ESRF | The European Synchrotron

Solid state RF amplifier development at ESRF

Participants:

- ➢The RF group with special thanks to Pierre Barbier, Philippe Chappelet, Philippe Chatain, Alexandra Flaven-Bois, Claude Rival, Georges Gautier and Denis Vial.
- ➢Jean-Michel Chaize, Jean-Luc Pons and Marc-Antoine Denis for advice on the 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 its manufacture.
- ➢Nicolas Benoist, Loïs Goirand and Francois Villar for their large input 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.

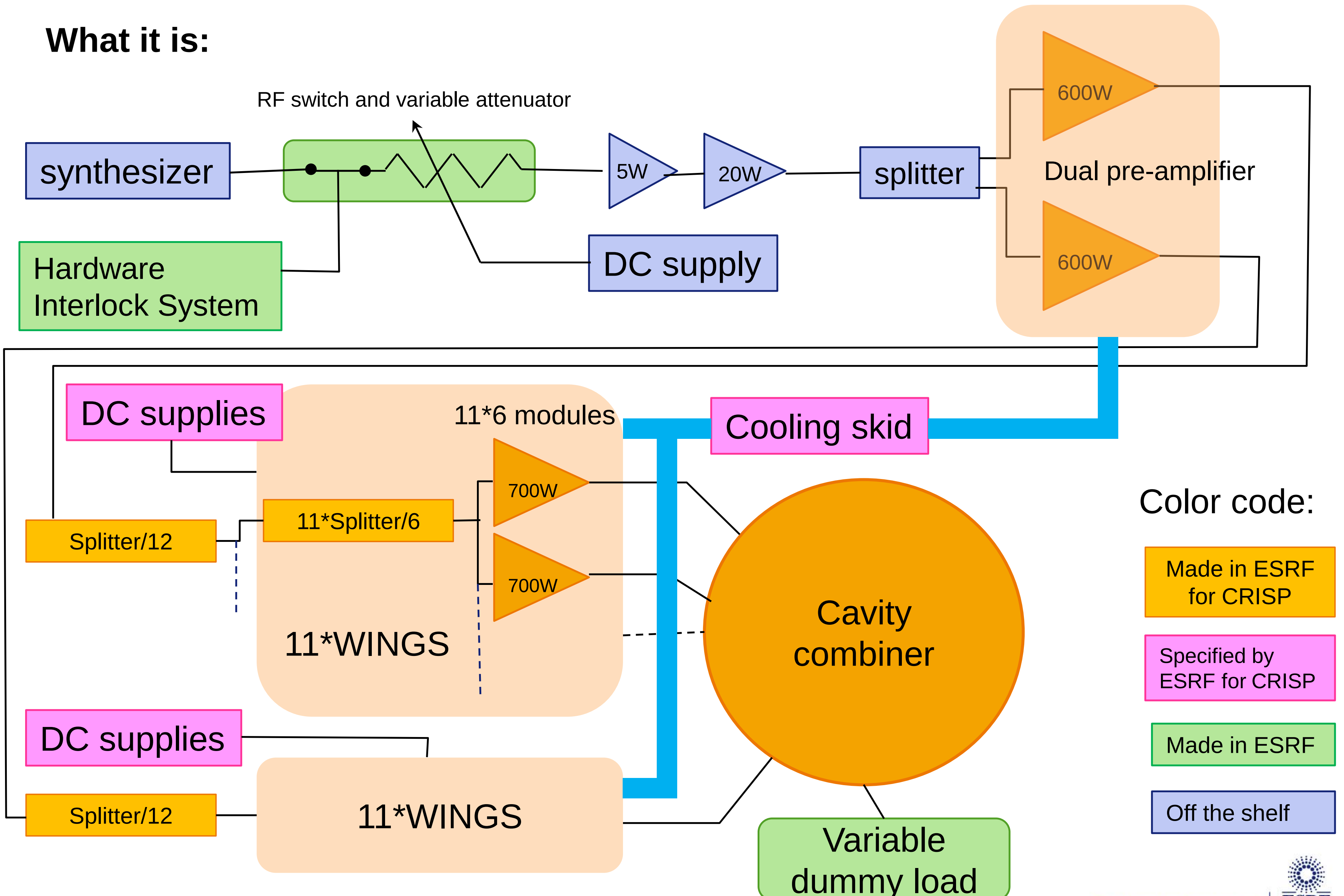
85KW RF AMPLIFIER AT 352 MHZ

What it looks like:

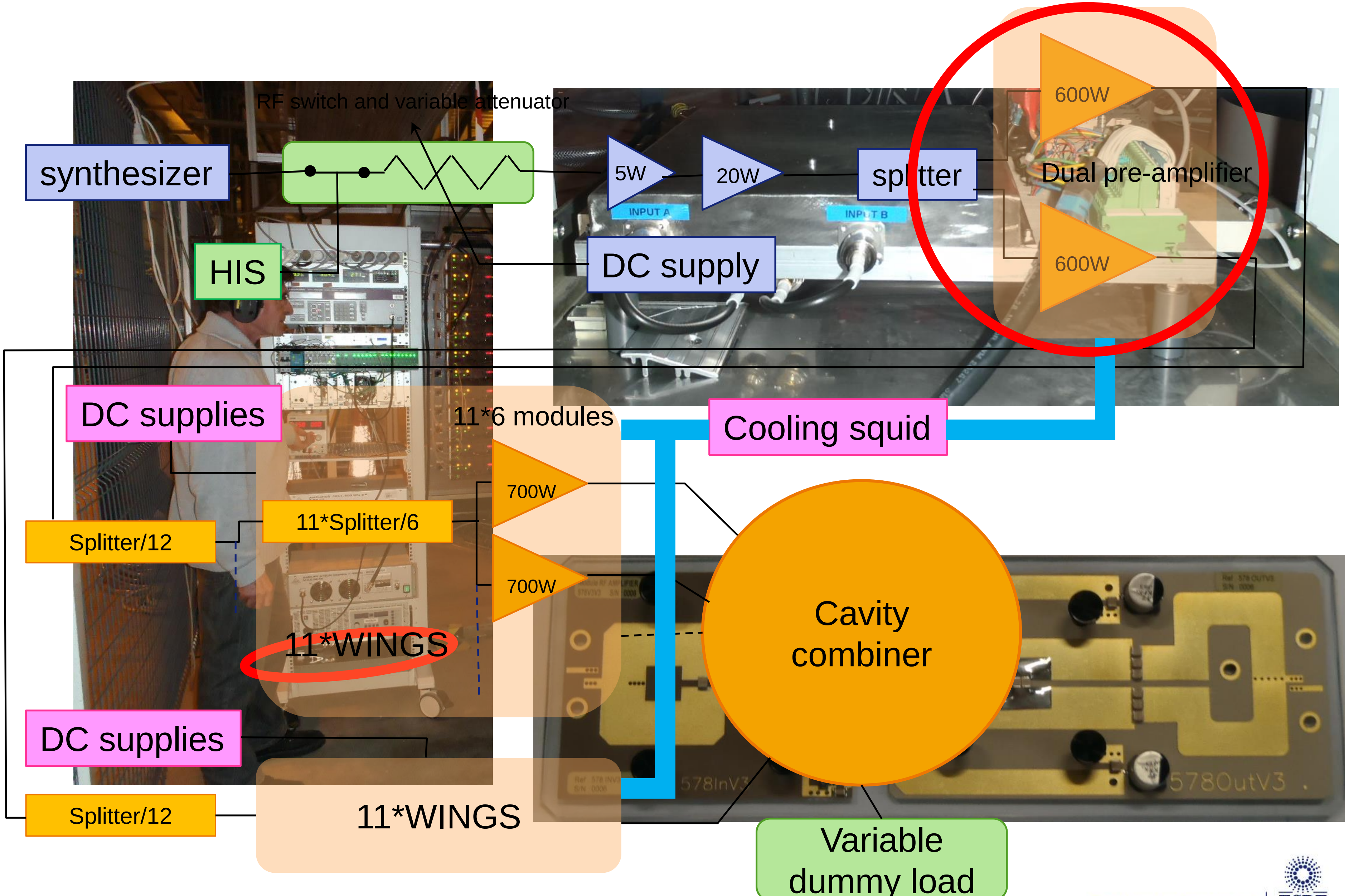
The R&D of cavity combiner received funding from the EU as working package WP7 in the framework of the FP7/ESFRI/CRISP program.

