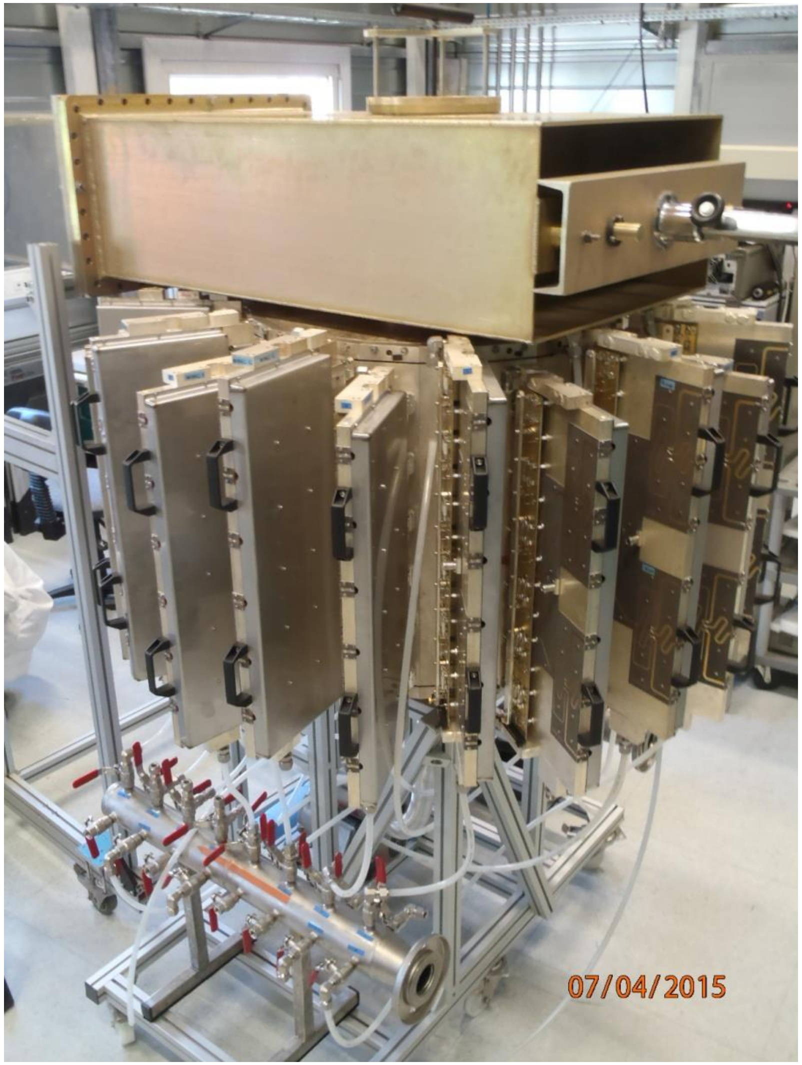
ESRF | The European Synchrotron

Solid state RF amplifier development at ESRF



Starring:

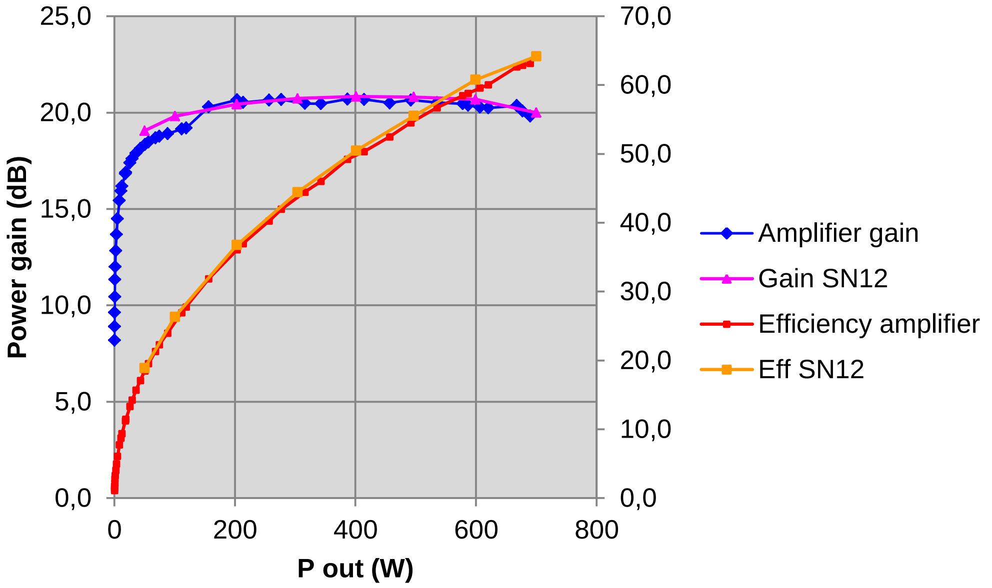
- The RF group with special thanks to Pierre Barbier, Philippe Chappelet, Alexandra Flaven-Bois and Denis Vial.
- Jean-Michel Chaize for advice on the power supplies control.
- Jean-Francois Bouteille and Kumar Bulstra for advice on the power supplies.
- Frederic Favier and Pascal Roux-Buisson for the cooling skid design and manufacture.
- Nicolas Benoist, Loys Goirand and Francois Villar for their large inputs in the mechanical design.
- Lin Zhang for fruitful discussions about cooling
- Cecile de la Forest, Jean-Charles Deshayes et Jean-Michel Georgoux for the purchasing.

2013 RESULTS

In 2013, we proved that a solid state amplifier using a cavity combiner to sum the power of many modules could work. We reached 12.4kW of average power with 18 modules distributed on 3 “wings”.

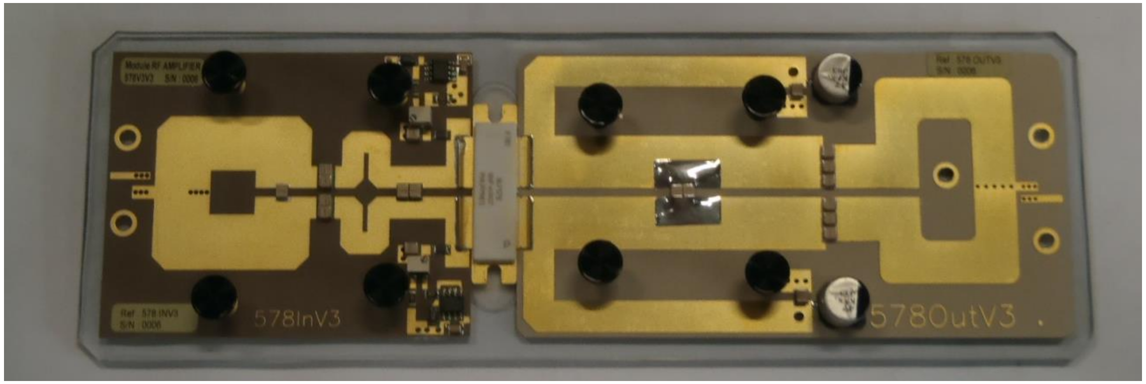
- **The combining losses were too small to be measured conveniently.**
- **We could operate the amplifier in both pulse mode and continuous wave (pulse mode is suitable to condition accelerating cavities).**
- **All tests were performed with a matched load .**

Combiner vs. “average” module



2014-2015 ASSIGNMENT: PRODUCTION

We found a French company (TRONICO in Vendée) to manufacture 114 RF modules according to ESRF design for a decent price.



