



Commissioning status of the RFQ Solid-State Amplifier

Task 2.2

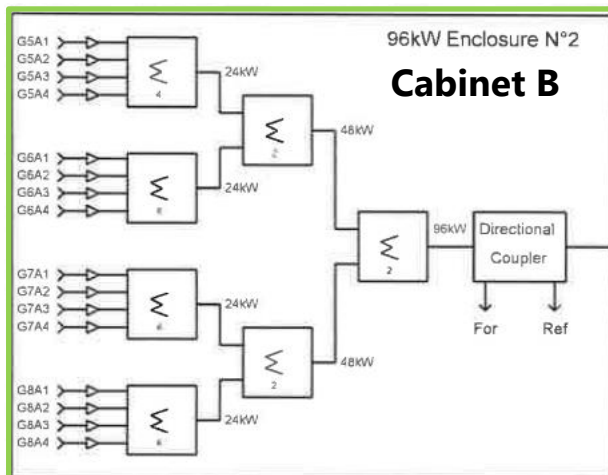
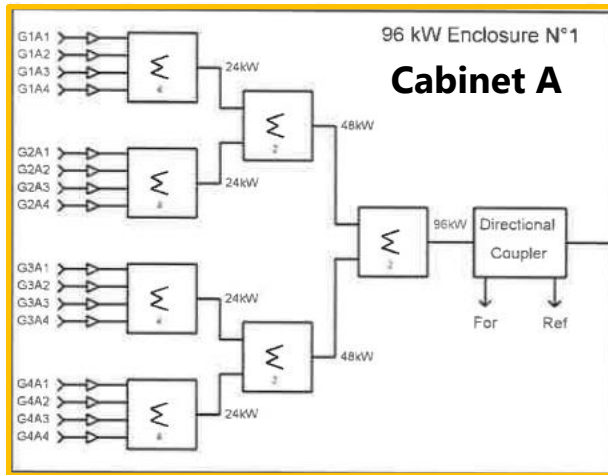
7th WP2 MYRTE meeting, CERN, October 22nd, 2018

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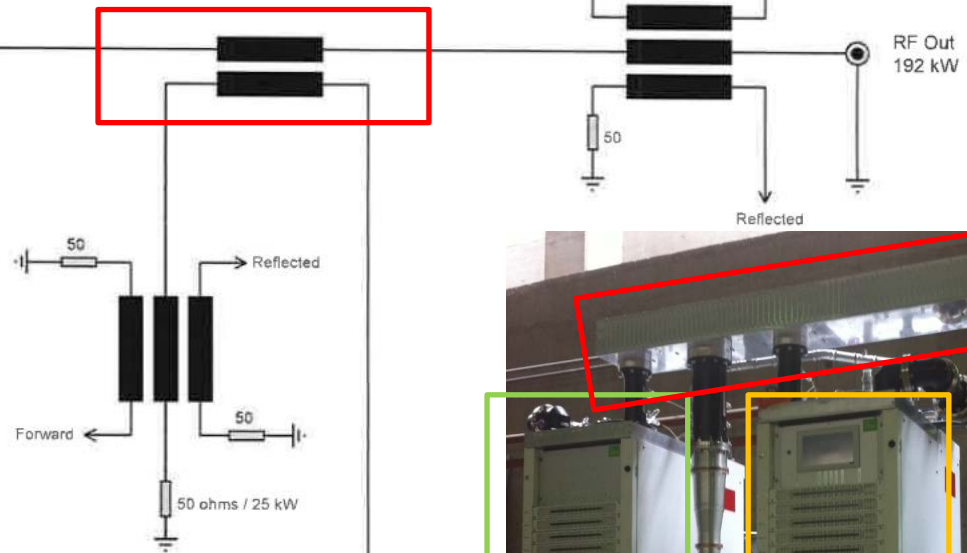
Outline

- RFQ SSA structure
- Overview of last status (04/2018, Lubjana)
- SSA integration @ UCL/CRC
- First commissioning – Main results
- Remaining commissioning steps
- Conclusions & planning

RFQ SSA structure



External combiner



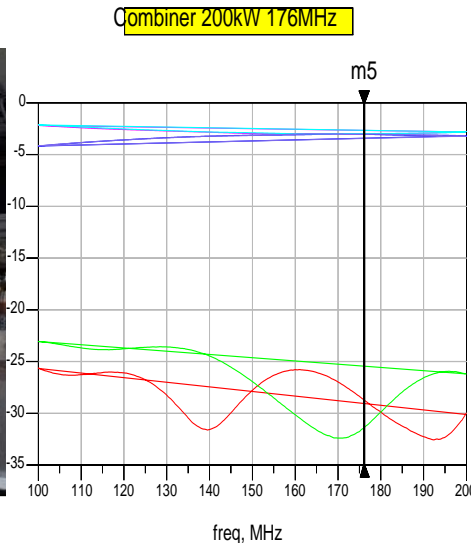
Overview of last status (04/2018, Lubjana)

- Manufacturing was completed
 - 210 x 1 kW pallets
 - 35 x 6 kW modules
 - 2 x cabinets with integrated combining structures



Overview of last status (04/2018, Lubjana)

- Each 96 kW cabinets tested separately at full power at IBA site
 - Full power easily and quickly reached
 - First characterization (gain, phase, efficiency, pulse...)
 - Minor EMC issues – solved by shielding improvements
- External combiner assembled and tested at low level
 - Very good match with calculations



m5
freq=176.1MHz
dB(S(1,2))=-28.714
dB(S(1,3))=-3.031
dB(S(1,4))=-3.002
dB(S(2,3))=-2.974
dB(S(2,4))=-3.022
dB(S(3,4))=-31.397



- Delivery foreseen: 30th April 2018

SSA integration @ UCL

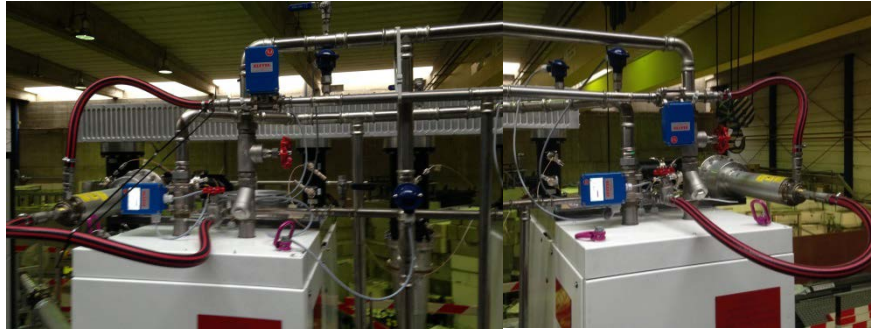
- Delivery at UCL on 9th of May:
(safely packed even for less than
1 km distance 😊)



- Re-assembling of the two cabinets
(32 x 6 kW modules and 18 power supplies)
- Assembling of the external combiner with
the two cabinets + 125 kW dummy load