75KW RF AMPLIFIER AT 352 MHZ

What it is:

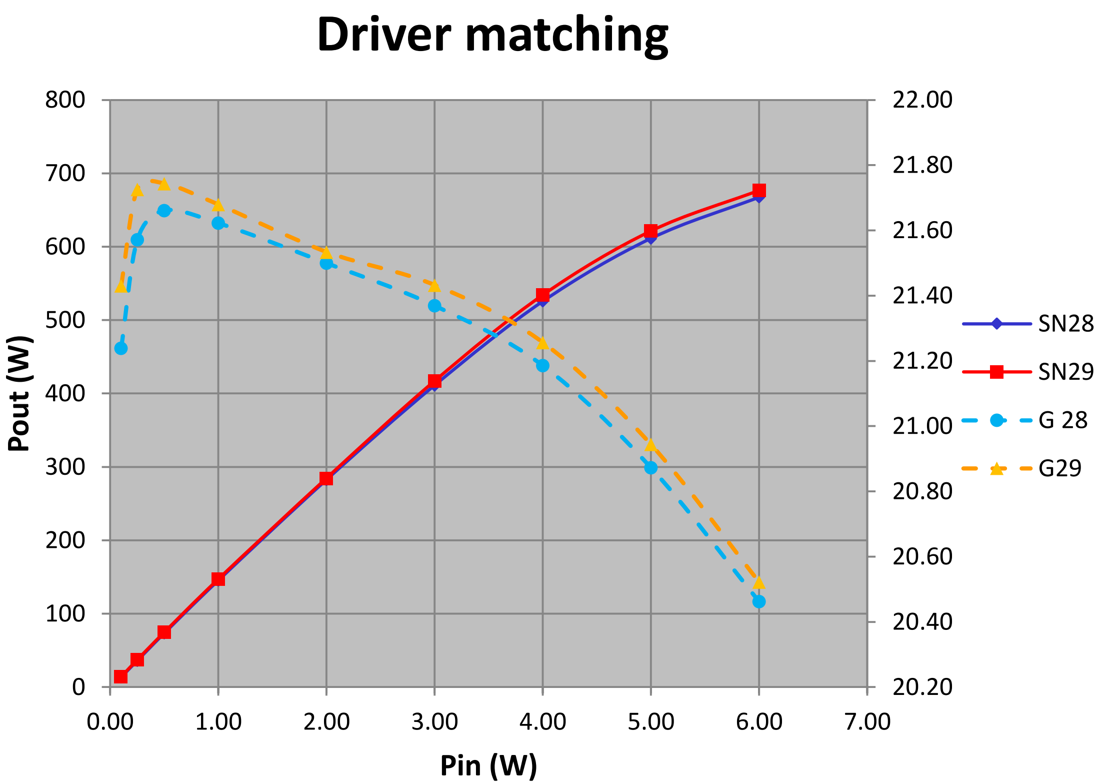


DUAL PRE-AMPLIFIER



DUAL PRE-AMPLIFIERS

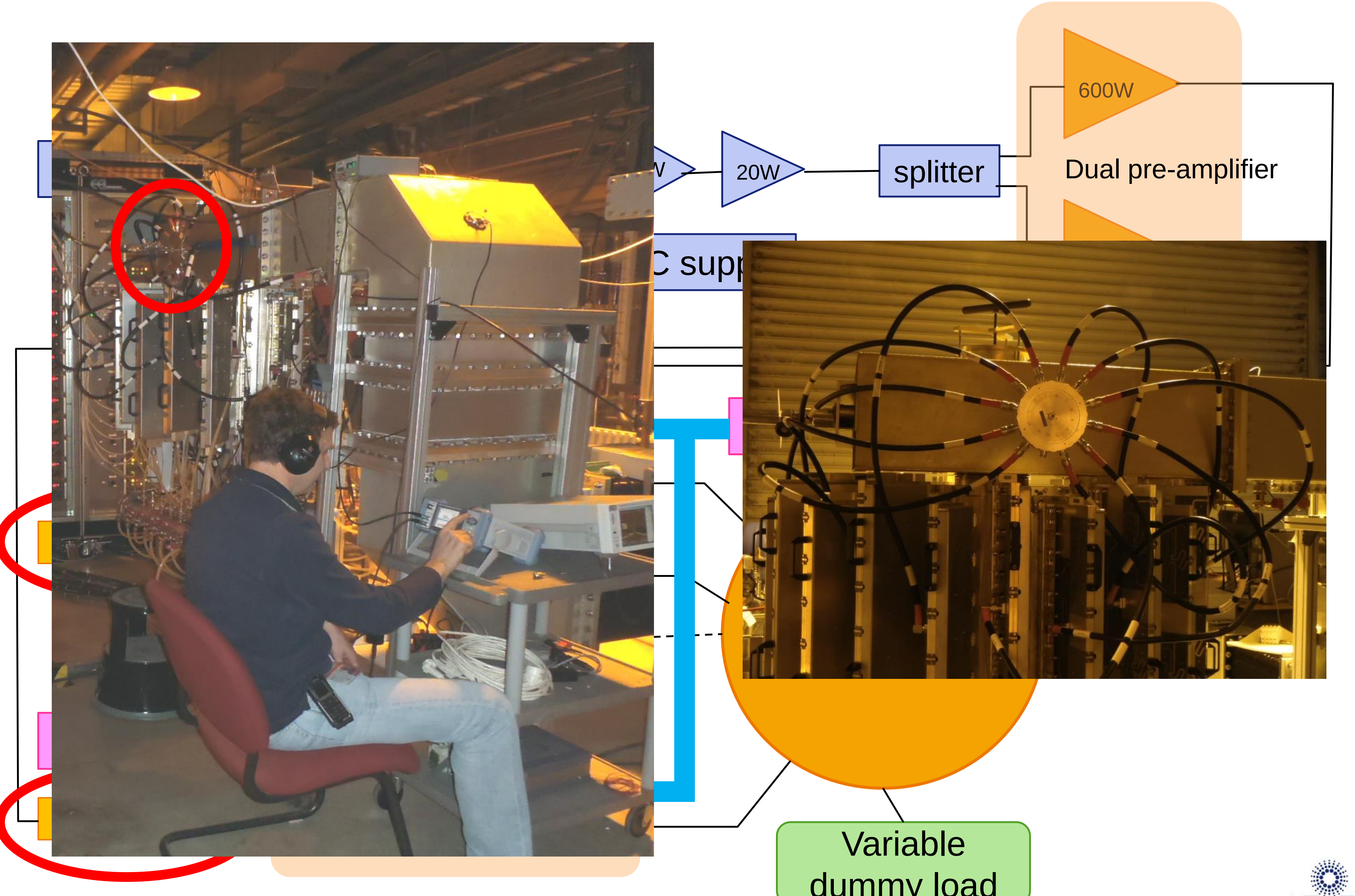
The idle currents of the drivers (SN28 and 29) have been set at 2*1A to ensure a fair gain even at low level.