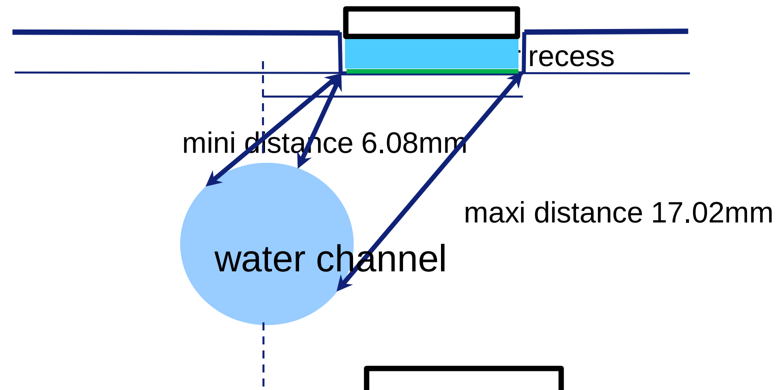
An Italian company extruded 500kg (minimum order) of 6063 Al alloy and roughed out 60 cooling plates . They were milled by another company. We could do without drilling 650mm long cooling channels (copyright Loys Goirand!).

COOLING ISSUES

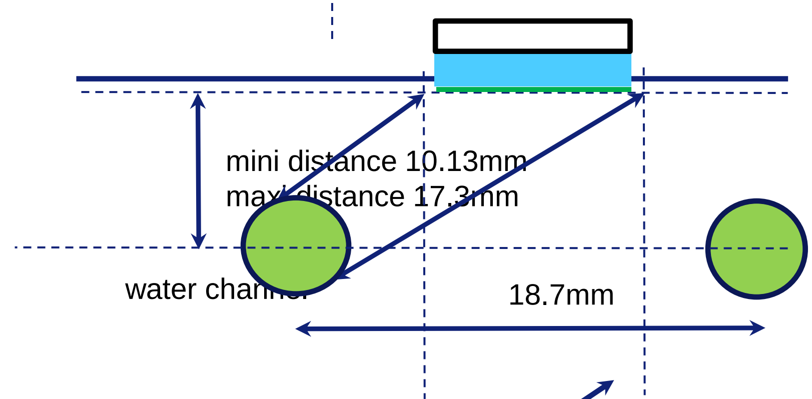
In our module, the transistor maximum dissipation is around 330W.

Transistor cooling on the 3 wings prototype: single channel Φ10mm, off centered.

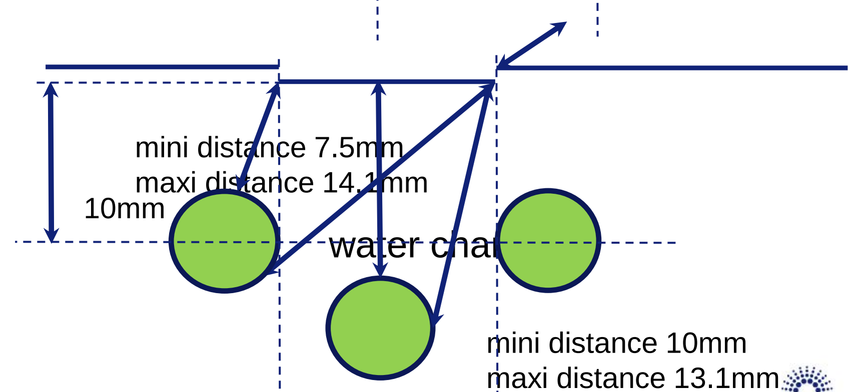
Computed (with CST) junction temperature at 10l/min: 120°



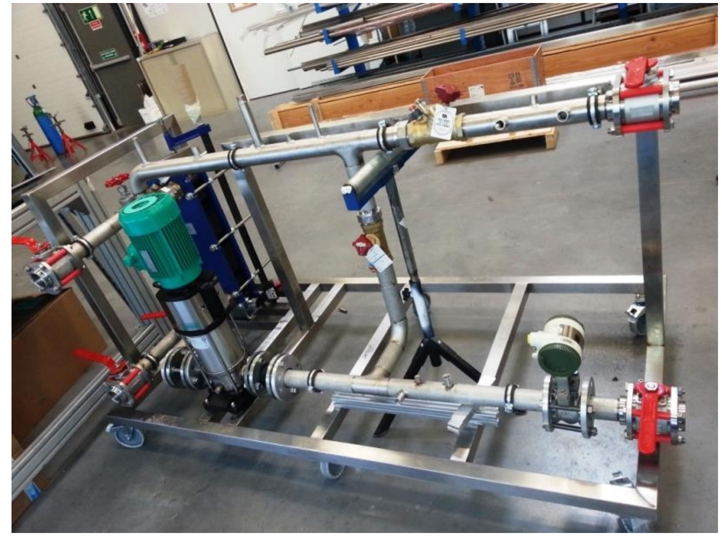
Transistor cooling on the other wings: 2 channels Φ7mm in //.
Computed (with CST) junction temperature at 2*5 l/min: 113°.



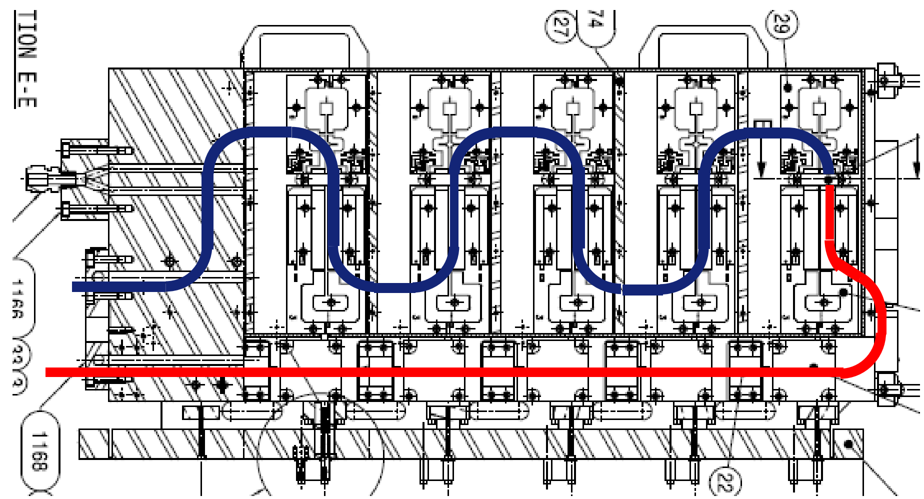
Other possibility with 3 channels in //.
Computed (with CST) junction temperature at 2*5 l/min: 112°. Not worth the trouble.



