MAX

MYRRHA ACCELERATOR EXPERIMENT

RESEARCH & DEVELOPMENT PROGRAMME

Development of 700 MHz SS Amplifiers

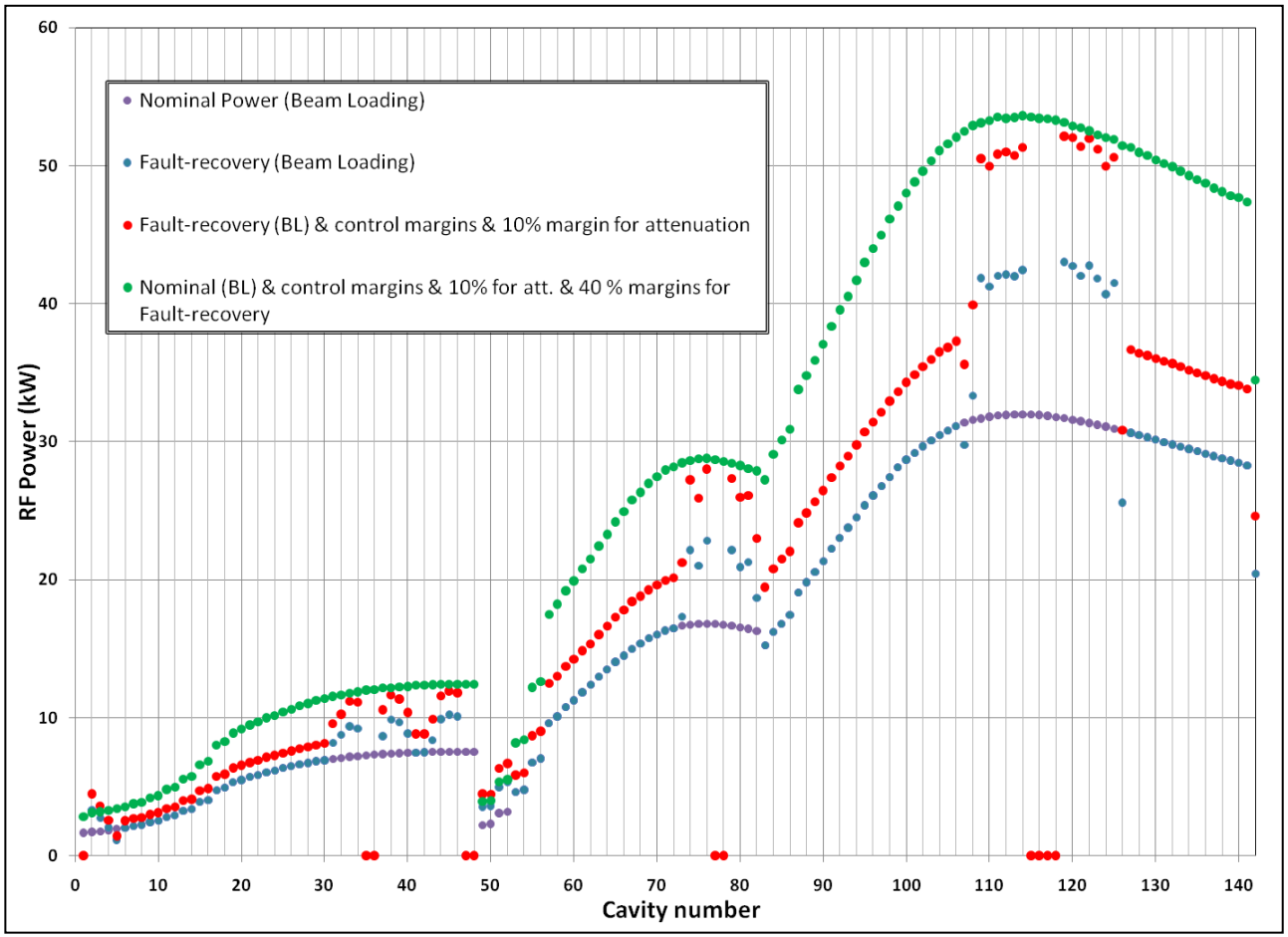
EuCARD-2 Accelerator for ADS

CERN 20/ 21March 2014

S.Sierra/ B.Darges

THALES

For the record: RF needs along the Linac



See F Bouly presentation

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- Major requirements:
  - 94 cavities have to be fed with RF @ 704MHz and in CW
  - Reliability of the RF amplifier & ancillaries has to be optimized (> 50 000h)
  - Fast beam recovery procedures using neighboring cavities in case of failure is foreseen.

- The recovery procedure (neighboring cavities) is not thinkable with a power distribution through several cavities
- It's always better to independently phased cavities
- Power distribution through the linac is not constant (from 18 to 55 kW cw)