Unusual features:

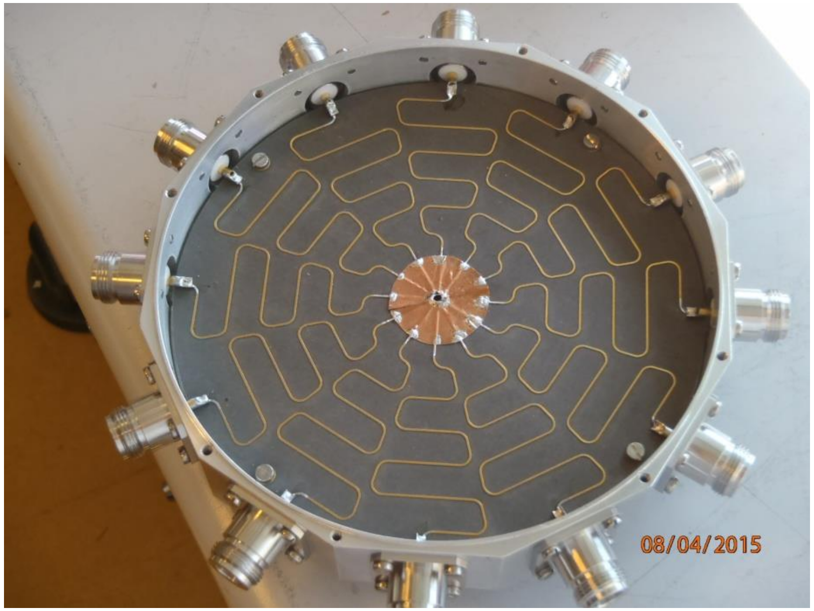
1/ The baluns of the modules are planar and can be printed on the board: cheaper and more reproducible.
2/ No trimming of the modules: far cheaper but a big risk.
3/ DC chokes are replaced by printed λ/4 lines: cheaper and more reproducible.
4/ ceramic matching capacitors: cheaper and easier to place on the boards.
This could be reached only via careful thermal management.

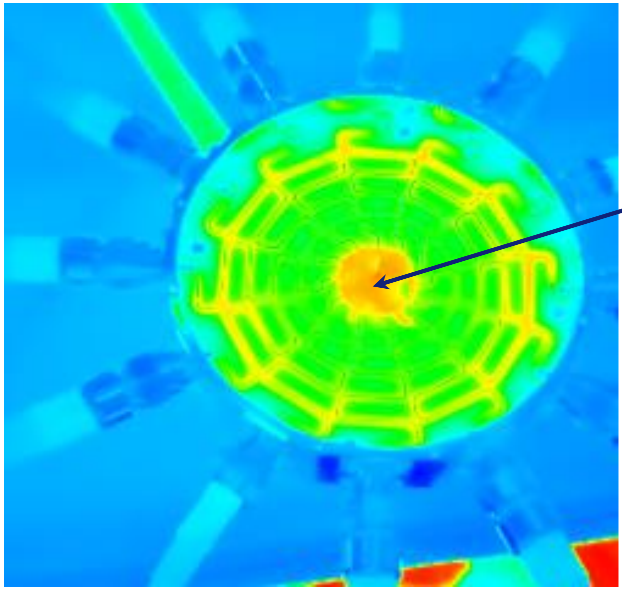
12 WAY SPLITTER



12 WAY SPLITTER

Splitting in 12 calls for high impedance transmission lines ($\sqrt{(12*50*50)}=173\Omega$) . This means very thin printed lines. A thick substrate with low ε was chosen to allow them to each be able to keep conveying 55W.