COOLING ISSUES



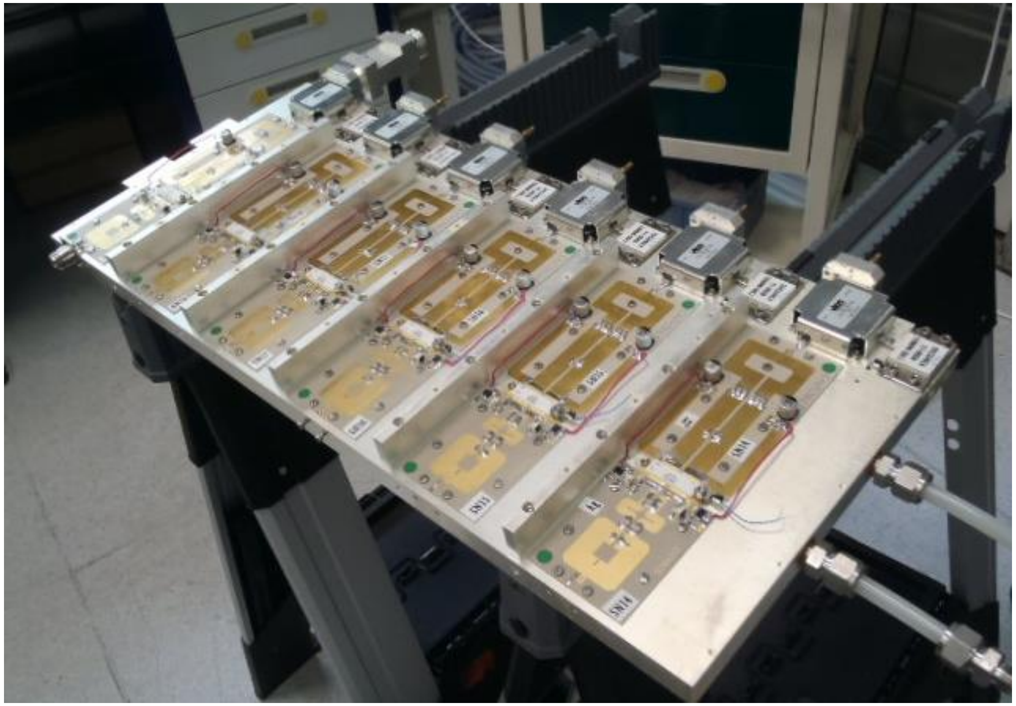
Alas, de-ionized water is not permitted to flow in aluminum channels at ESRF. We use a skid with pump and heat exchanger. This is not so good for efficiency and cost. We investigated other possibilities.



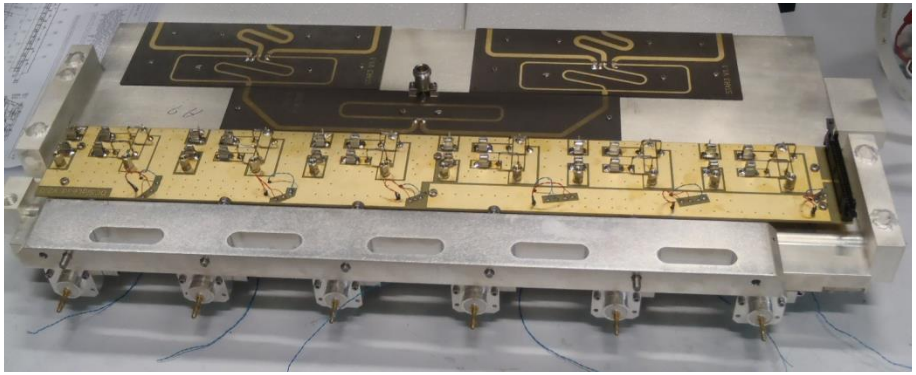
PADA (Italy) can bury copper tubes in aluminum plates. This configuration gives a computed junction temperature of 116°.

The ELTA version was simulated the same way and yielded 111°, with 16 l/min.

2014-2015 ASSIGNMENT: PRODUCTION

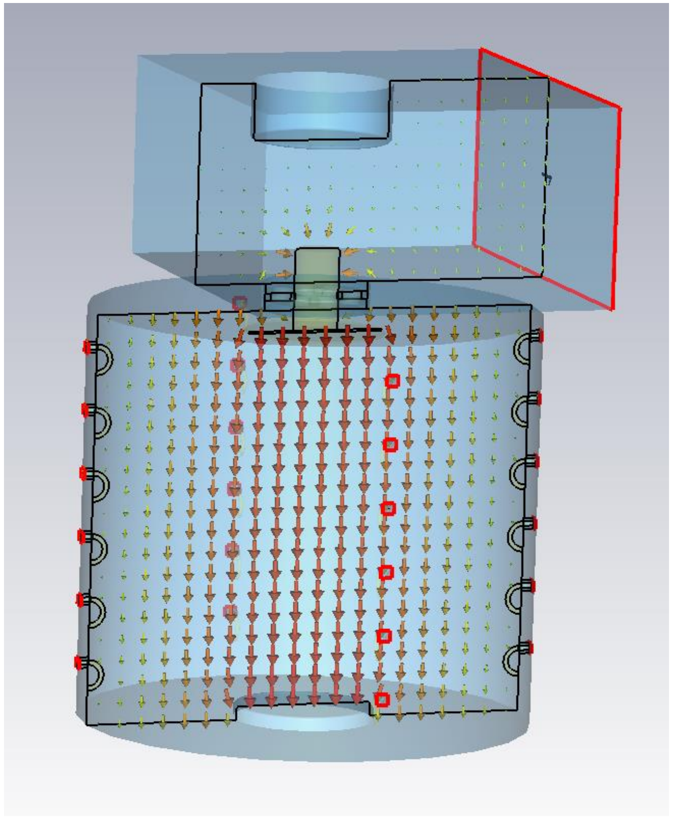


- **We ordered all mechanical parts, the electronic parts which were not included in the modules and the hydraulic fittings.**
- **We designed and made a DC distribution circuit which also include temperature and current measurements for each module.**
- **We had to fight a parasitic oscillation in the bias circuit (which we discovered after “mass” production was launched, of course!)**
- **We fitted 22 complete wings, tested all amplifiers and installed them on the cavity combiner.**



2014-2015 : PRODUCTION TROUBLE

- **A cavity combiner works ideally if all input loops are fed with the same current amplitude and phase.**
- **Many facts conspire to destroy this harmony.**



Namely:

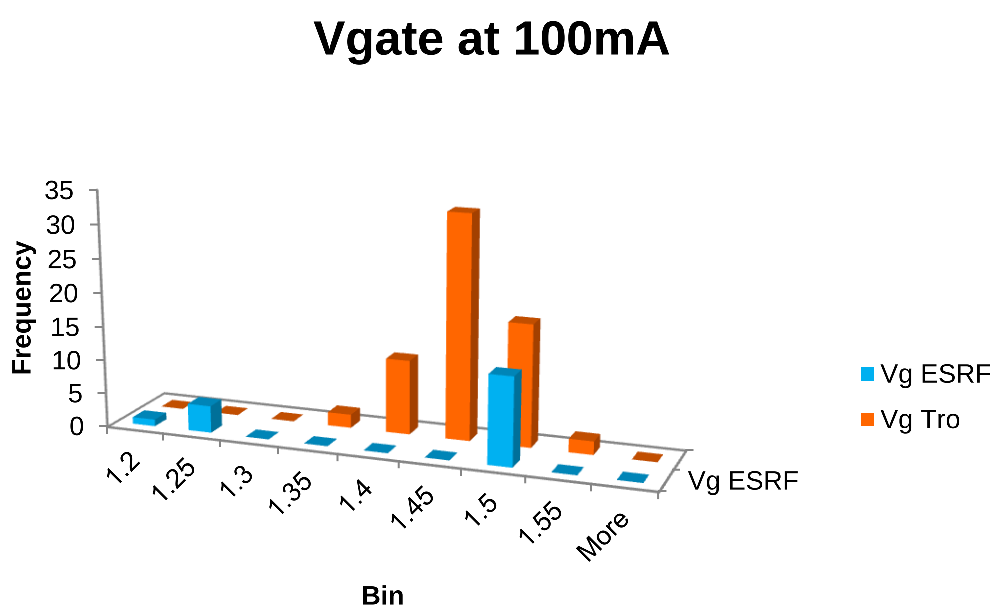
- The transistors have some discrepancy.
- The circulators have also some discrepancy.
- The input and output circuits are not exactly alike.
- The 6 branches of the splitters do not feed the modules with exactly the same input signal.
- The loops have machining and fitting tolerances.
- The 2 preamplifiers have gain and phase discrepancy.
- The 12 ways λ/4 splitters do not feed the wings with the same input signal amplitude and phase.

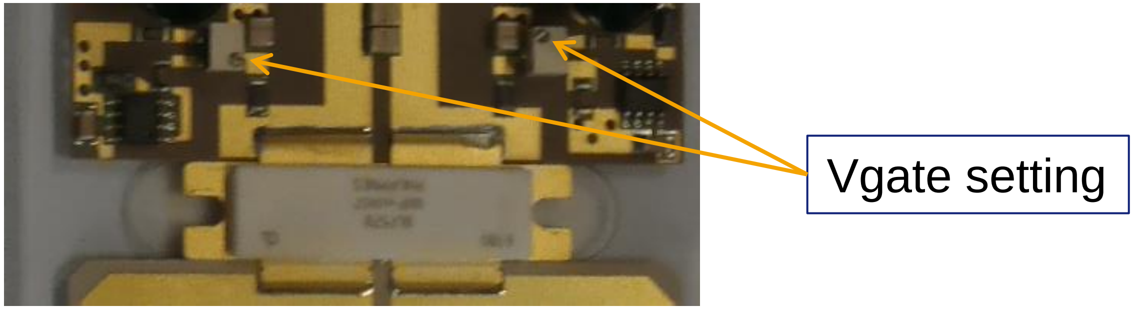
2014-2015 : PRODUCTION TROUBLE - TRANSISTORS

➢**Let’s have a look at NXP’s transistor reproducibility.**

✓The ESRF modules were made with 2 batches of transistors BLF578. The first batch had a gate voltage of 1.2V for 100mA. The second had 1.5V with very little dispersion.

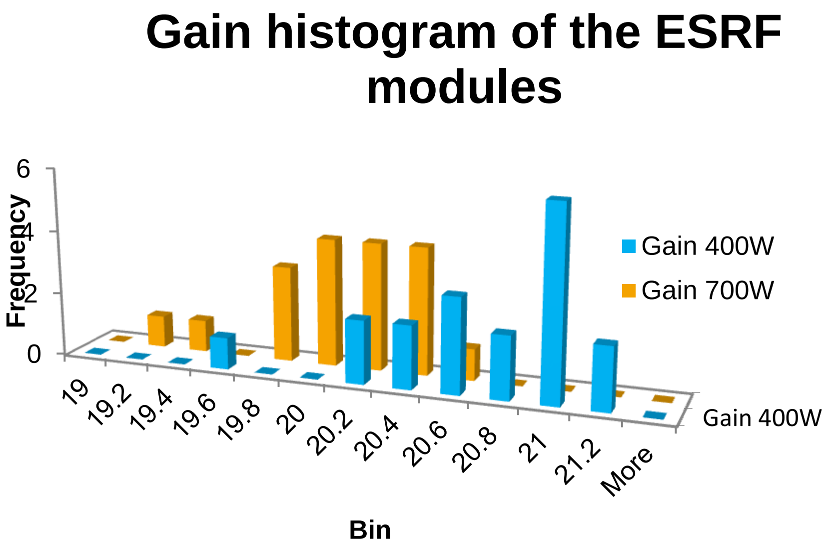
✓The Tronico modules used a single batch of BLF578, produced later. The average value is close to our 2nd batch, but with more spread.

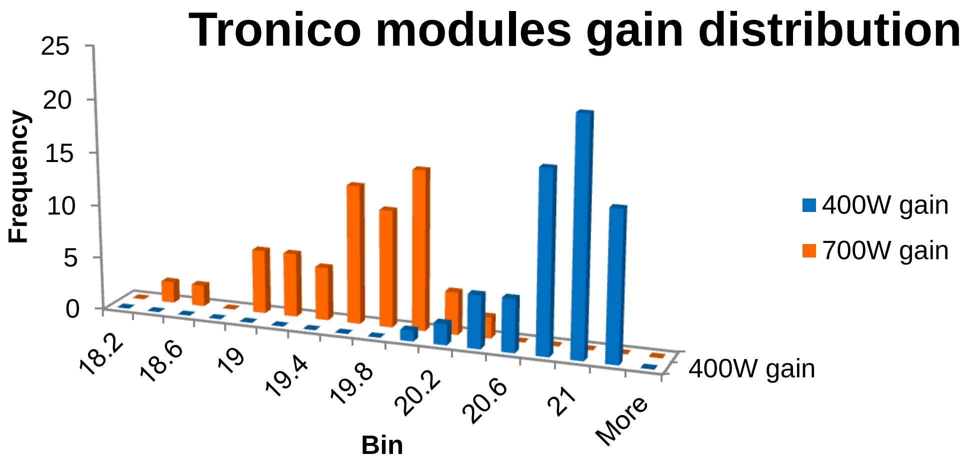




PRODUCTION TROUBLE -MODULES

To make cheap modules, we went for trimless design. The target is to skip the expensive RF test and have them made in Europe.