- The RF power need for each cavity is rather low (few tens of kilowatts)

- **In this particular case, SSPA is foreseen for RF amplifiers**

Advantages:

- No High Voltage (few tens of V)
- Power adjustments configuration possible at the installation :
  - A common design of cabinets could be foreseen with cabinets receiving individuals modules adapted to the position along the linac
- Sufficient space is necessary
- Due to the relative low power the balance efficiency between recombination losses/ SS efficiency is acceptable
- One single module fault RF is still available

But:

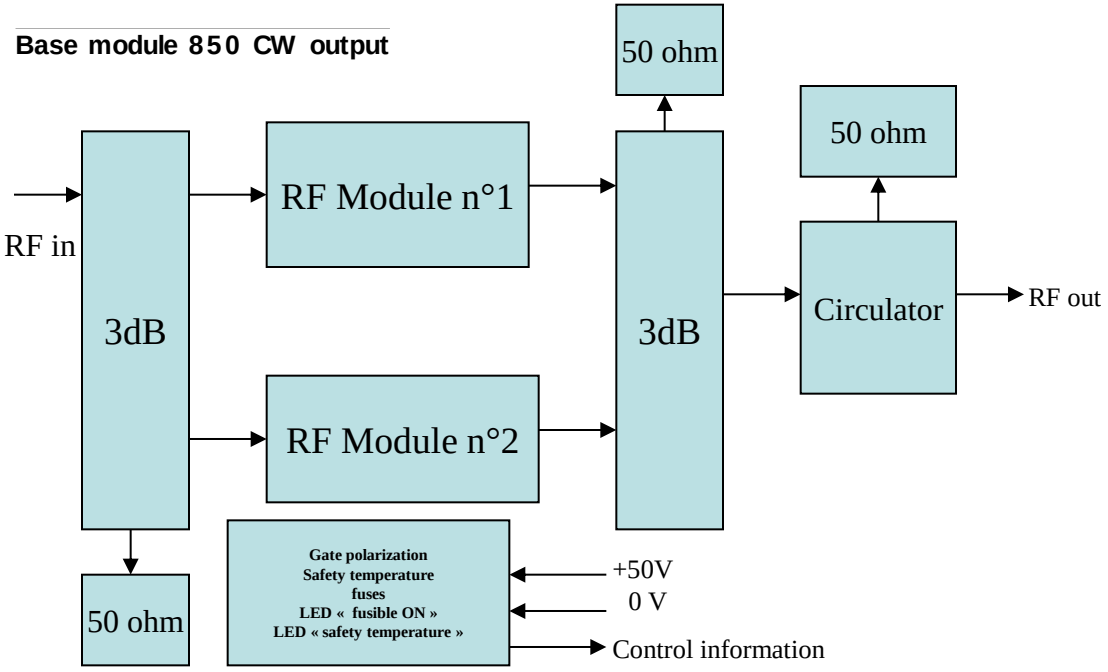
- Special attention must be done on the design and protection of individual modules and power supplies (including redundancies of these PS)
- with all protective devices, redundancies on the power supplies and architecture this solution is quite expensive.