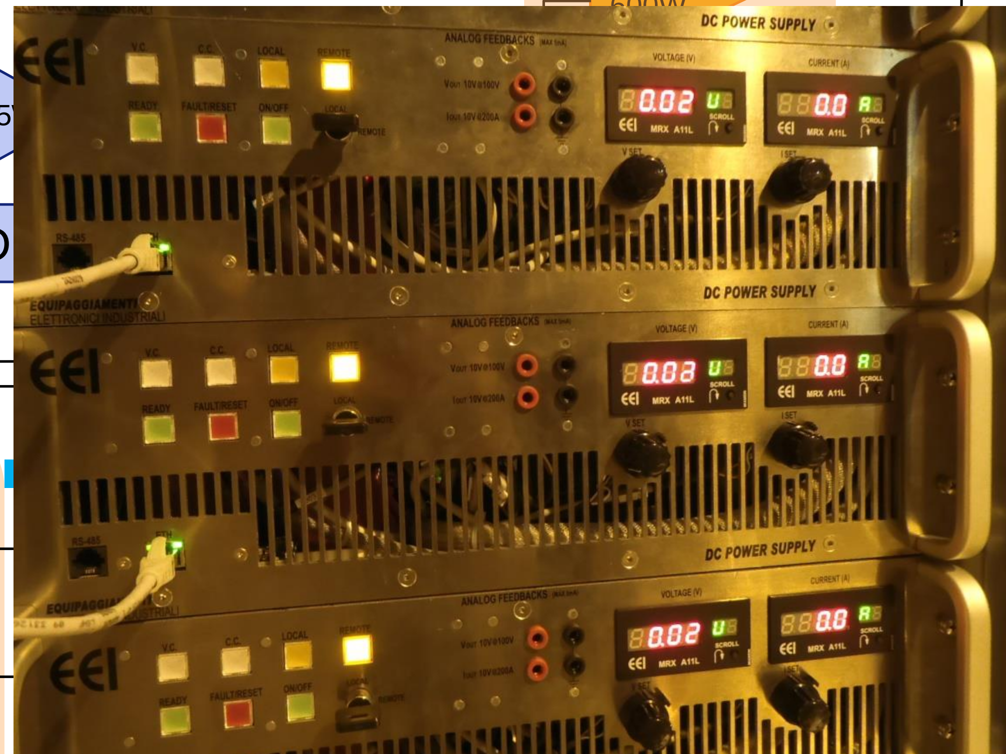


Θmax=56.5°
at 55 W

Maximum discrepancy between ways=0.2dB=4.7%

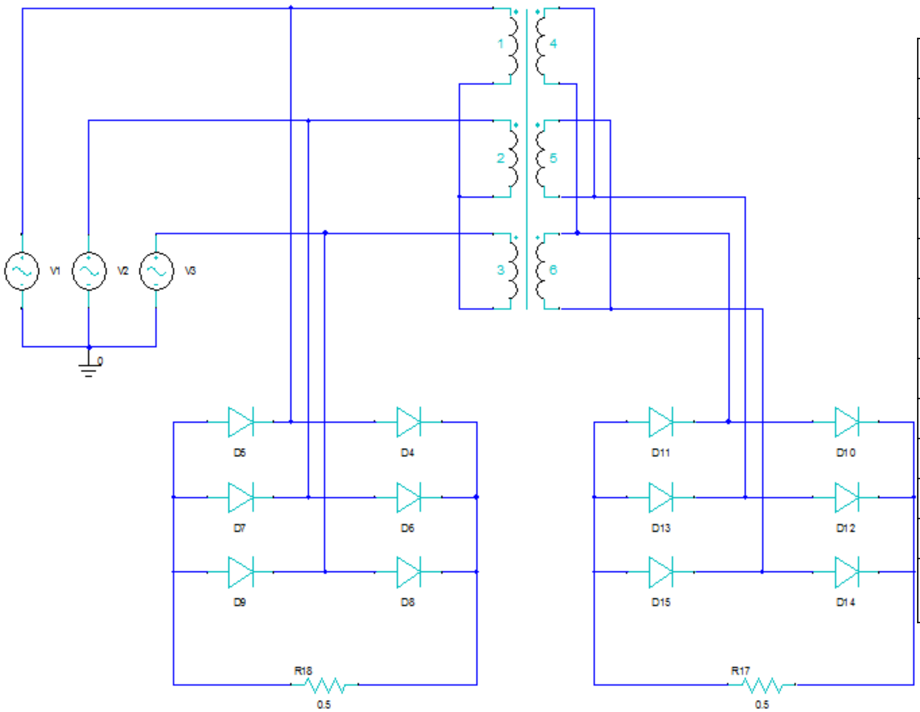
AC/DC CONVERTERS

RF switch and variable attenuator

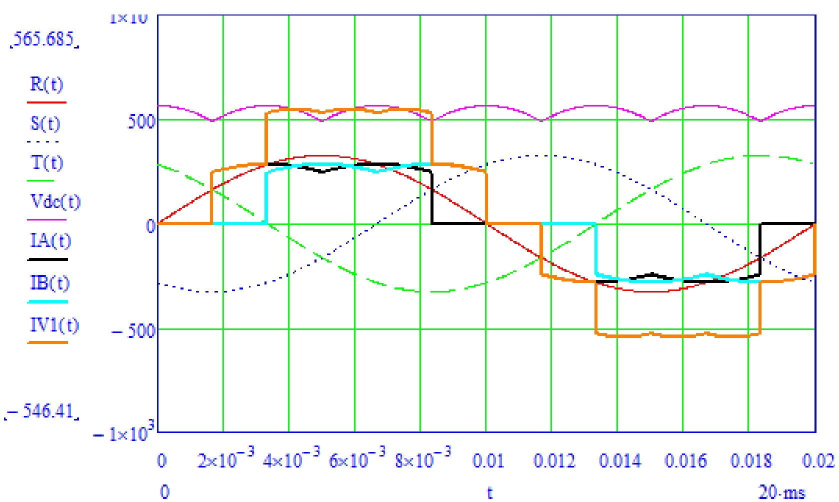


AC/DC converters:
Up to 55V, 8kW
The load can be pulsed (cavity conditioning).
One of the 2 cabinets is fed through a transformer to decrease harmonic currents

EFFECT OF THE TRANSFORMER



					wingA→J	wingK→V + driver
	ϕ1	ϕ2	ϕ3	Σ	Cab 1	cab2
50 Hz	100.0%	100.0%	100.0%			
H2						
H3	1.2%	0.9%	0.7%			
H4	0.0%	0.0%	0.0%			
H5	5.7%	5.6%	5.3%			
H6	0.0%	0.0%	0.0%			
H7	5.0%	4.6%	4.6%			
P	50.5 kW	52.5 kW	52.3 kW	155.2 kW	75.1 kW	80.2 kW
S	51.5 kVA	53.3 kVA	53.4 kVA	158.3 kVA	80.1 kVA	85.6 kVA
Power f				0.98		
Σidc				2690 A	1212 A	1478 A
Pdc				134.5 kW		
η	Converters	+cables	+Xformer	86.7%		