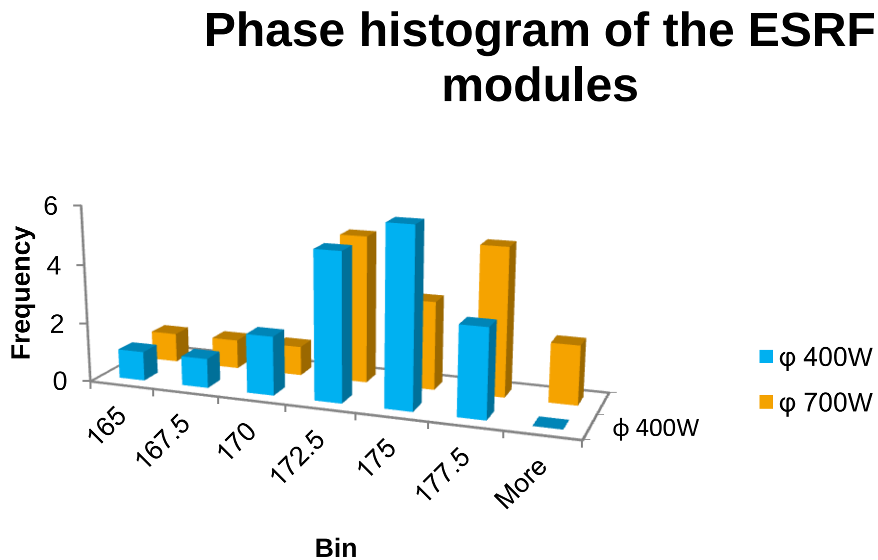
	ESRF modules	Tronico modules
Average gain 400W	20.61 dB	20.78 dB
Average gain 700W	19.95 dB	19.52 dB

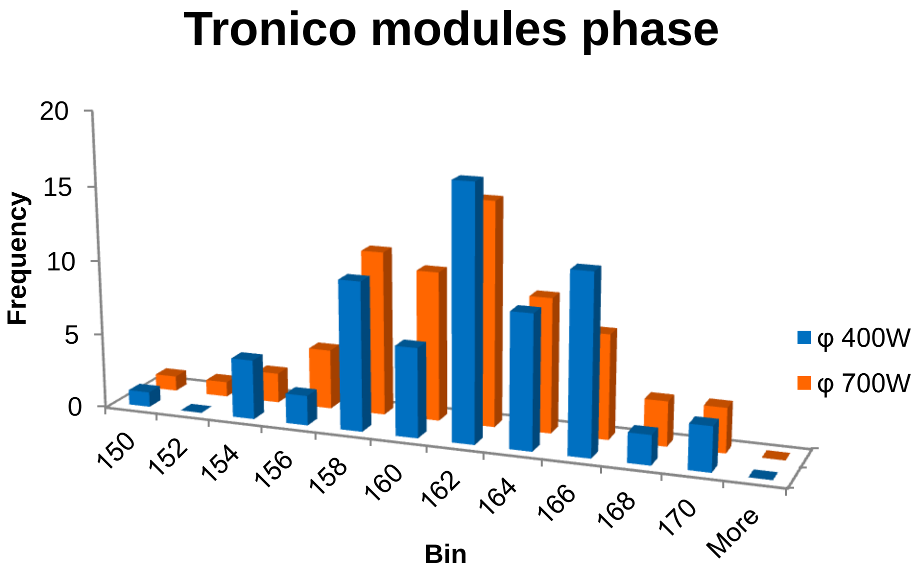
Will they still combine harmoniously?

PRODUCTION TROUBLE -MODULES

How about the phase?

(The offset comes from test bench different calibration)