SSA integration @ UCL

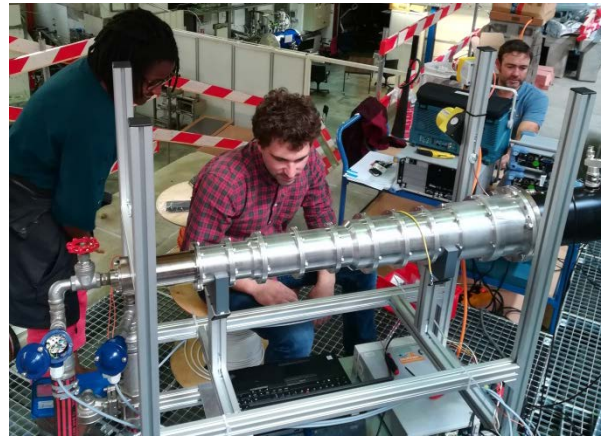
Water cooling systems integration (PT100, flow meters & flow switches, all wired and monitored into the SSA PLC)



Electrical switchboard wiring:



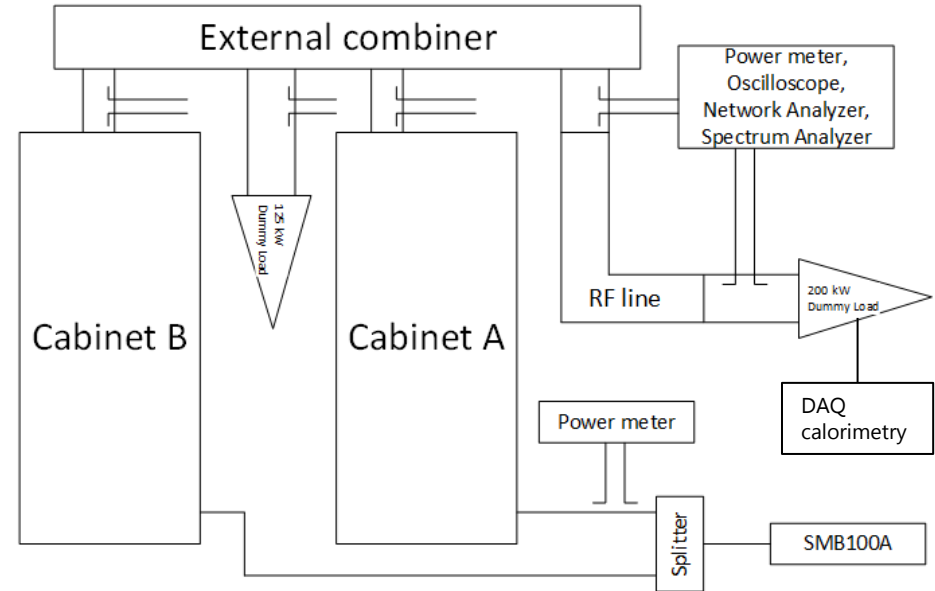
6 1/8" Tx line preparation and assembling:



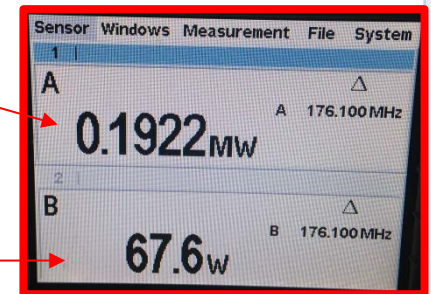
200 kW dummy load integration (PT100 & flow meter wired to temporary DAQ system for calorimetric measurement)

First commissioning - Setup

- Full characterization of the SSA on matched load (50 ohm)
 - All directional couplers, attenuators and RF cables carefully calibrated

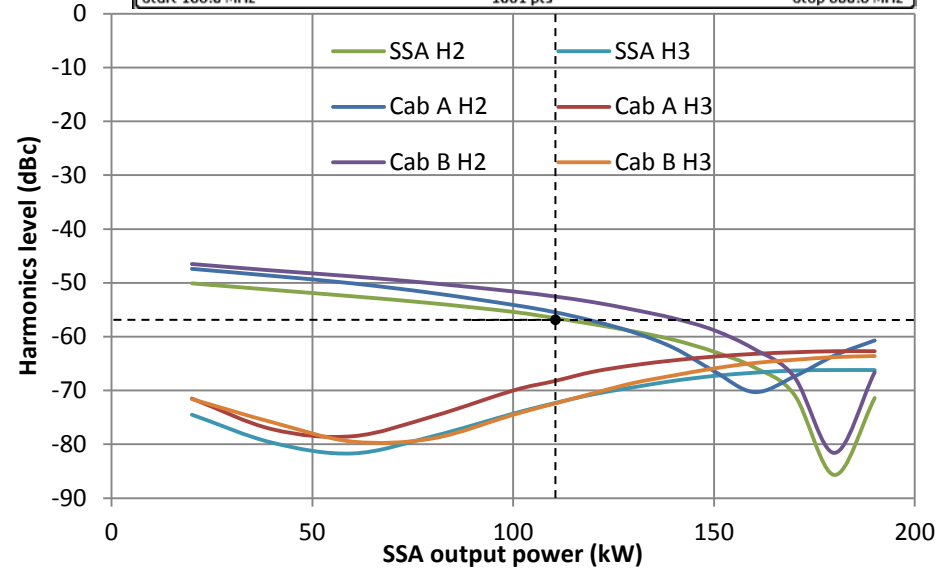
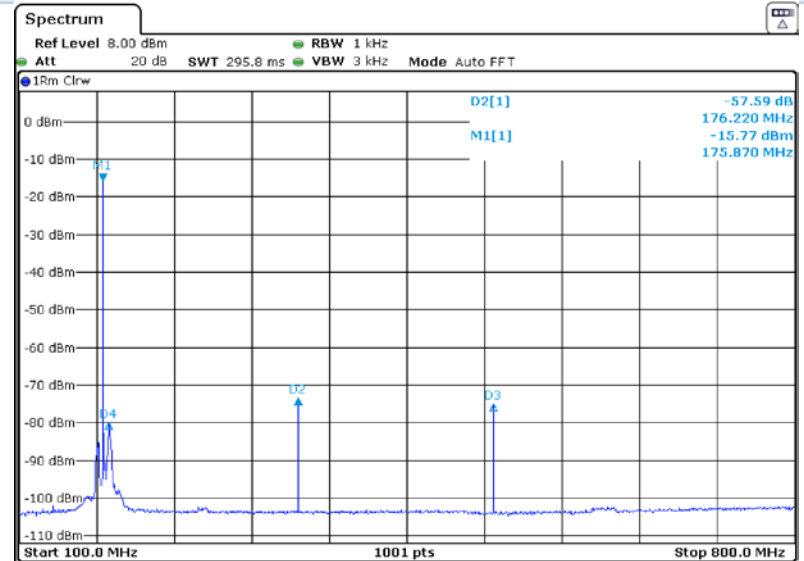
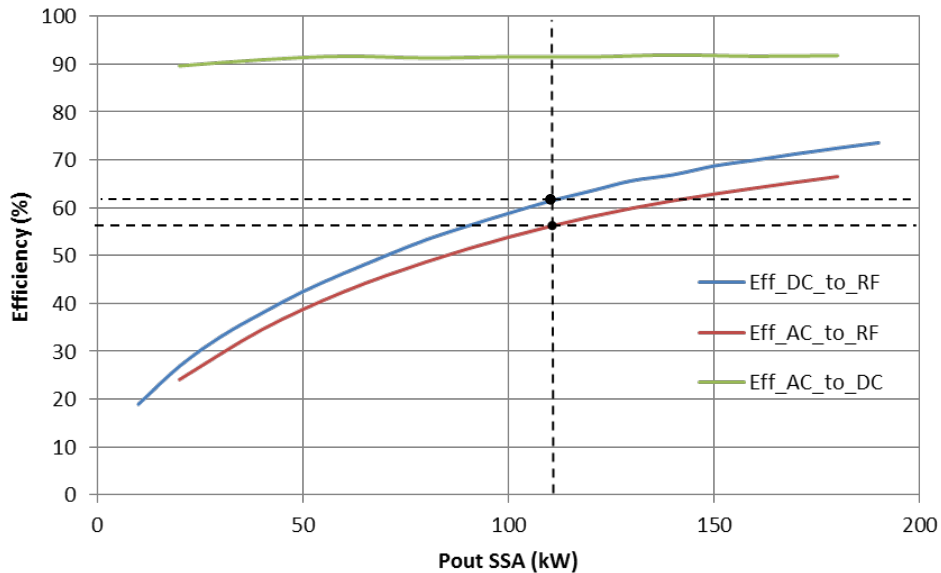