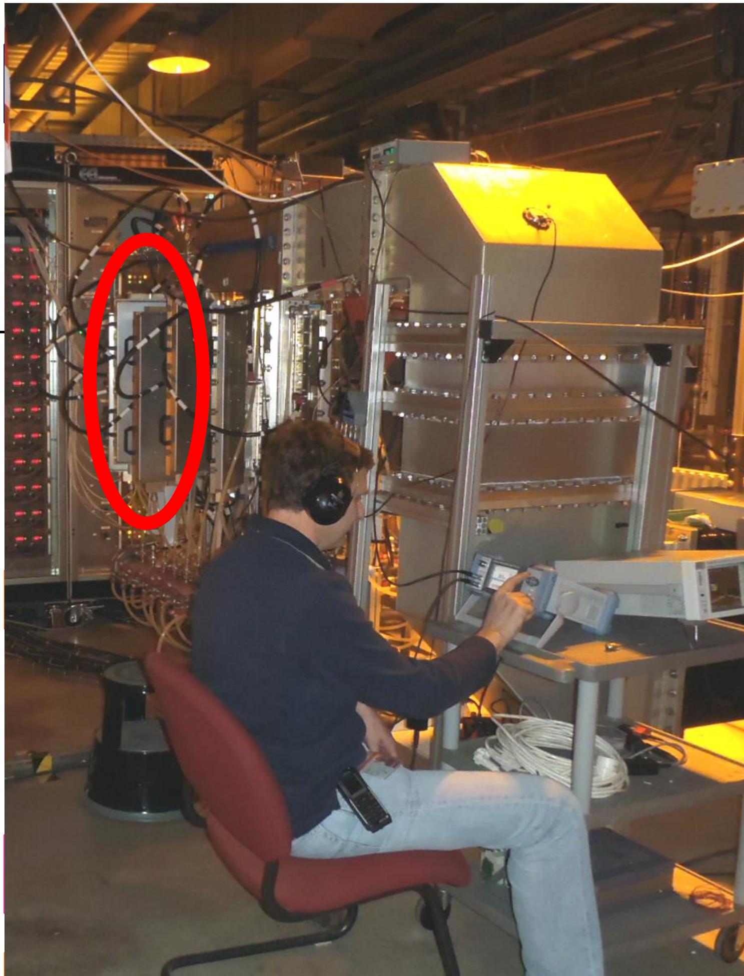


Theory with perfect mains and yd11 transformer

	w/o Xformer	with Xformer
H5	22.6%	6.1%
H7	11.3%	3.0%

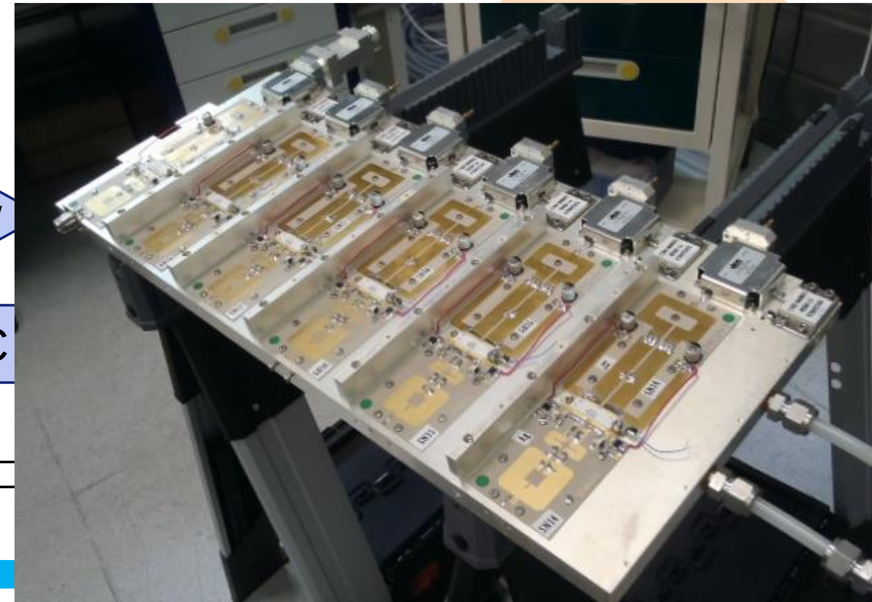
WINGS

RF switch and variable attenuator



5W

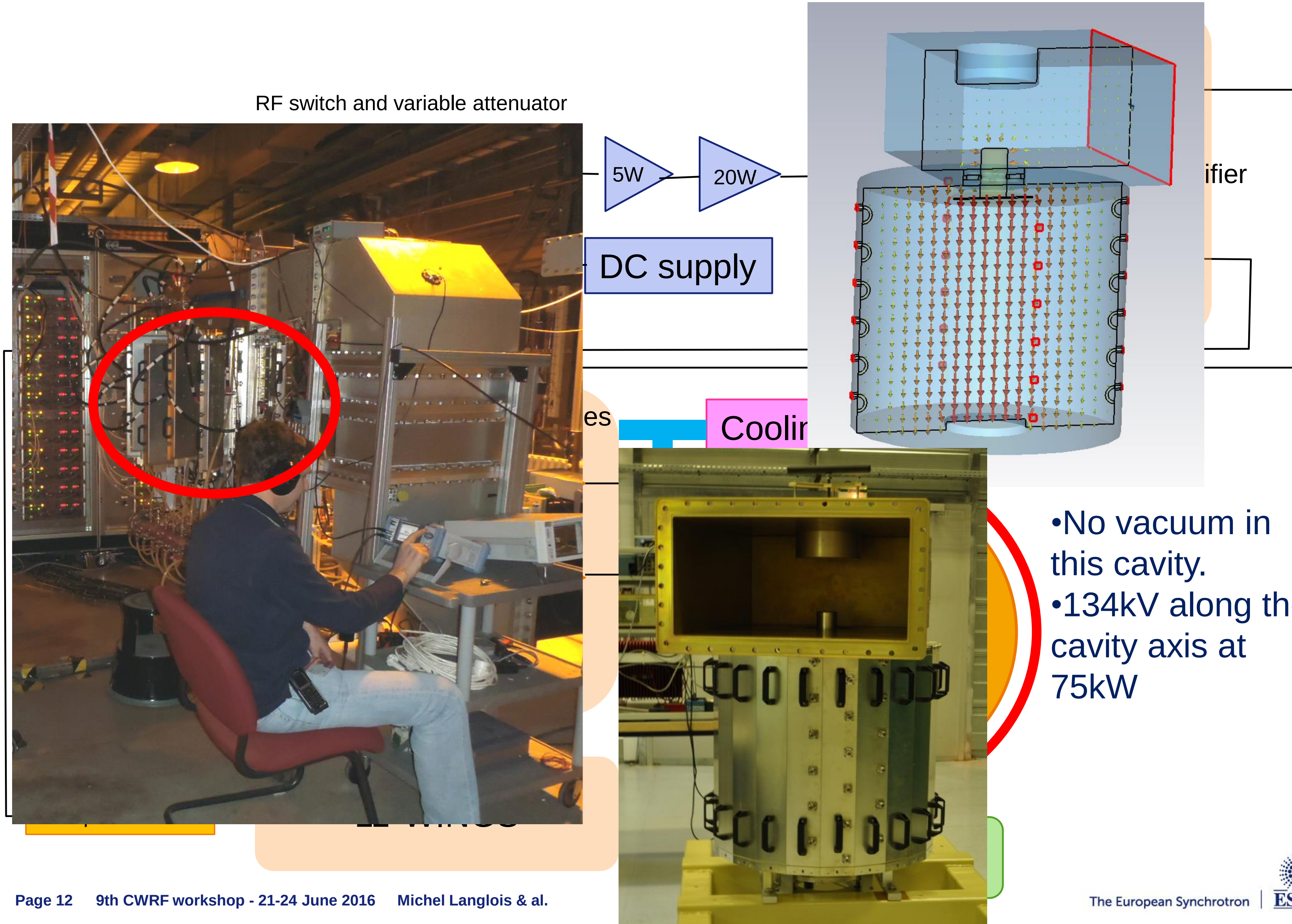
DC



Variable dummy load

CAVITY COMBINER

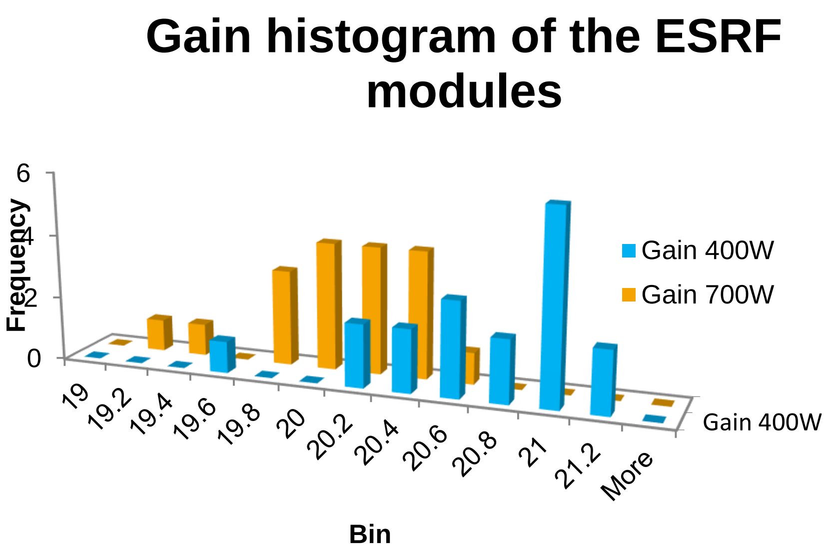
RF switch and variable attenuator

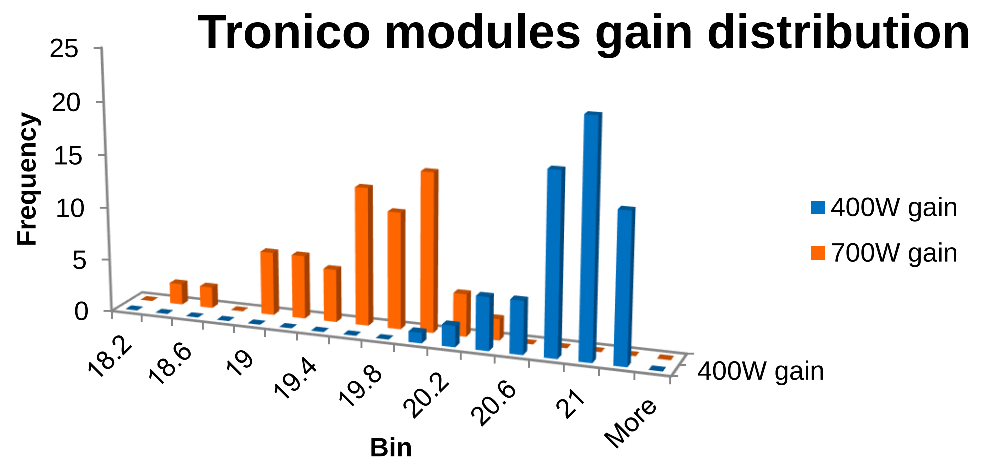


- No vacuum in this cavity.