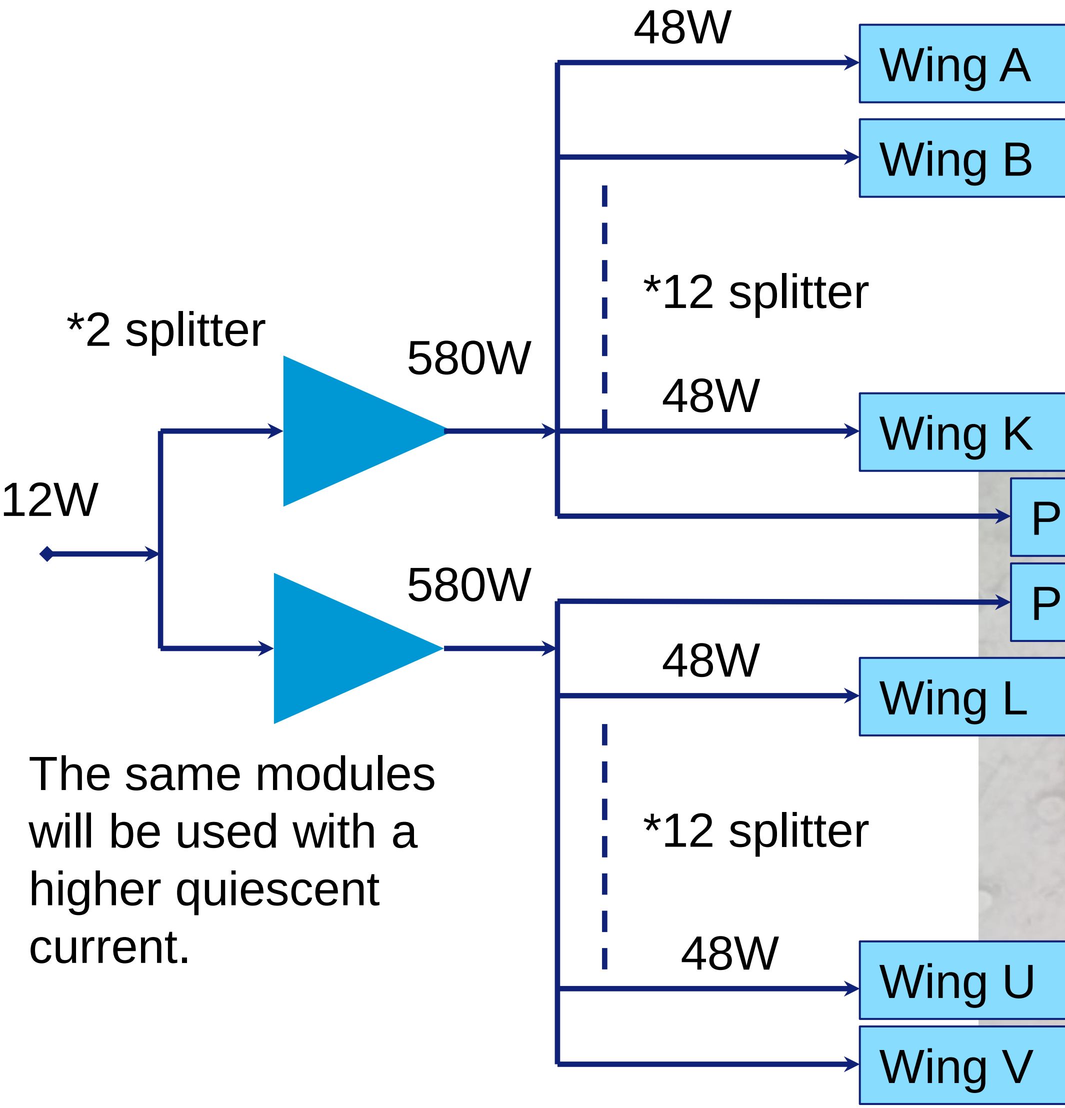


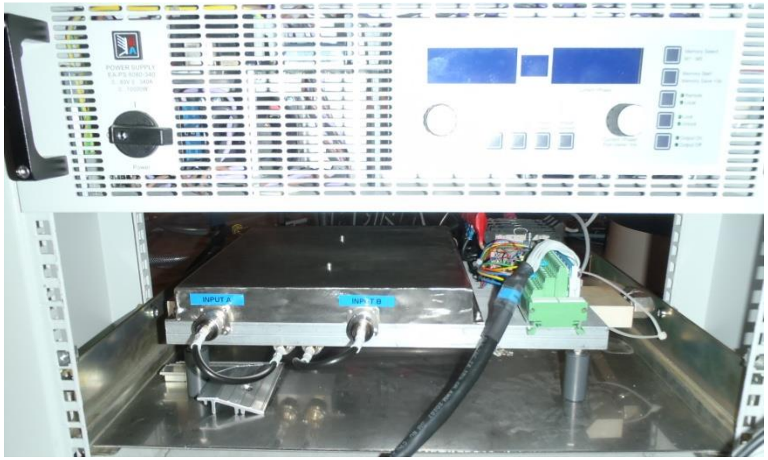
	ESRF modules	Tronico modules
σ 400W	3.53°	4.25°
σ 700W	4.03°	4.21°

Will they still combine harmoniously?

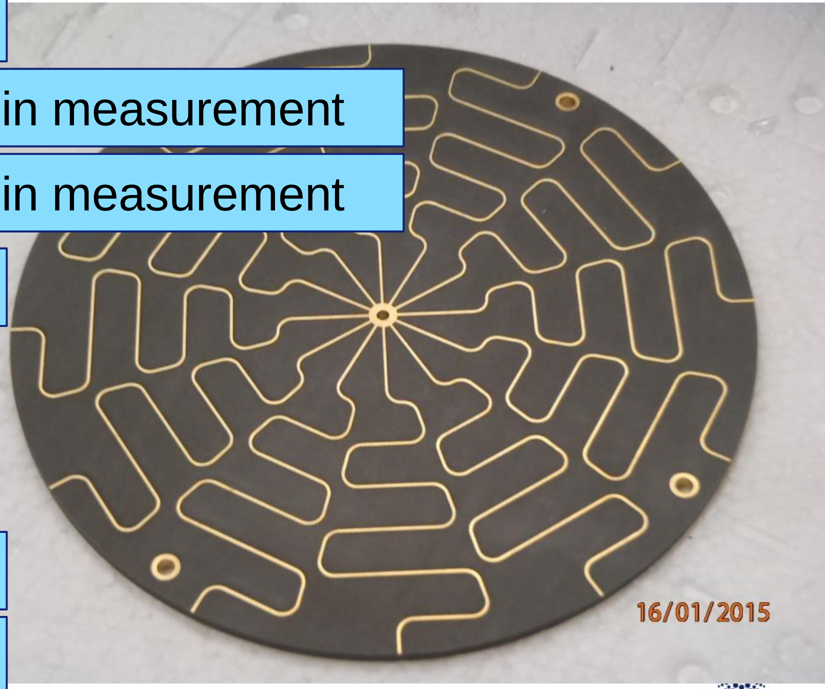
PRE-AMPLIFIER

Each module will need about 7W to drive 700W into the cavity combiner.





The 12 ways splitter PCB



The same modules will be used with a higher quiescent current.

The drain voltage (50V) of each “wing” is supplied by one AC/DC converter.
There will be 2 cabinets of 12 converters, 11+1 spare.
ESRF policy demanded de-ionized water cooling.
Call for tender necessary! 

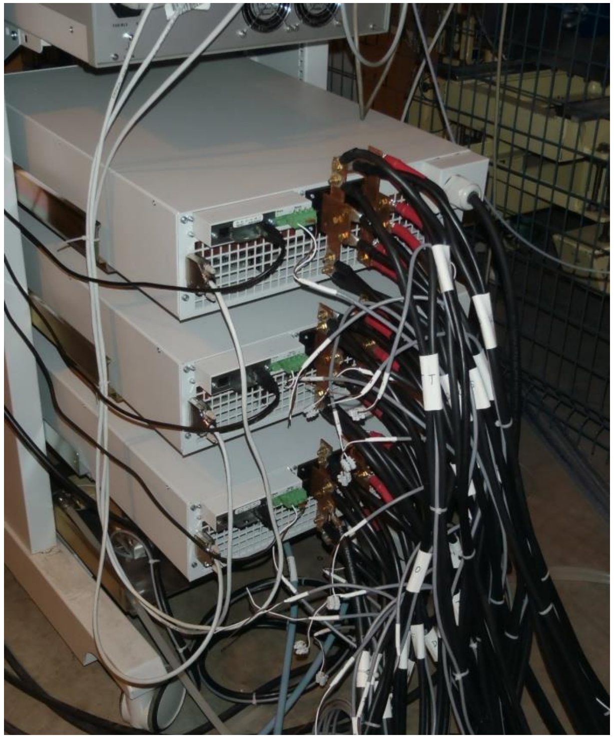
The Italian company EEI in Vicenza got the order after a lot of twists and turns. We tested successfully a prototype converter which had 92% efficiency.
Delivery is scheduled for October 2015, pretty soon!
All in all, the procurement will last 16 months (at best)!

A control box was developed in house to monitor the 4 parameters of each module: Id1, Id2, θtrans. and θload and send data to a PC.
Three prototypes were installed on wings.

[Philippe Chappelet]

WHILE WAITING…

We connected all 22 wings+preamplifier to 3*10 kW AC/DC converters (air cooled, hushh!) we had from our former 3 wings set-up and applied some power…
and got massive RF leakage with 150W output power!
The culprit was the ill designed WR2300 sliding short. Its fingers had sagged, leaving a gap between waveguide and short.
After fixing it, we could crank the power up to 4.2kW and check that we had not forgotten too many welds.



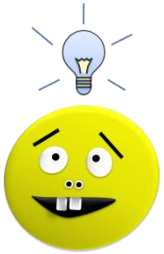
WHILE WAITING… RF TRANSITION : REQUIREMENTS

ESRF frequency is 352.2 MHz and we use WR2300 waveguides. They are quite large and crossing the tunnel roof is made more difficult. We thought a double transition could be convenient:
1/ full height to coaxial above the tunnel.
2/coaxial to cross the roof.
3/coaxial to half height inside the tunnel.