- On the 7th of September, during the first days of RF power tests, **the design RF power output could be reached!!!**
- Input phases of the external combiner optimized ($\sim 90^\circ$)
 - Minimized losses into the 125 kW dummy load (isolation > 33 dB)



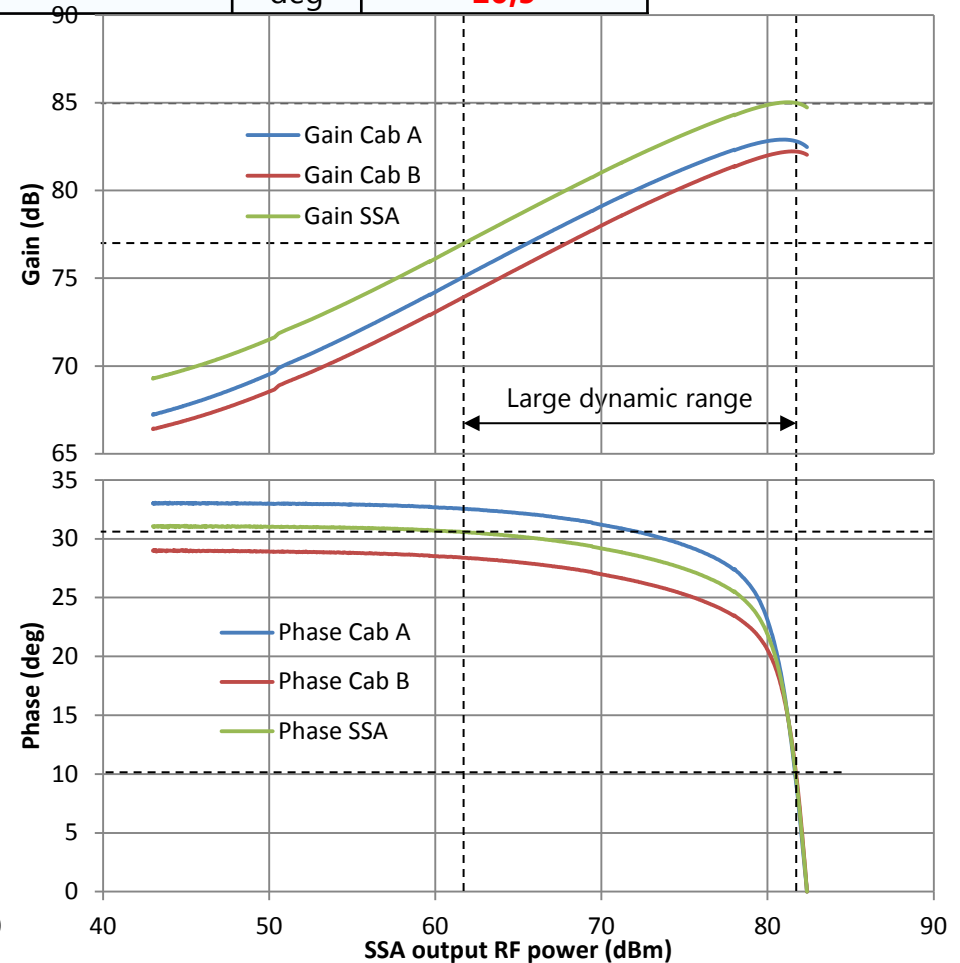
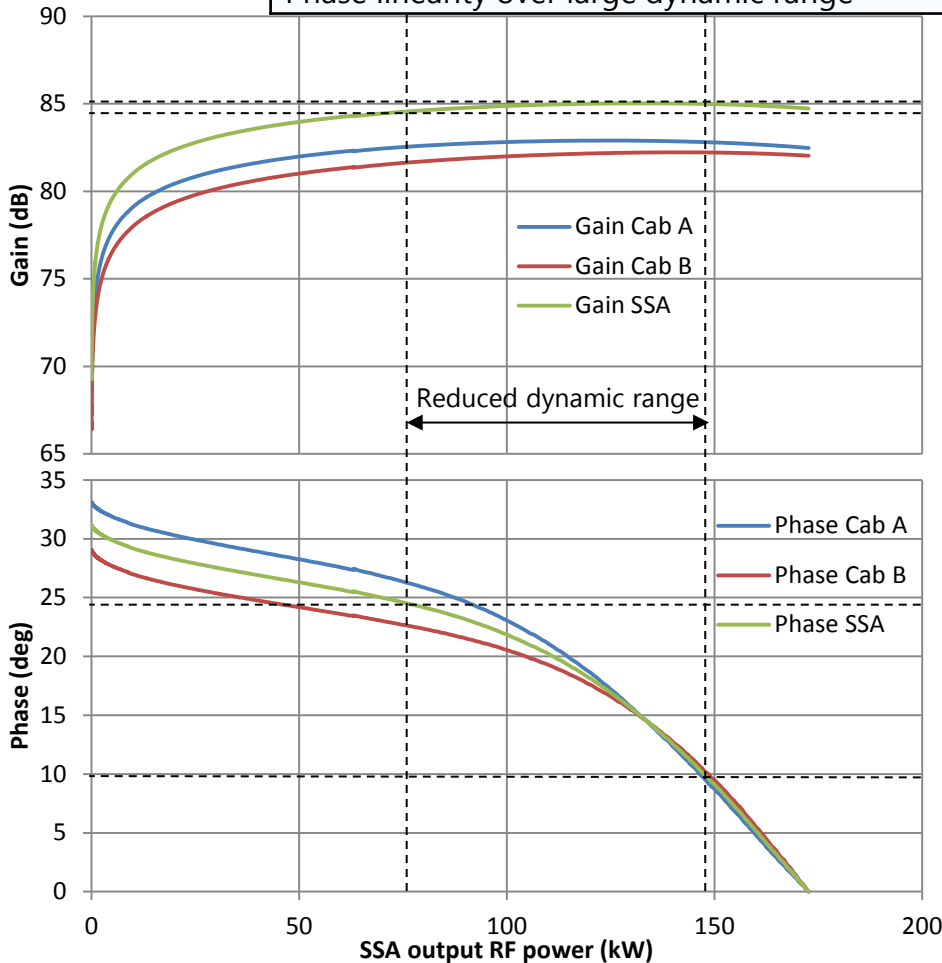
First commissioning – Main results – Efficiency/Harmonics