- 134kV along the cavity axis at 75kW

THE BIG RISK (GAIN)

A cavity combiner works ideally if all input loops are fed with the same current amplitude and phase. It means that the gain and the in-out phase difference of all modules should ideally be equal.

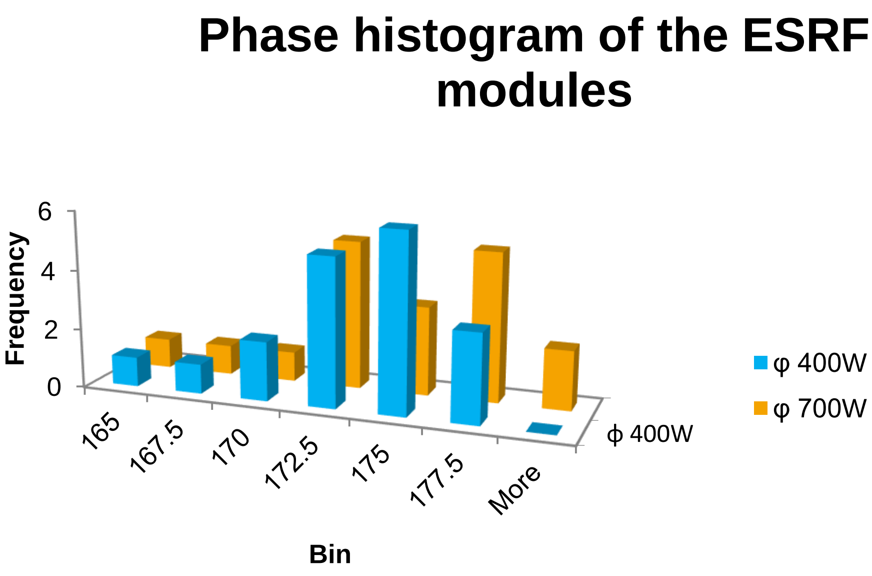


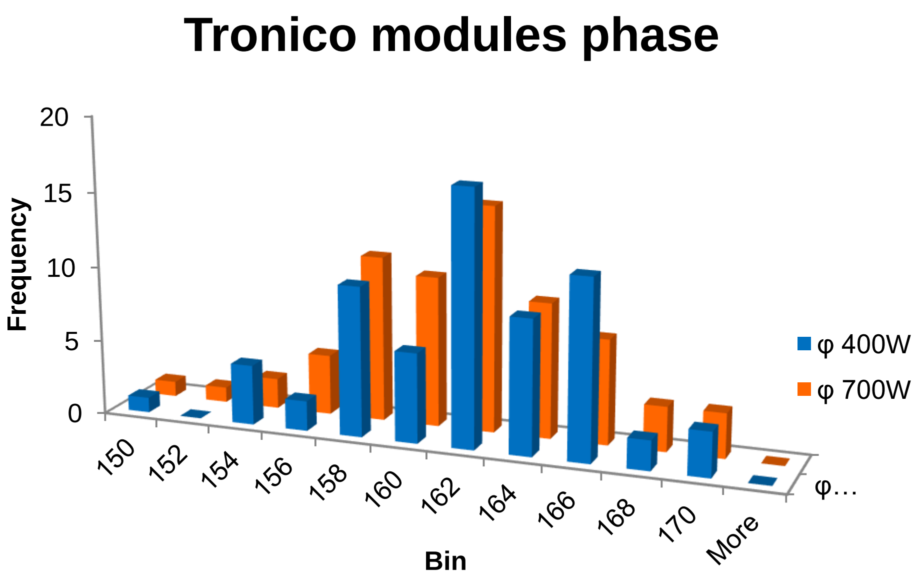


	ESRF modules	Tronico modules
σ gain 400W	0.33 dB	0.25 dB
σ gain 700W	0.60 dB	0.43 dB

Not exactly ideal…

THE BIG RISK (PHASE)