Power rating

limitation	FWD P	REF P	VSWR	Eq. power
0.5MV	85 kW	12 kW	2.2	160.9 kW
cavity	110.0 kW	15.5 kW	2.2	208.0 kW
amplifier	150.0 kW	21.1 kW	2.2	283.6 kW

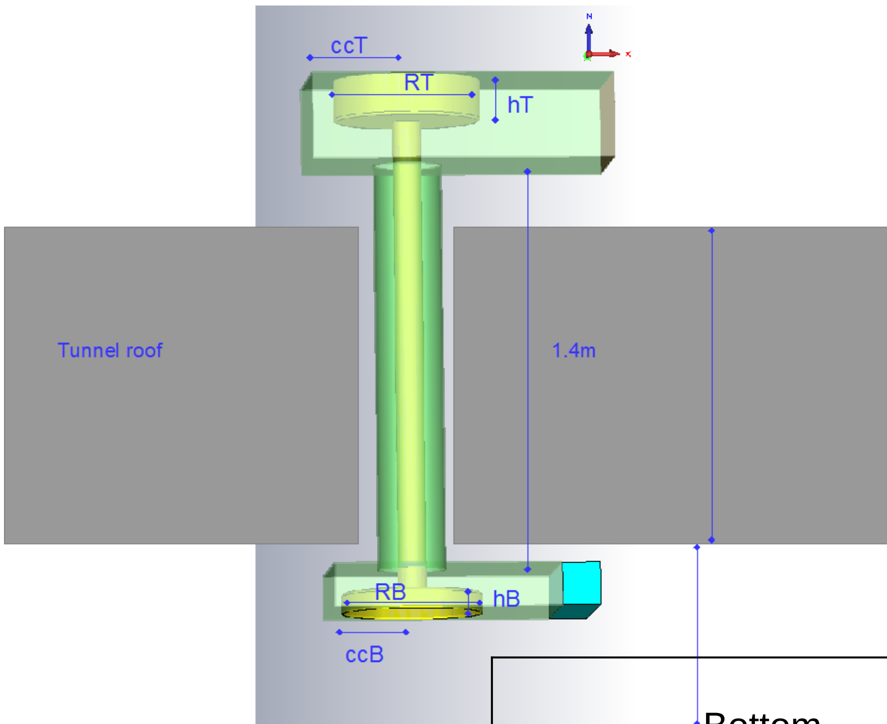
manufacturer	100/230 CW power	6"1/8 CW power
SPINNER	260 kW	118 kW
MEGA	200 kW	100 kW

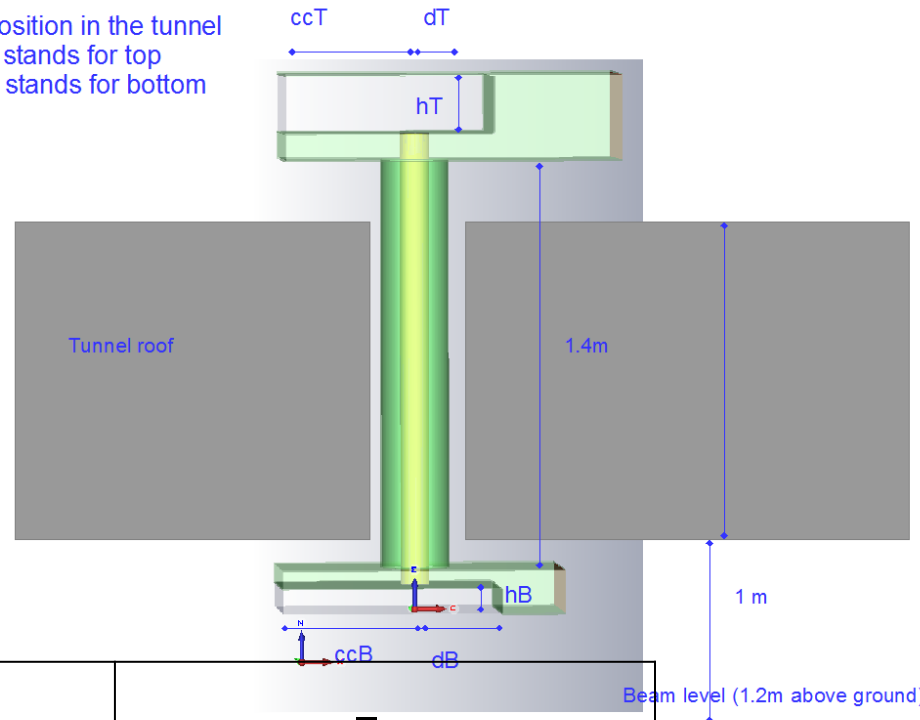


We could use the air cooling the coupler to cool the coaxial line as well.
We could draw the air from the tunnel, filter it, cool the assembly and pump it out. The pump would stay outside the tunnel where room is scarce.

2 matchings were investigated:

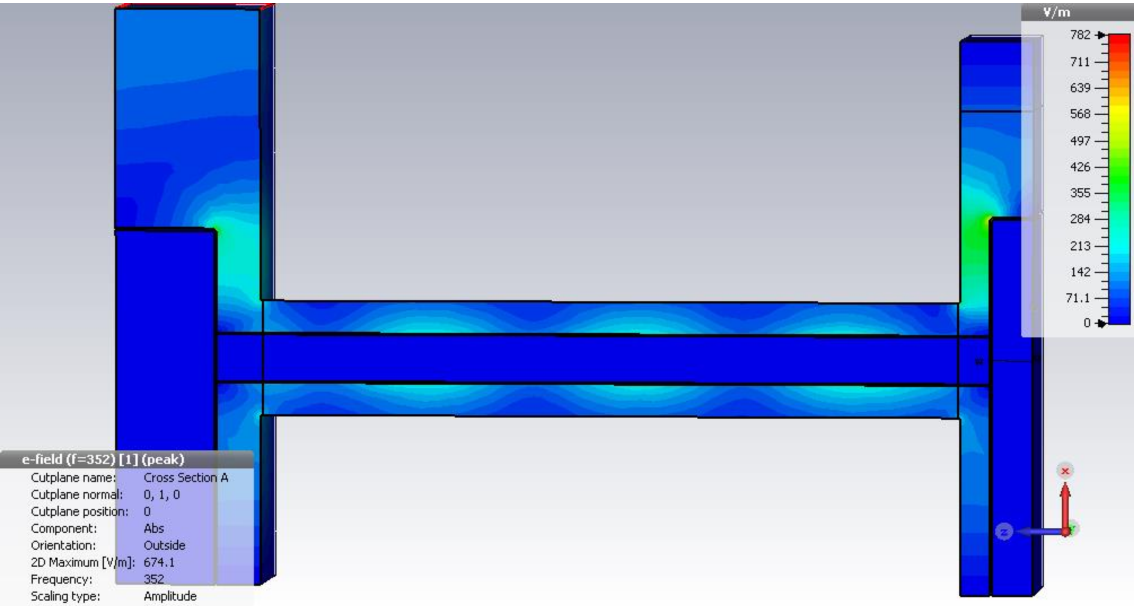
cylindrical | step



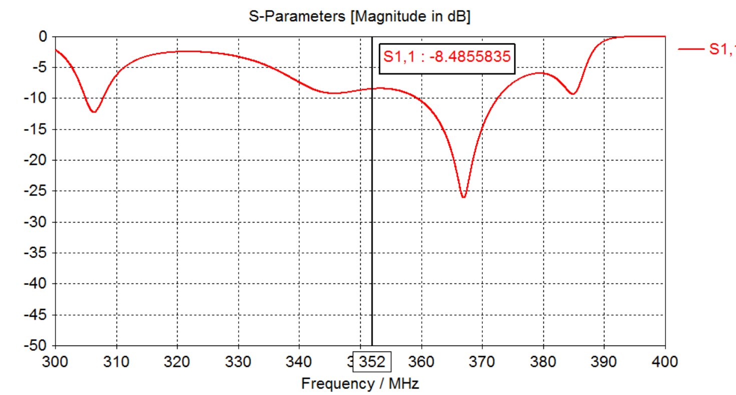


	Bottom		Top	
COAX 110kW	cylinder	step	cylinder	step
100/230	213 kV/m	239 kV/m	212 kV/m	259 kV/m
6”1/8	184 kV/m	225 kV/m	175 kV/m	256 kV/m

