*

SUMMARY & CONCLUSIONS

- **RF Booster upgrade**
  2nd RF station implemented (5-cell Cu cavity + 60 kW SSPA) → V_{RF} increased from 1 MV to 3 MV
  - *SR injection efficiency improved in low-α operating mode from 19% to 35%*

- **RF Storage Ring upgrade**
  - IPC : 200 kW → 300 kW
  - Waveguide network modification (power combination through Magic Switch)
  - 180 kW SSPA refurbishment (LR301 → BLF574XR transistor + 2.5 kW combiner modification)

  Additional redundancy → Store full I_{beam} with a single CM or 2 CMs with only 3 running amplifiers/cavities

- **500 MHz SSPA for ThomX (50 kW) and SESAME (4 x 80 kW)**
  New SOLEIL homemade design that has benefited from upgrades developed after years of operation

  And for ThomX : Elettra type cavity refurbishment + LLRF and feedbacks (LFB + TFB)

- **1.3 GHz CW RF station for LUCRECE**
  20 kW SSPA (GaN transistors) + CW TESLA-shaped sc cavity + 20 kW IPC + LLRF

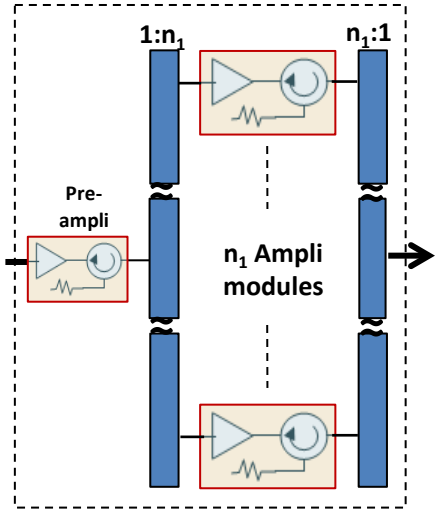
- **SOLEIL Upgrade towards DLSR**
  Preliminary RF design for CDR in 2020


THANK YOU FOR
YOUR ATTENTION
SOLEIL
SYNCHROTRON

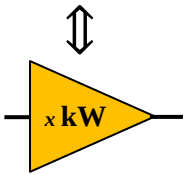
BACKUP SLIDES

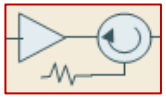
SSPA PRINCIPLE

Combining in // a number of elementary amplifier modules (or pallets) of a few 100 W (up to ~ 1 kW)

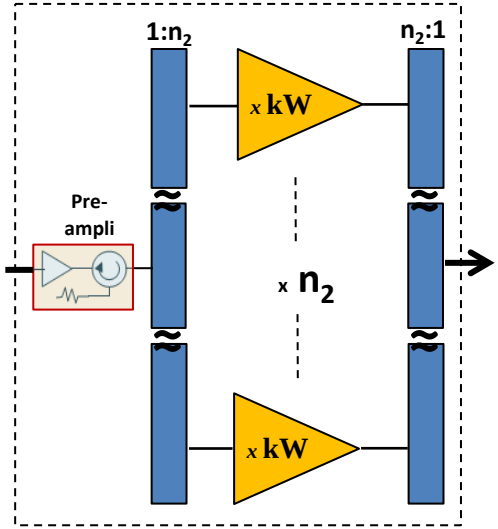


Few kW unit

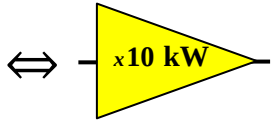




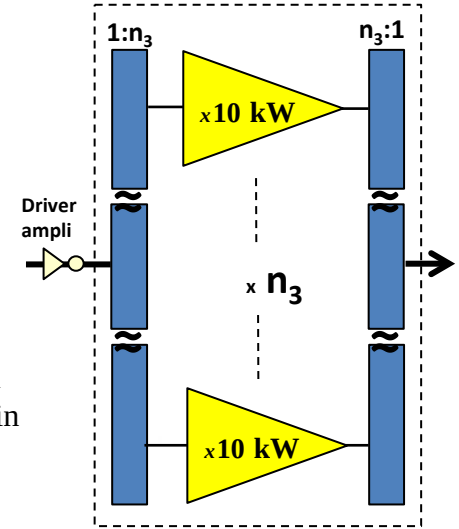
- MOSFET (V_d = 30 - 50 V) → **No HV & Low phase ripple**
- Circulator & its load to ensure a good isolation (even a small residual VSWR can affect the MOSFET power capability !!)