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

Not exactly ideal…

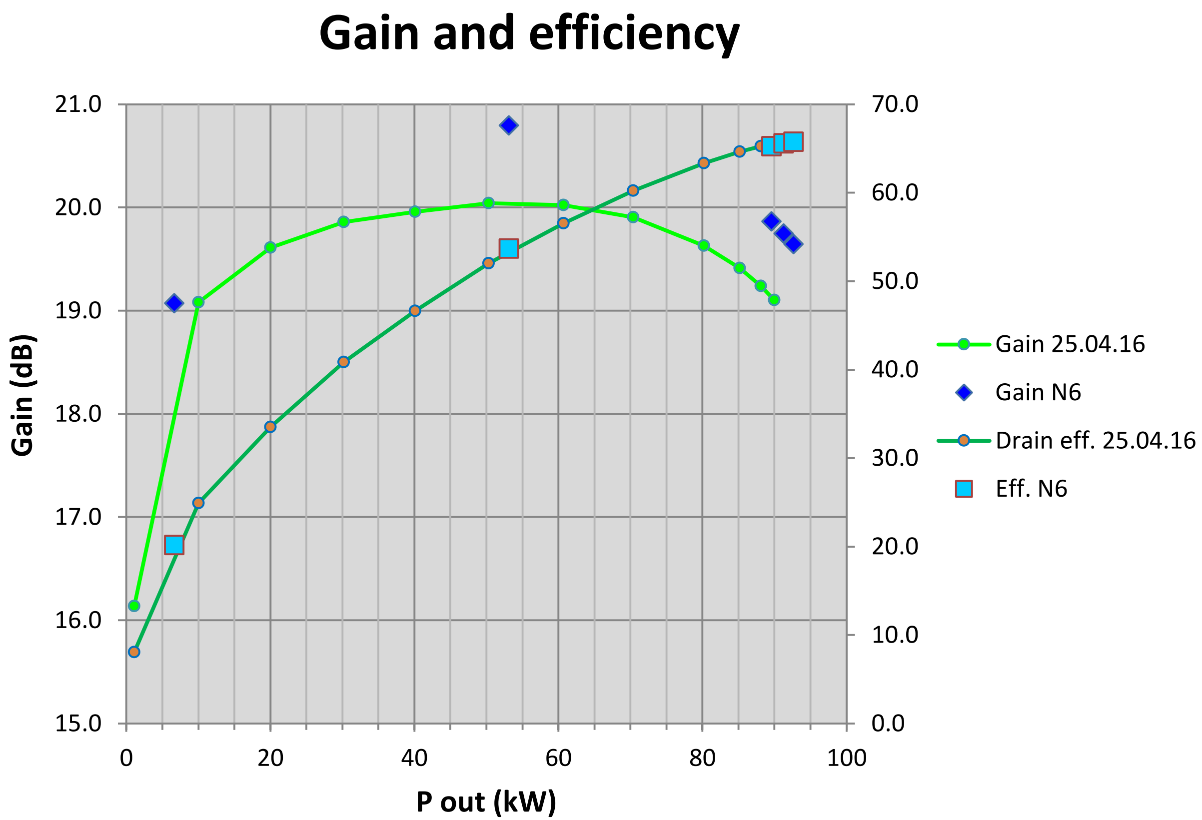
EVEN BETTER…IT WORKS!!!!

Output power
(confirmed by calorimetry)

Input for 11 wings

We do measure some RF leakage around the combiner

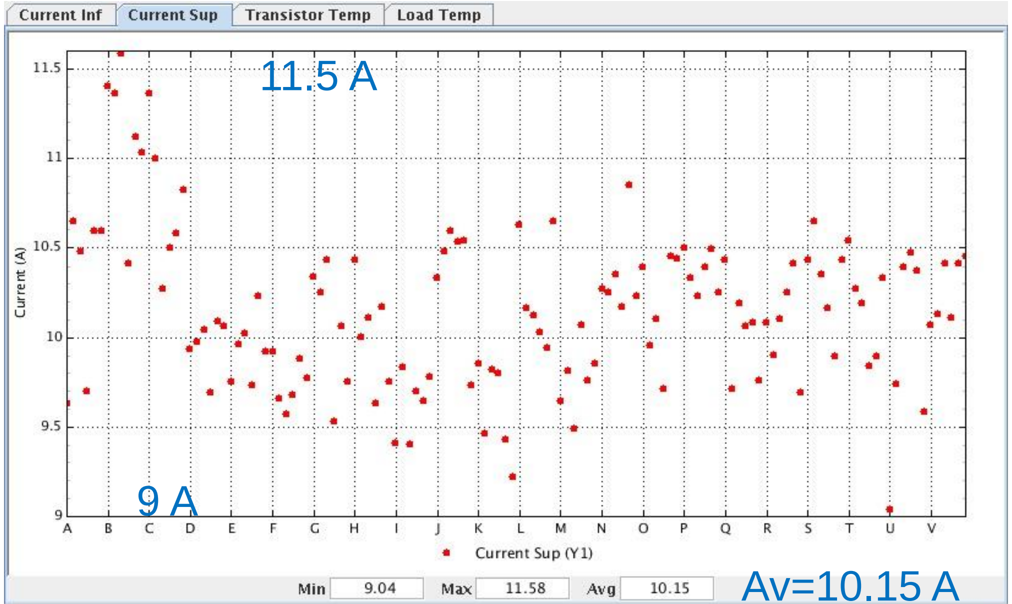
GAIN AND DRAIN EFFICIENCY

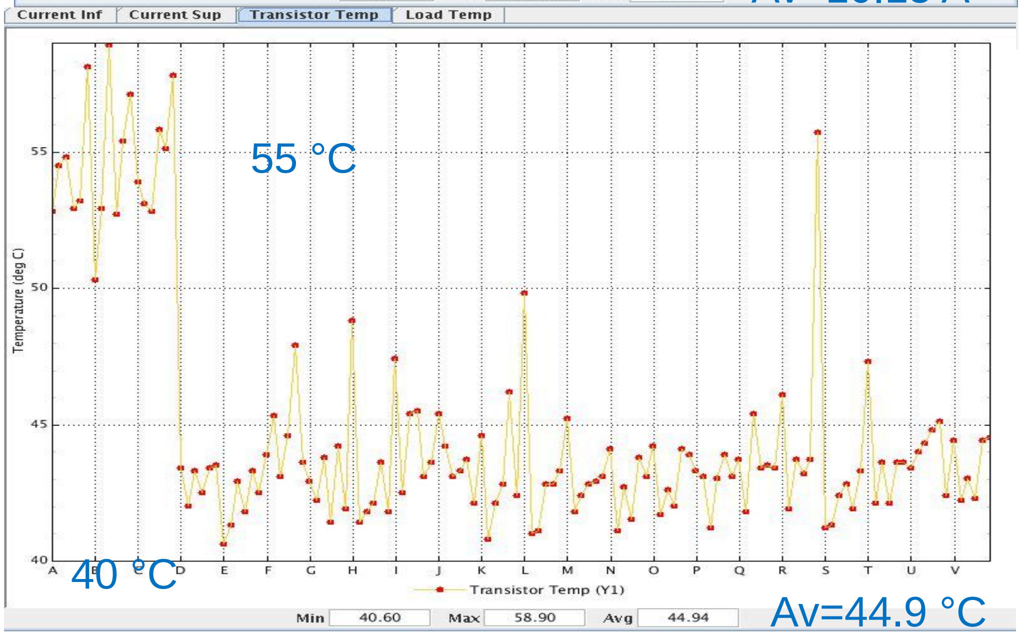


Compression at 85kW is -0.6dB.
Drain efficiency reaches 64.6%.

3 modules have their gains and efficiencies within 0.1dB or 1% of the average of the whole population. N6 is one of them.