- DC to RF efficiency @ 190 kW = **73,6 %**
- AC to RF efficiency @ 180 kW = **66,5 %**
- AC to DC efficiency > 90%
- @ 111 kW (operating level):
 - DC to RF efficiency ~ **61,5 %**
 - AC to RF efficiency ~ **56 %**
 - Can be improved by VDD adjustment (+3 to 4 %)
- Harmonics level < **-55 dBc** around operating level



First commissioning – Main results – Gain/Phase linearity

Large dynamic range (up to required level: 147 kW)	dB	> 20
Gain linearity over large dynamic range	dB	8
Phase linearity over large dynamic range	deg	20,5

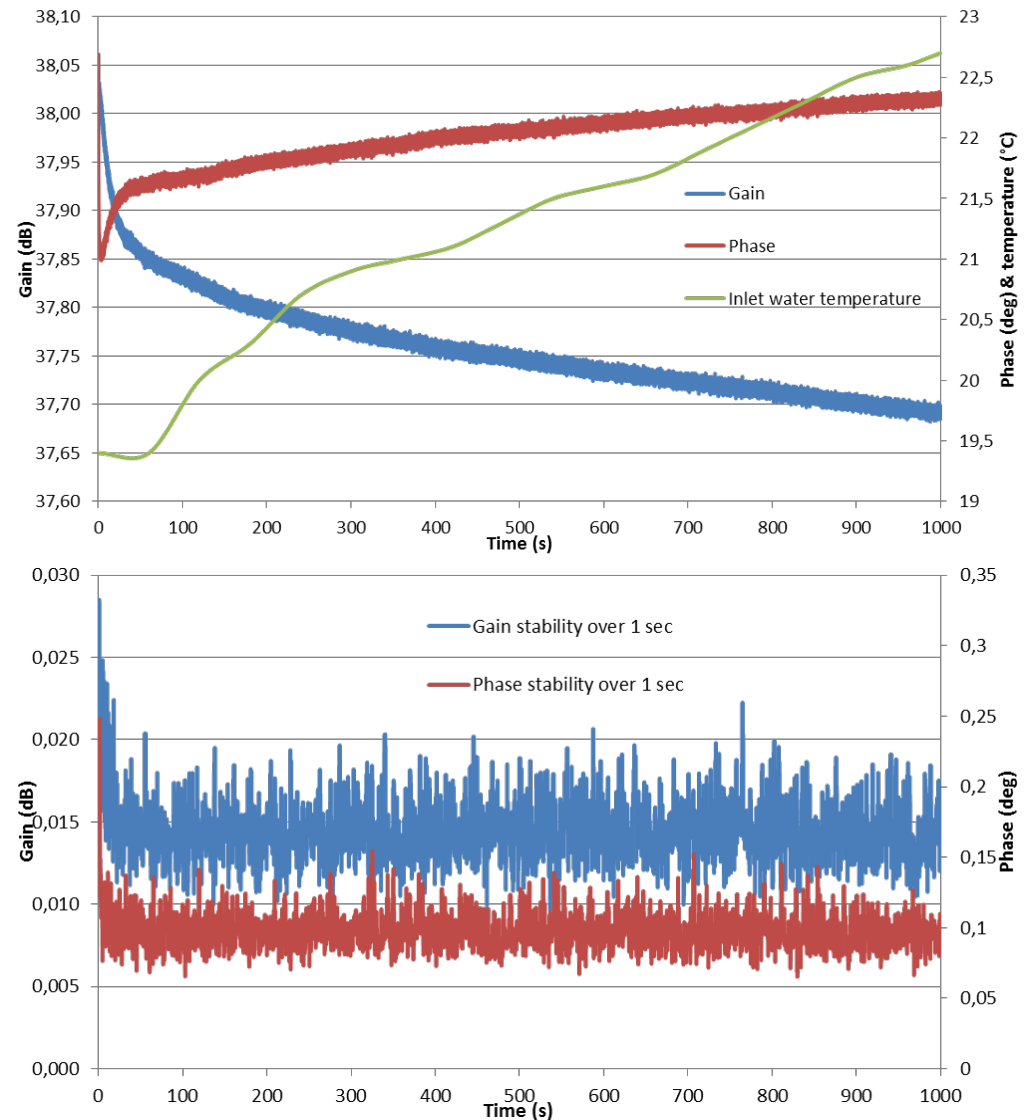


Reduced dynamic range (around operation level: 111 kW)	dB (%)	+/- 1.22 (+/- 32,5)
Gain linearity over reduced dynamic range	dB	0,46
Phase linearity over reduced dynamic range	deg	14,5