SSPA architecture

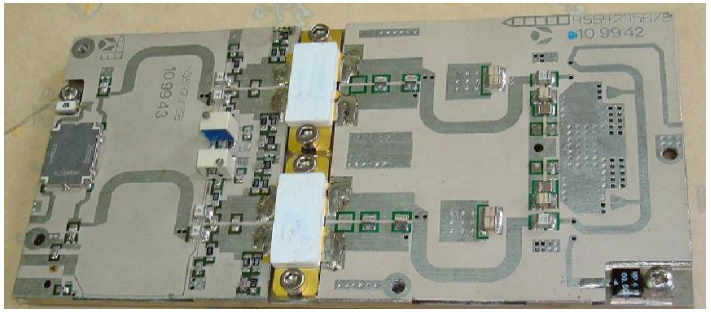
From individual modules up to the final amplifier

With individual fault operation consequency

RF base Module 850CW @ 700MHz



Example RF base module 300W@500MHz



- None adjusting RF
- 90% CMS devices
- Last generation Technologies Transistors
- RoHS compliant

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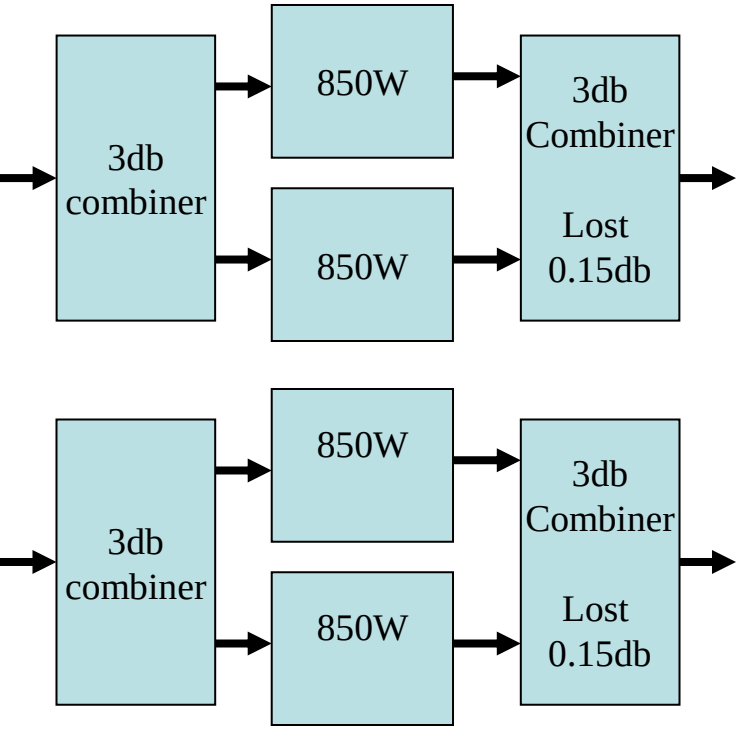
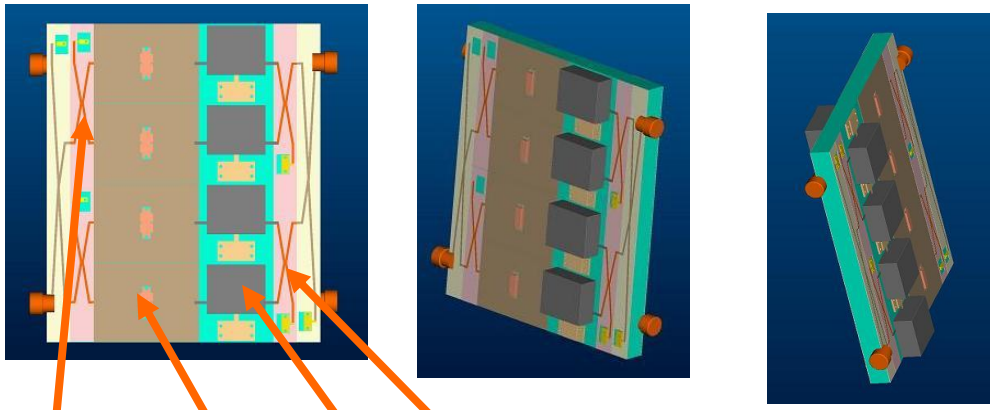
2 x 1.6 kW CW @ 700MHz base block (two sides)