1000H TEST



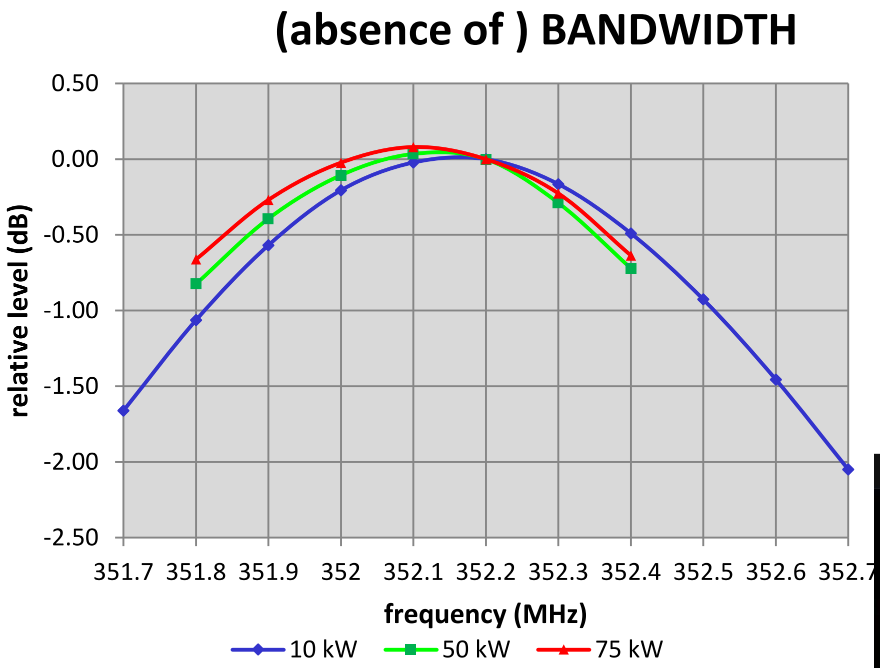


At 85 kW

The current in the A, B and C wings are higher than the rest: the modules of these wings were made at the ESRF AND their input powers are high.

The transistor temperatures of wings A,B and C are 10° above the rest. These wings have a single channel transistor cooling as the others have two smaller channels with the same overall flow (10l/min).

BANDWIDTH , ETC…



Only 500kHz @ -0.5dB

Pulse mode works fine. Example below with 1ms pulse at 83 kW: 3.6V variation on the 50V drain voltage.
We could have from 20us up to 10ms width without problem.

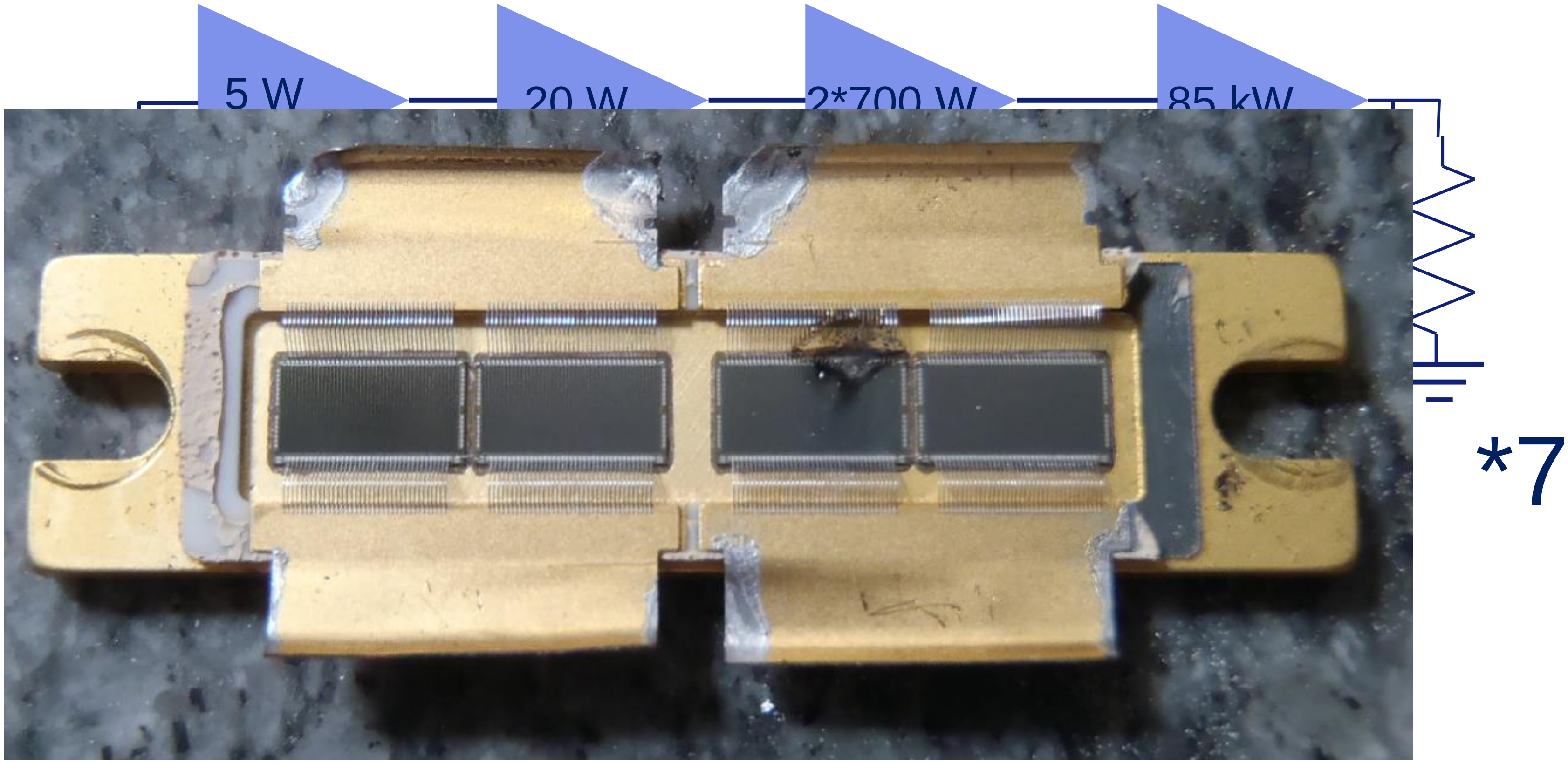
Still pending:

VSWR tests

To assess the operation on an unmatched load.

TROUBLE

Gain : 35dB + 30dB + 22dB + 20dB =107 dB!



PRODUCTION PRICES

Hardware: 177.8 k€
Manpower (100 €/h)

combiner and support fitting	: 4 k€
cooling fitting	: 2.4 k€
wings fitting	: 36.8 k€
test	: 4 k€
Σ	: 47.2 k€

Total : 225 k€ or 2.65 €/W

Development efforts, documentation, purchasing manpower are not included.
The 50V supplies, the transformer and the DC or 50Hz cabling are not included in this price.
Full commissioning (VSWR, partial loss, etc…)is not included.

THANKS

Thanks to everyone who is participating in this interesting development

…and to all of you for listening quietly

If you found this talk interesting, you are more than welcome to visit us in the RF lab in SRRF1, close to pillar 24 of the technical zone.

ADVERTISEMENT

1.3 MW
352 MHz
Dummy
load