First commissioning – Main results – Gain/Phase stability

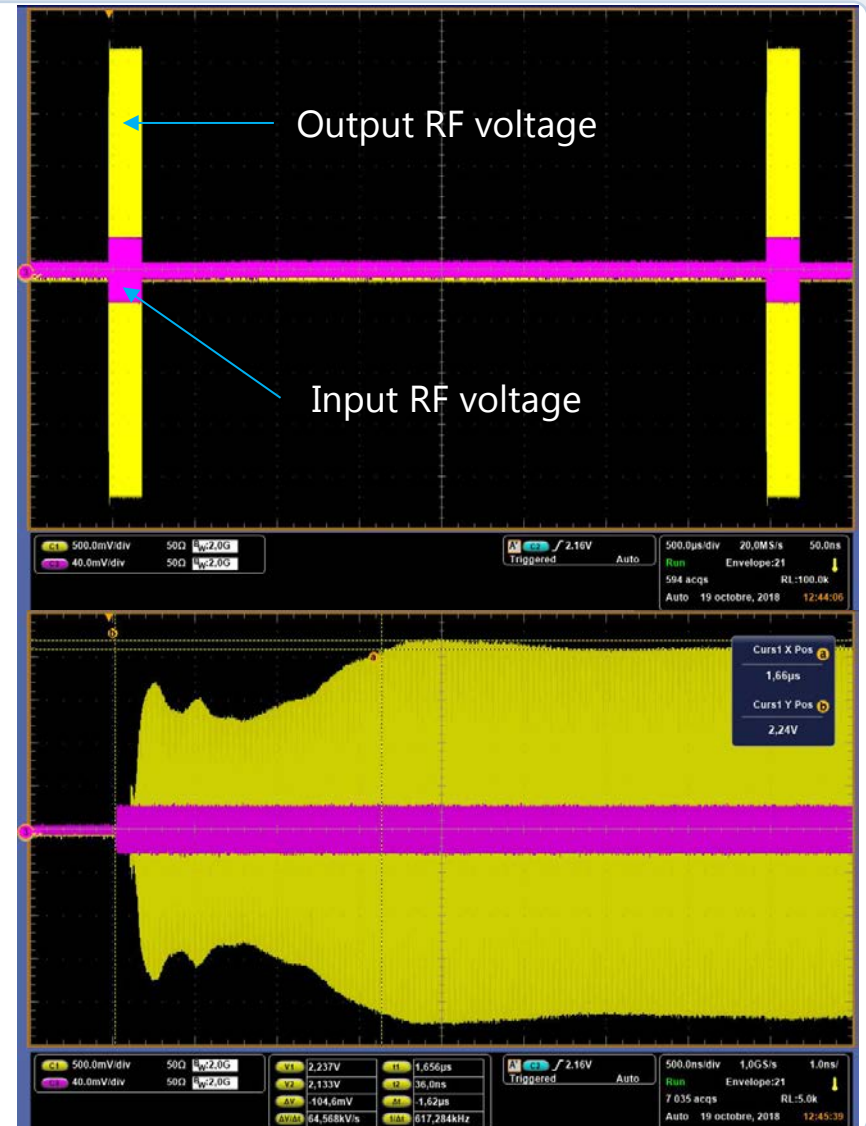
Gain & phase stability @ 120 kW

- Fast variation during the first seconds (SSA warming up)
- No stabilization because of non-stable inlet water temperature!
- Expected to reach stabilization in winter...
- Nevertheless, **gain and phase stabilities are very good!**
- Gain stability over 1 sec **< 0,02 dB**
- Phase stability over 1 sec **< 0,15°**



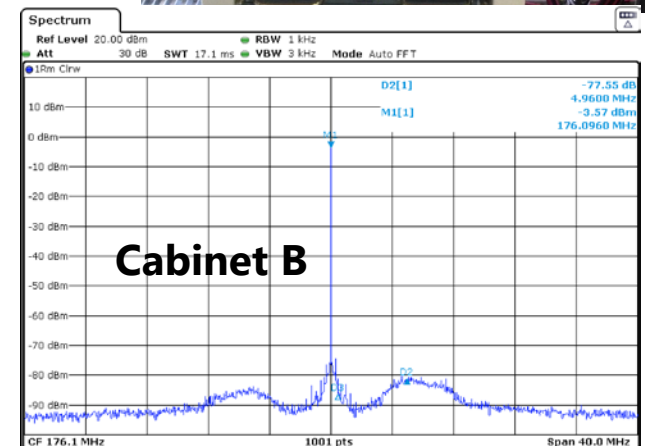
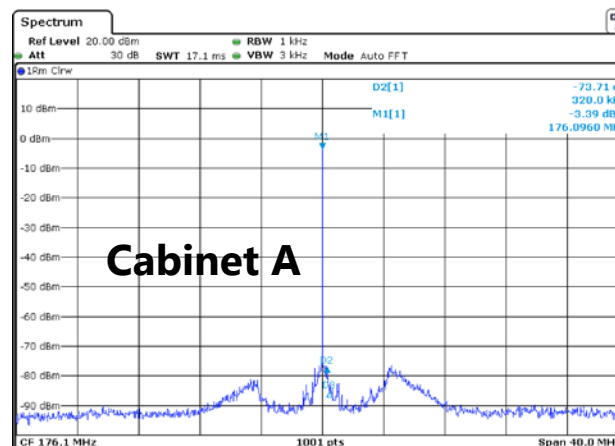
First commissioning – Main results – Pulse operation

- For the example:
 - Pulse duration: 200 μs
 - Repetition rate: 250 Hz
 - RF power: **150 kW**
 - Rise time \sim **1,6 μs**
 - Overshoot \sim **5 %**
- **Transient shape** due to voltage ringing on transistor supply (low decoupling capacitor for low energy storage)



First commissioning – Fuse issue

- **Repetitive failure** during the last weeks:
 - Fuse failure on the DC supply of the 1kW pallet driver
 - Several days in total of repair!
- **Up to 49 fuses simultaneously burnt!** ☹️
- Always occurring in cabinet B...
- Diagnostic: **EMC issue between RF cable and a noisy CAN bus**
- After reducing the coupling with CAN bus noise, the output noise level has been reduced by 20 dB and is similar to cabinet A.
- No more failure, but to be confirmed... 😊



Remaining commissioning steps

● On matched load

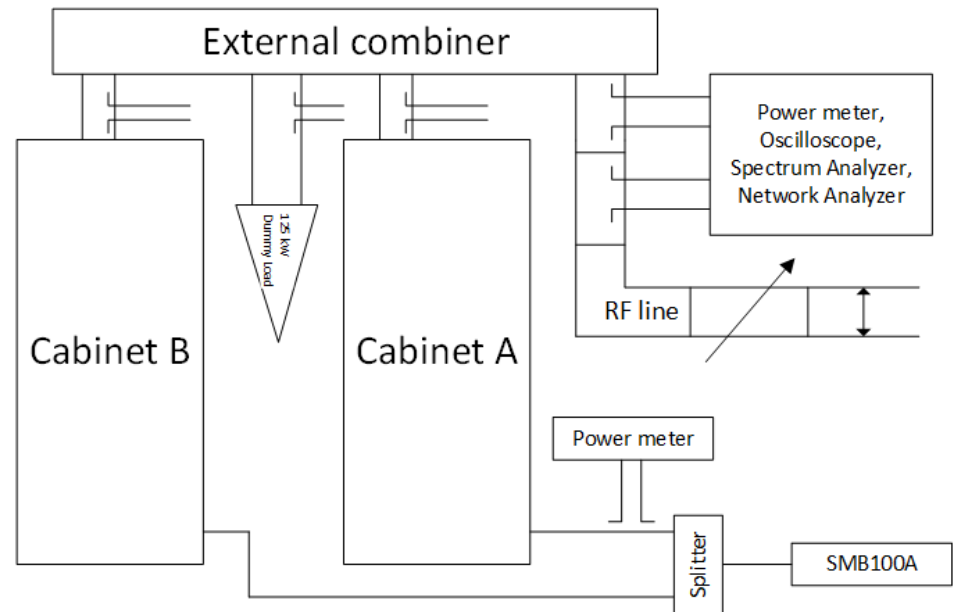
- Few measurements (stability with constant input water cooling, noise factor, efficiency optimization...)
- EMC measurements w.r.t. standards
- Run tests (duration to be defined)

● On mismatched load

- With $\lambda/4$ transformer and variable length
- VSWR of 2, 3 and 5 any phase (45° steps)
- Power capability characterization

● At full reflection

- Short-circuit between inner and outer conductors
- Extreme high VSWR (limited by losses in the lines), any phase (45° steps)
- Power capability characterization



Conclusion & planning

● RFQ SSA commissioning

- A successful integration (mechanical, electrical, cooling, Tx line)
- Commissioning on matched load almost completed with a **high level of performances**
- **Weakness of the fuses** on driver's pallets -> solved (to be confirmed)
- Most interesting tests are coming (mismatched and short-circuited load) -> Nov-18
- Run tests will last until RFQ is ready for conditioning
- SSA remote Control System is freshly operational (see Robert's talk)

● Toward RFQ conditioning

- The LLRF is in house, starting stand alone commissioning (see Wladimir's talk)
- The integration of RFQ cooling and vacuum systems will start soon -> Nov/Dec-18
- The 6 1/8" Tx line will be prepared and installed soon -> Nov-18
- In principle, the **RFQ conditioning may start in Dec-18**, if:

- All above activities are completed on time
- The test bench requirements are met (interlock, control...)
- The commissioning steps are defined