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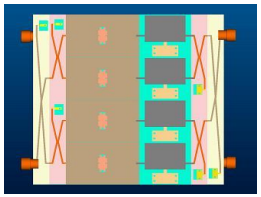
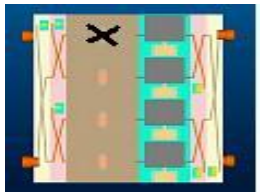
Calculation on lost config. N°1

Place	Base power	Transistors OFF	Output Power (W)	db
A	1600	0	1600	0,0
B	1600	1	900	-2,5
C	1600	2	400	-9,0
D	1600	3	100	-12,0
E	1600	4	0	



A



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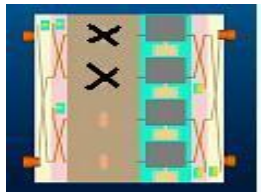
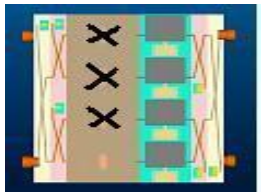
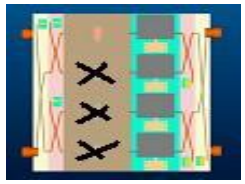


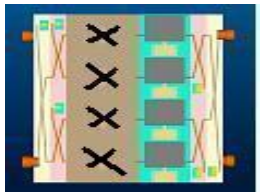
C



D



D



E

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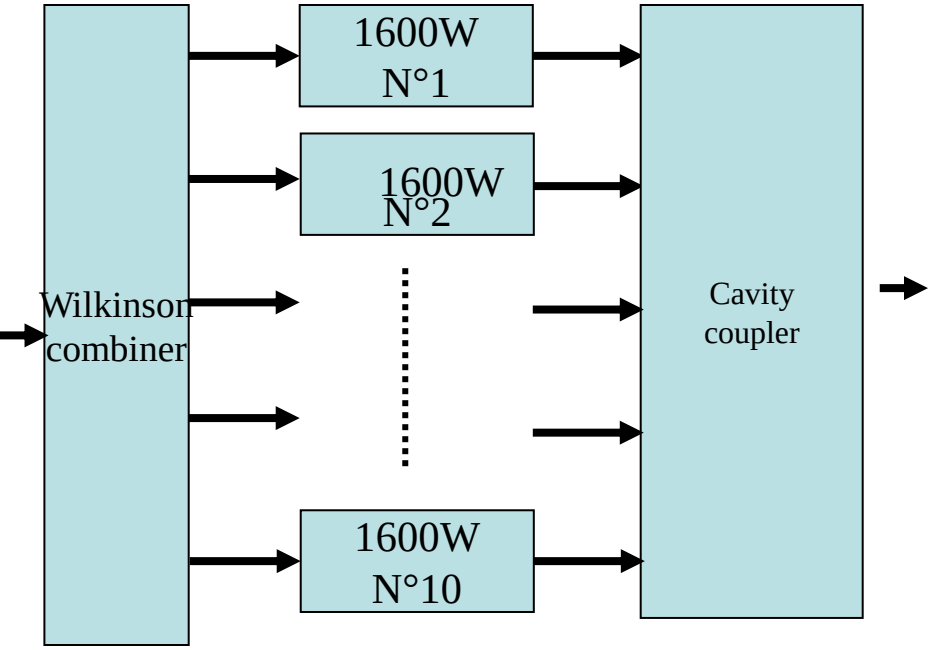
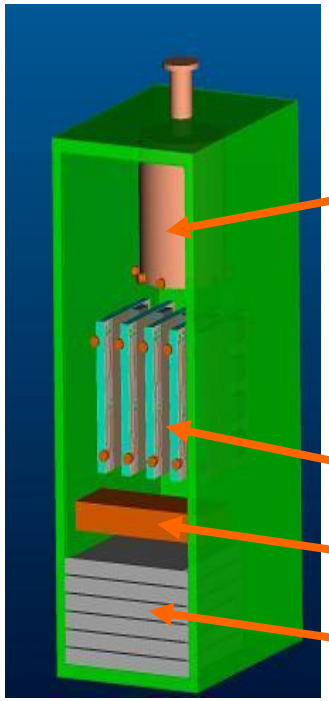
16 kW CW @ 700MHz base block