Few 10 kW unit



The number of pre-ampli depends on the module gain



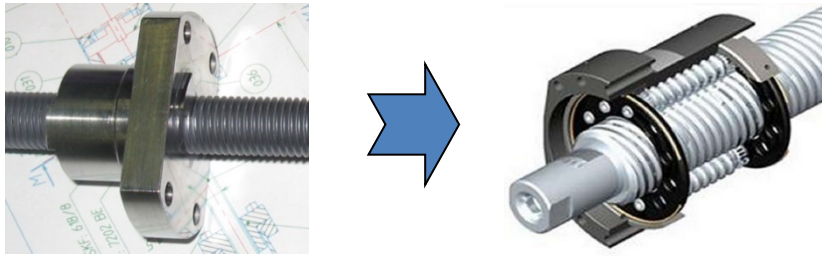
Few 100 kW unit

→ **Modularity & Redundancy inherent to such a design**

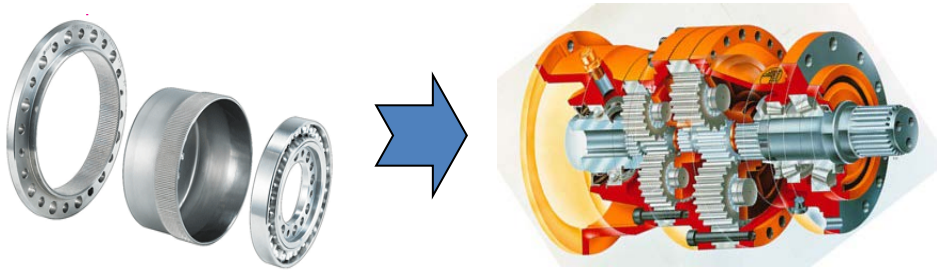
TUNER UPGRADE

New version

1) Standard screw-nut assembly replaced by « planetary roller » screw



2) « Harmonic drive » gear box replaced by « planetary » gear box



The four tuners have worked without any trouble for ~ 7 years. In 2016, we detected a change in behavior on one of them ; when dismounting, we found that the cage of its screw was broken.

- **Replaced by a roller screw without prestressing (no surface treatment)**

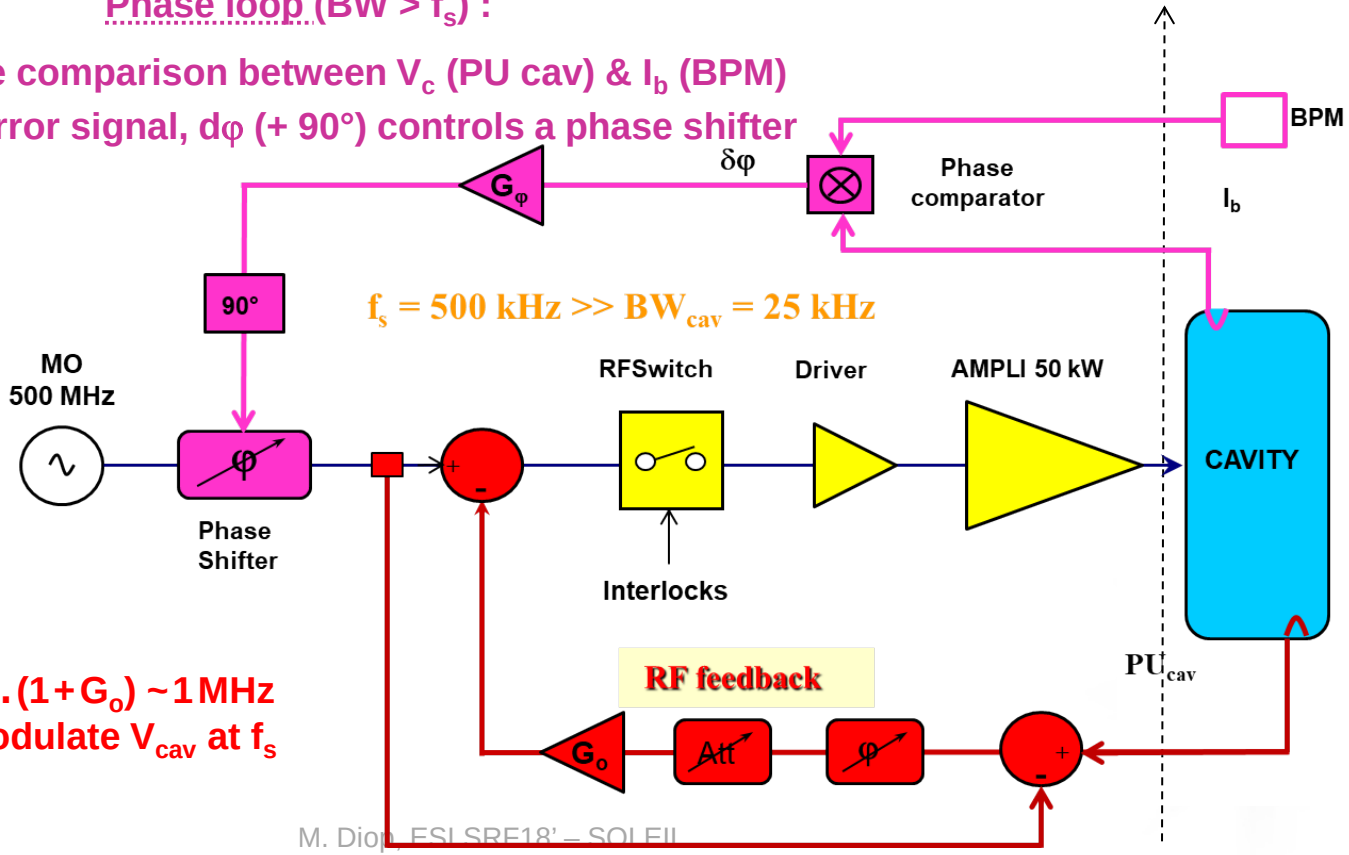
The 3 other ones are still working well and no visible wear → preventive replacement planed

THOMX LONGITUDINAL FEEDBACK

LFB = direct RF FB + Phase loop

Phase loop (BW > f_s) :

- Phase comparison between V_c (PU cav) & I_b (BPM)
- The error signal, dφ (+ 90°) controls a phase shifter



RF FB → $BW_{cav}.(1+G_o) \sim 1$ MHz
→ One can modulate V_{cav} at f_s