**Tuesday afternoon
satellite meeting**

A jump in the future for innovation in Belgium



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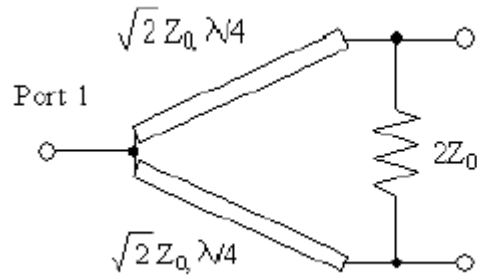
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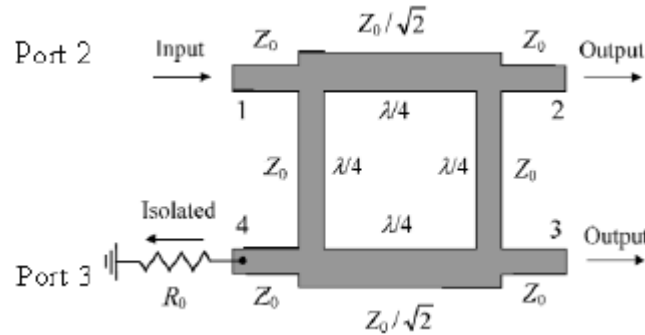
BACK-UP SLIDES

Combining structures

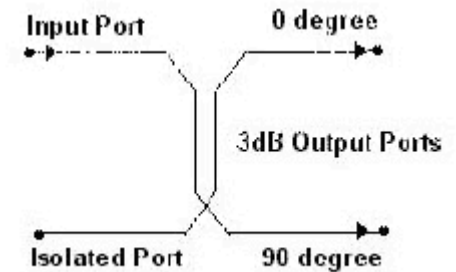
Wilkinson combiner



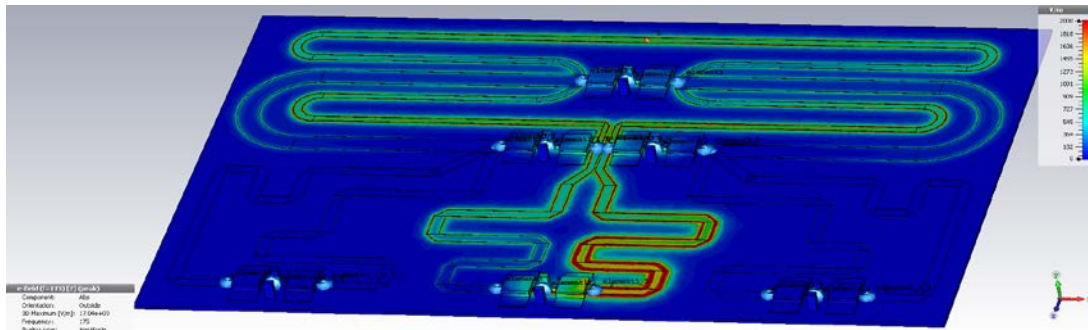
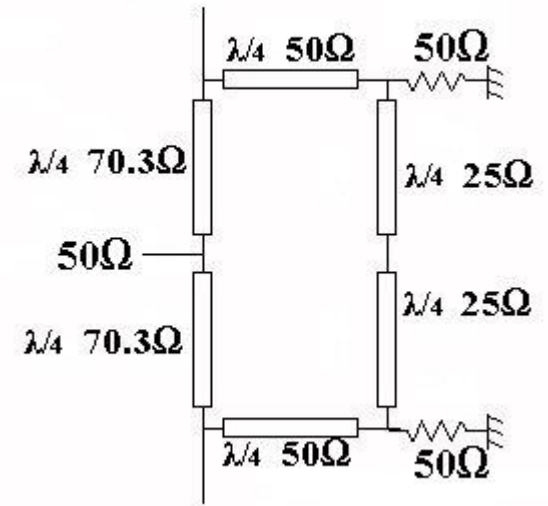
Branch-line combiner



Coupled line combiner

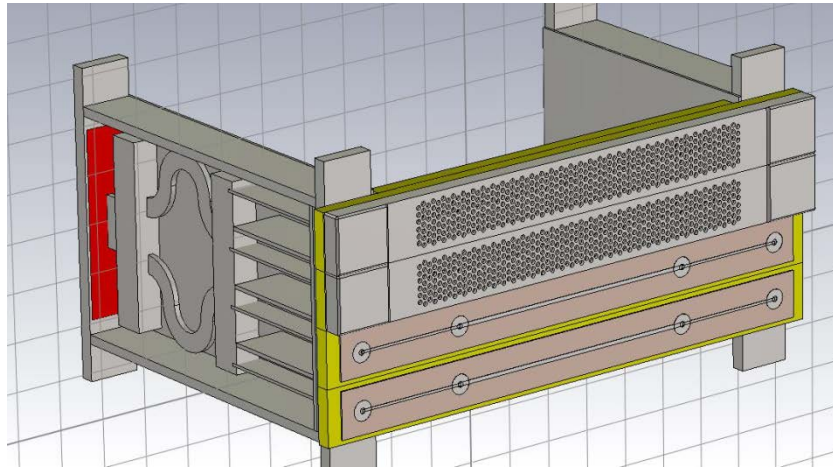
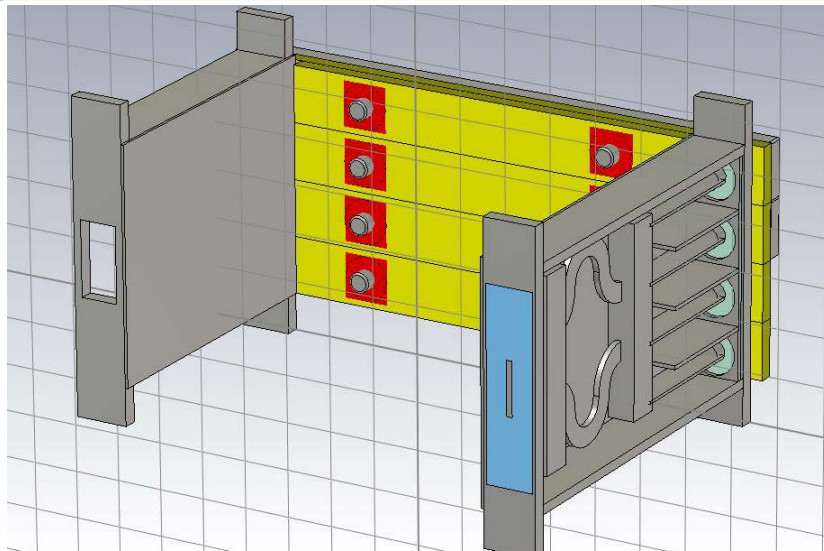