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Evaluation Output Power=F(Transistors ON/ OFF)

Cavity coupler (example ➔ 4 inputs)
(Thales Patent)

Cavity 10 inputs		
N	Lost	Pout
0	0db	16Kw
1	0,2db	15,3Kw
2	0,45db	14,4Kw
3	0,67db	13,7Kw
4	0,9db	13Kw

THALES

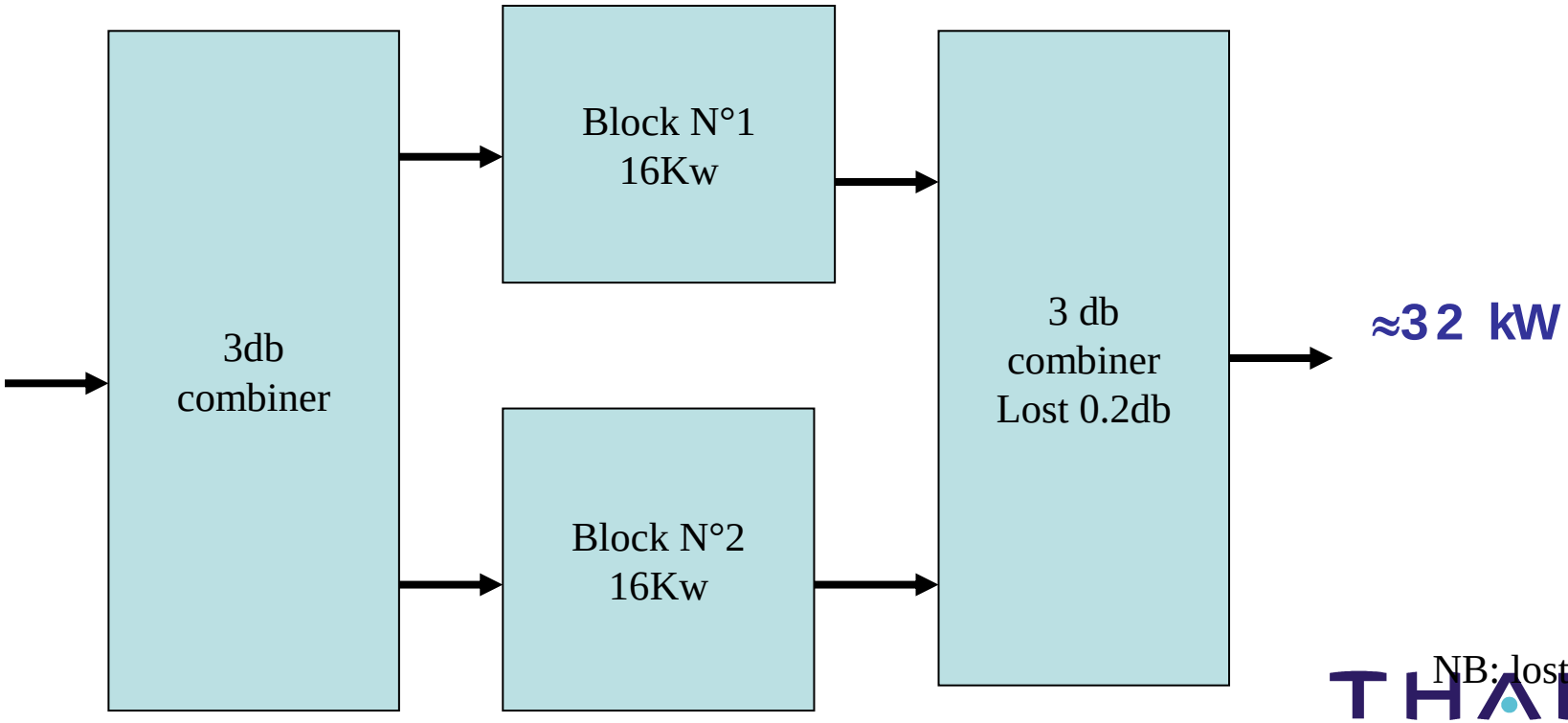
Evaluation Output Power=F(modules ON/ OFF)