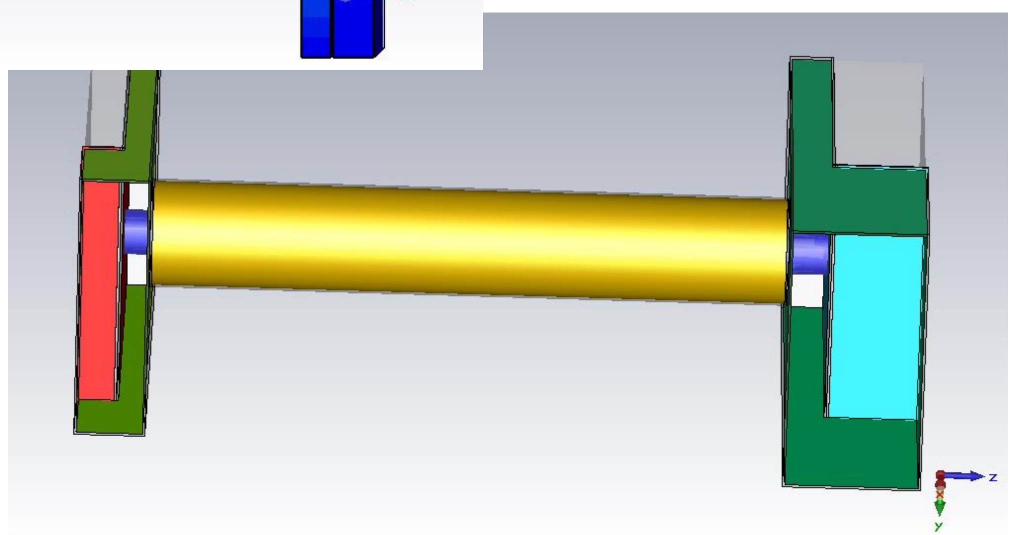
Thermal computation conditions with CST:



RF losses # 300W at 110 kW

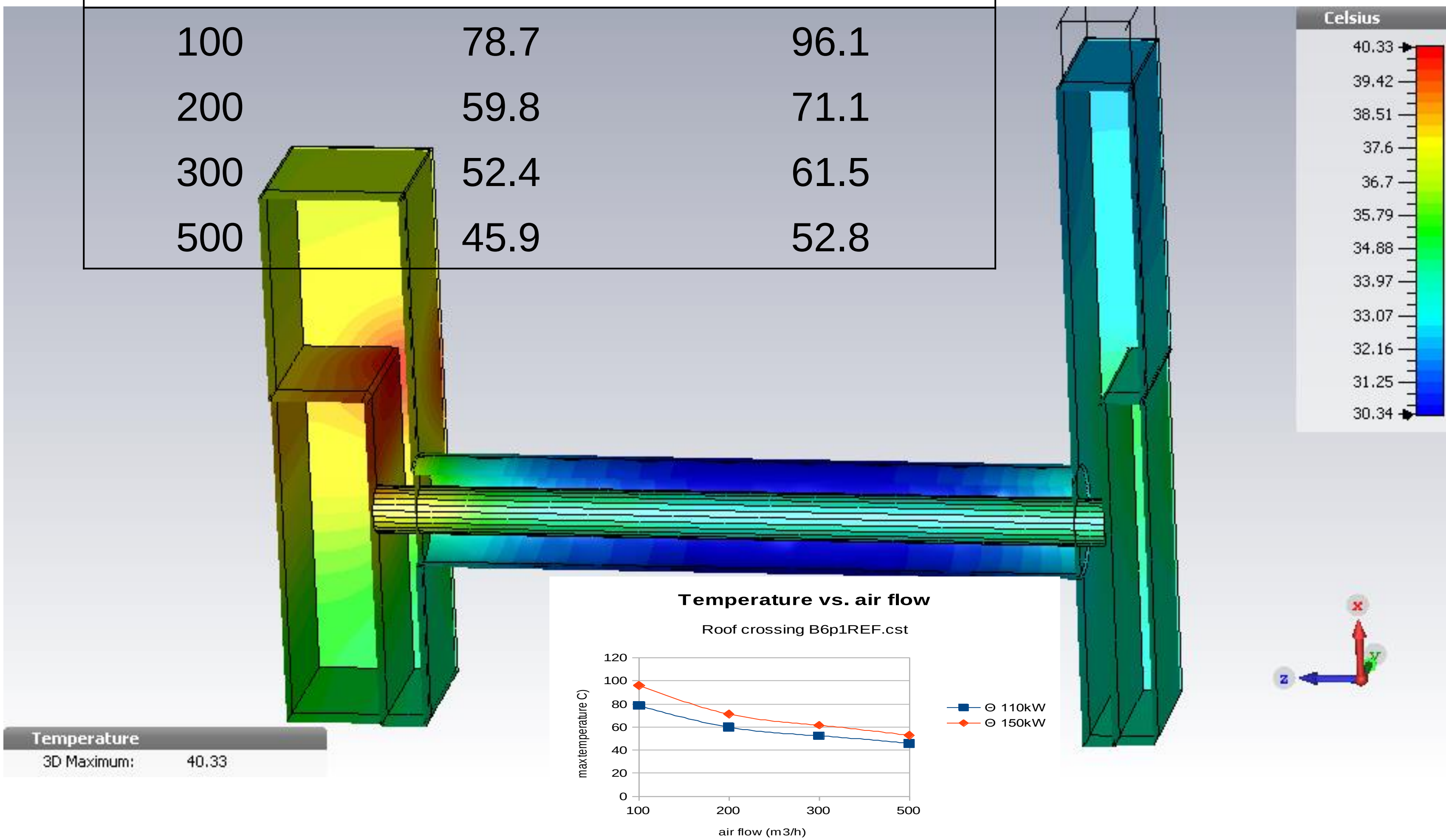


Convection settings for 500m3/h air flow:
Coax: 17 W/(m2*K)
Bottom box: 7 W/(m2*K)
Top box: 3.6 W/(m2*K)



Thermal computation results :

Dv (l/min)	Θ 110kW	Θ 150kW
100	78.7	96.1
200	59.8	71.1
300	52.4	61.5
500	45.9	52.8



THANKS

Thanks to all who participate in these (hopefully) interesting developments

…and to you all for patiently listening!!