Gysel Combiner

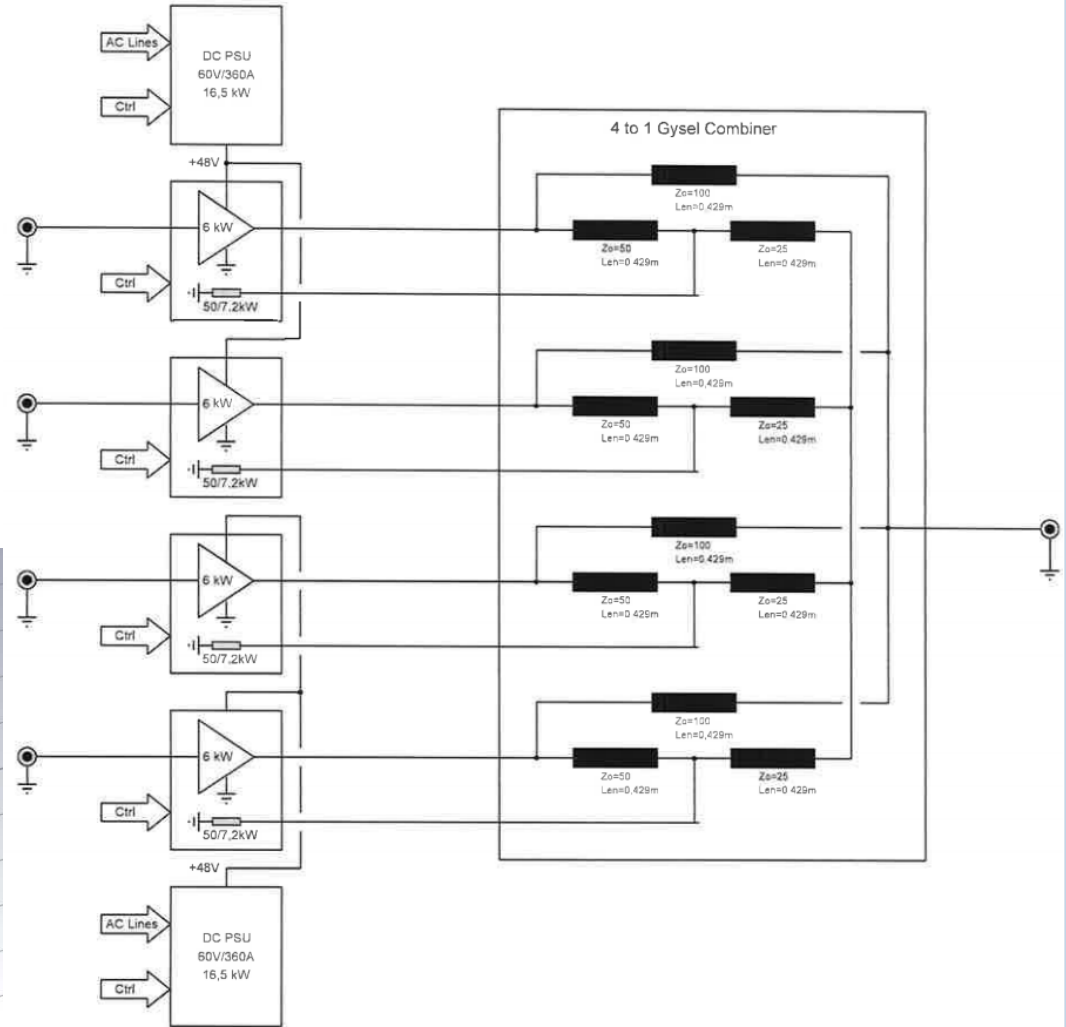


Wilkinson combiner 6-→3-→1 and input isolation simulation result (E field)

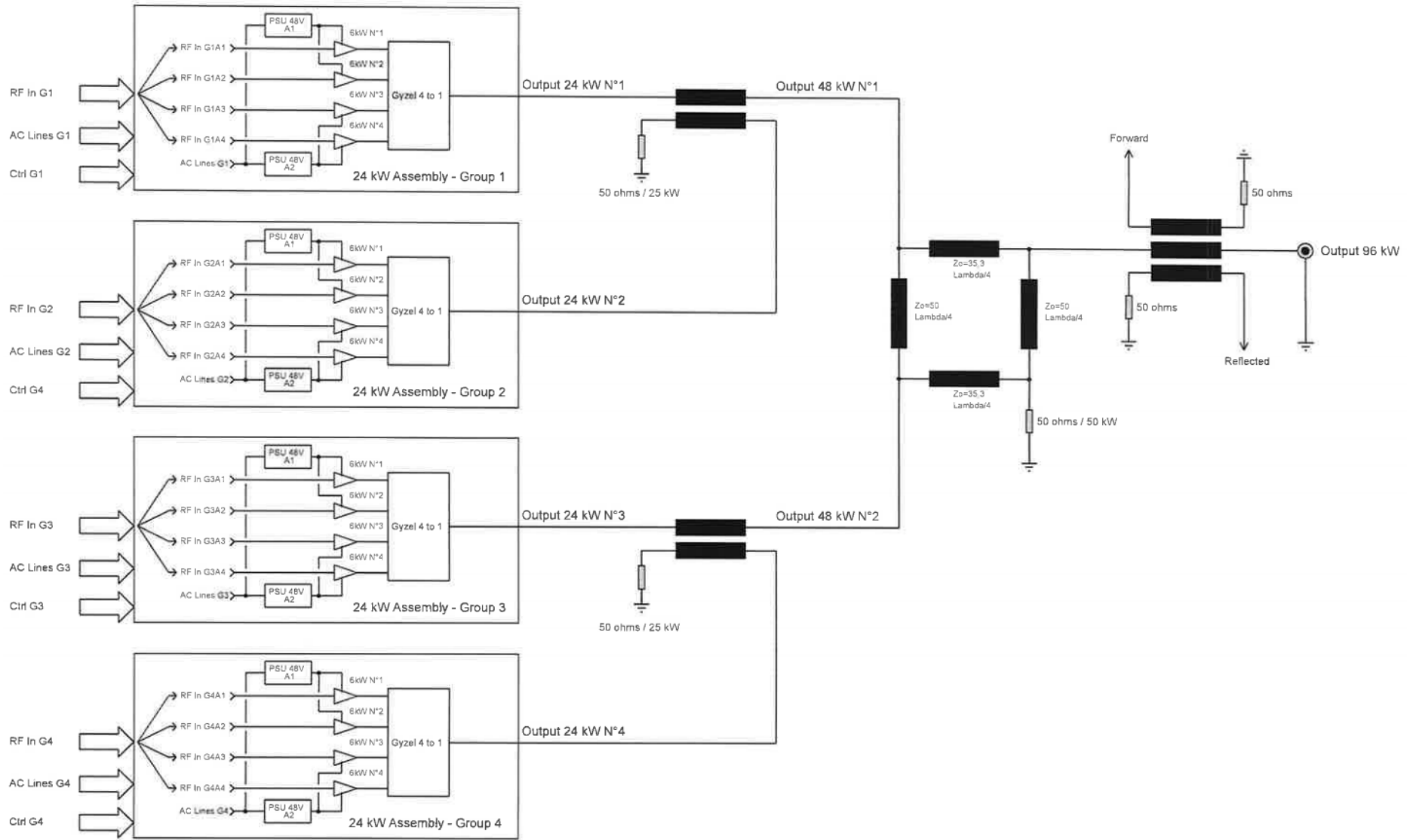
Gysel combiner integration



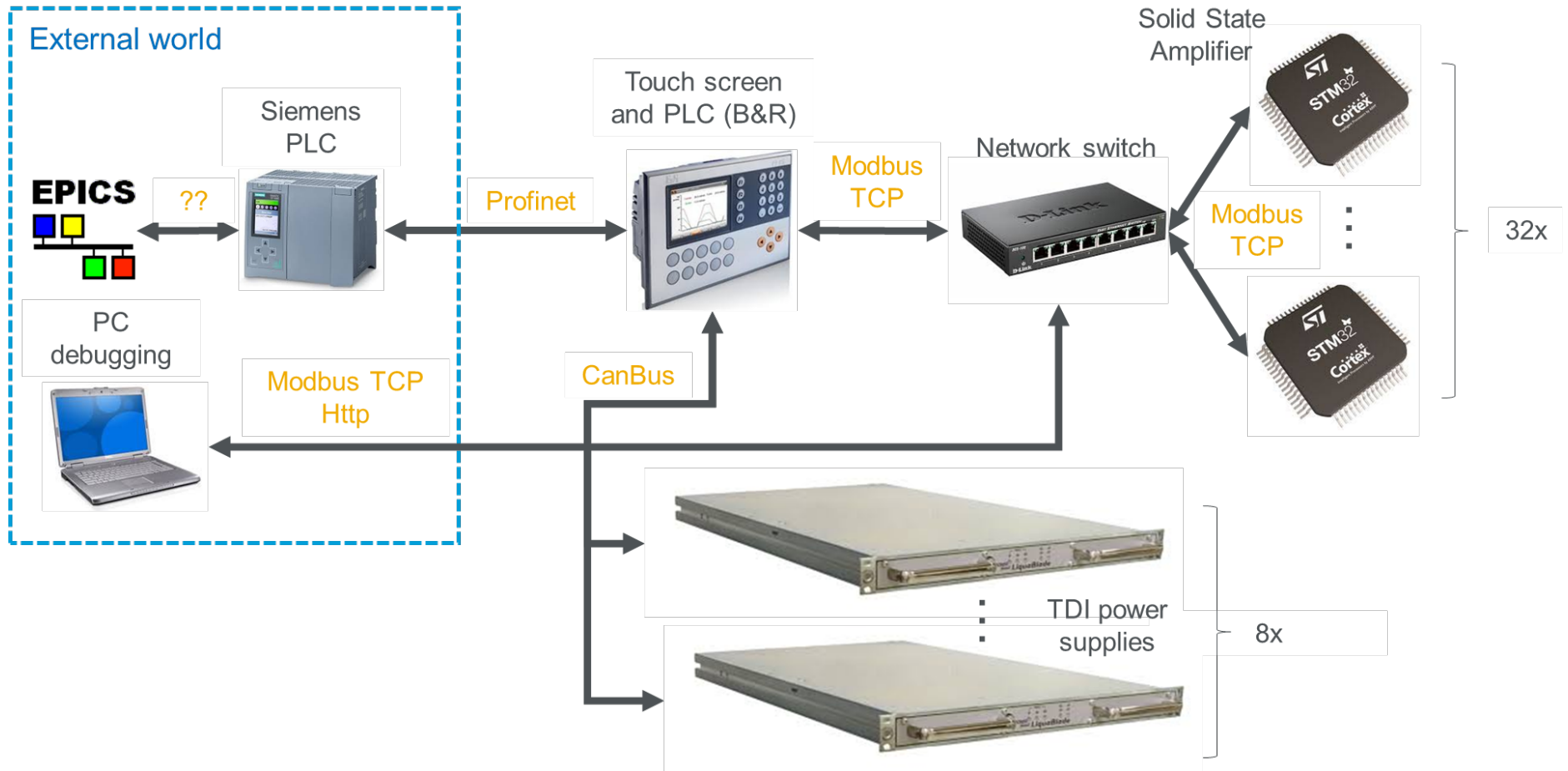
➤ IBA patent pending on this structure



Cabinet integration



Overview of the control system



Some screenshots of the local control system

VC Project 'Visu' - VNC Viewer

Myrte
RF Power Amplifier

General | SSA | **Power supply** | RF out 0.0 kW

02/22/2018 17:35:03

Global output power
All on | All off | Voltage 51.926 V | Current 7.96 A | Power 0.413 kW | Fault

Power supply details

Select unit: PSU 1

Unit start / stop: On

Power supply set point
Voltage limit 51.000 V | Current limit 0.00 A | Power limit 0 W

Power supply read back
Voltage 51.95 V | Current 0.94 A | Power 48.83 W

Module	Voltage	Current	Temperature	AC ok	Enable	DC on	Fault
Module 1	51.940 V	0.21 A	16.0 deg C	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
Module 2	51.970 V	0.09 A	16.0 deg C	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
Module 3	51.940 V	0.64 A	18.0 deg C	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>

General | SSA | Setup | Power supply | Alarms | Diagnostic | Local

VC Project 'Visu' - VNC Viewer

Myrte
RF Power Amplifier

General | SSA | Power supply | RF out 0.0 kW

02/22/2018 15:49:46

Cabinet 1

SSA 1 - 4 | SSA 9 - 12 | SSA 5 - 8 | SSA 13 - 16

Load | Output | Load

Pf 0.00 kW | Pr 0.00 kW

Pf 0.01 kW | Pr 0.01 kW | SWR 0.00 | RF Eff 0.0 %

Pf 0.01 kW | Pr 0.01 kW

General | SSA | Setup | Power supply | Alarms | Diagnostic | Local

VC Project 'Visu' - VNC Viewer

Myrte
RF Power Amplifier

General | SSA | **Power supply** | RF out 0.0 kW

02/22/2018 15:51:36

SSA 2

Power details | Rack details

display +peak value

Load | Output | Fan | Temperature

Pf 0.6 W | Pr 0.6 W | PWM 0 %

T water 1 12.24 °C | T water 2 12.76 °C | T air in 18.41 °C | T air out 16.47 °C | T board 16.59 °C

PSU 51.769 V

Pallet	Pf	Pr	I	V	Off	Reset
Pallet 1	0.0 W	0.1 W	0.318 A	51.908 V	<input type="checkbox"/>	<input type="button" value="Reset"/>
Pallet 2	0.0 W	0.1 W	0.330 A	51.913 V	<input type="checkbox"/>	<input type="button" value="Reset"/>
Pallet 3	0.0 W	0.1 W	0.333 A	51.926 V	<input type="checkbox"/>	<input type="button" value="Reset"/>
Pallet 4	0.0 W	0.1 W	0.293 A	51.917 V	<input type="checkbox"/>	<input type="button" value="Reset"/>
Pallet 5	0.0 W	0.1 W	0.340 A	51.915 V	<input type="checkbox"/>	<input type="button" value="Reset"/>
Pallet 6	0.0 W	0.1 W	0.291 A	51.900 V	<input type="checkbox"/>	<input type="button" value="Reset"/>

General | SSA | Setup | Power supply | Alarms | Diagnostic | Local

VC Project 'Visu' - VNC Viewer

Myrte
RF Power Amplifier

General | SSA | Power supply | RF out 0.0 kW

02/22/2018 15:48:54

External coupler

Cabinet 1 | Cabinet 2 | External Coupler

Cabinet 1 | Cabinet 2

Output | Load

Pf 0.00 kW | Pr 0.00 kW | SWR 0.00

Efficiency
PSU 1.81 kW | RF Eff 0.0 %

Pf 0.00 kW | Pr 0.00 kW

General | SSA | Setup | Power supply | Alarms | Diagnostic | Local