Cavity coupler (example ➔ 4 inputs)
(Thales Patent)

3.2Kw fail

Cavity coupler 10 inputs		
N (fail ==> Nx1,6Kw)	perte	Pout
0	0db	16Kw
1	0,9db	13Kw
2	1,7db	11Kw
3	2,5db	9Kw

Pout ≈32 kW CW @ 700MHz cabinet



NB: lost 0.3db

THALES

Evaluation Output Power =F(transistors ON/ OFF)

$$P_{out} = \frac{P_1 + P_2 + 2\sqrt{P_1}\sqrt{P_2}}{2}$$

Transistors fail	Pout cabinet 1	Pout cabinet 2	total Pout	Lost
0	16Kw	16Kw	32KW	0db
1	15,3Kw	16Kw	31,3KW	0,1dB
2	14,4Kw	16Kw	30,4KW	0,22dB
3	13,7Kw	16Kw	29,6KW	0,34dB
4	13Kw	16Kw	28.9KW	0,45dB

1.6Kw fail

Evaluation Output Power =F(modules 1.6 Kw ON/ OFF)

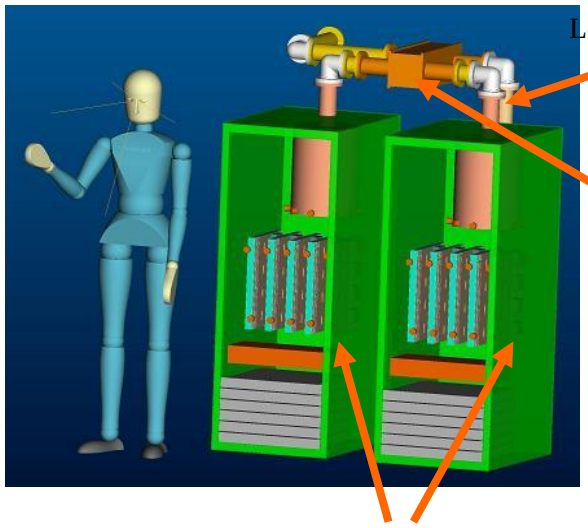
$$P_{out} = \frac{P_1 + P_2 + 2\sqrt{P_1}\sqrt{P_2}}{2}$$

3.2KW fail

1.6 KW fail

P1	P2	Pout
16Kw	16Kw	32Kw
13Kw	16Kw	28,9Kw
11Kw	16Kw	26,8Kw
9Kw	16Kw	19,5Kw

Pout ≈32 kW CW @ 700MHz Cabinet



What could be proposed for the linac:

3 kinds of cabinets:

- One family of 16 kW (11 kW with 3.2 kW off
- Another one at 32 kW (28kW with 3.2 kW off)
- Last at 64 kW (60kW with 3.2 kW off)

Prototyping and results

BLF888A ➔ NXP

1. Product profile

1.1 General description

A 600 W LDMOS RF power transistor for broadcast transmitter applications and industrial applications. The excellent ruggedness of this device makes it ideal for digital and analog transmitter applications.

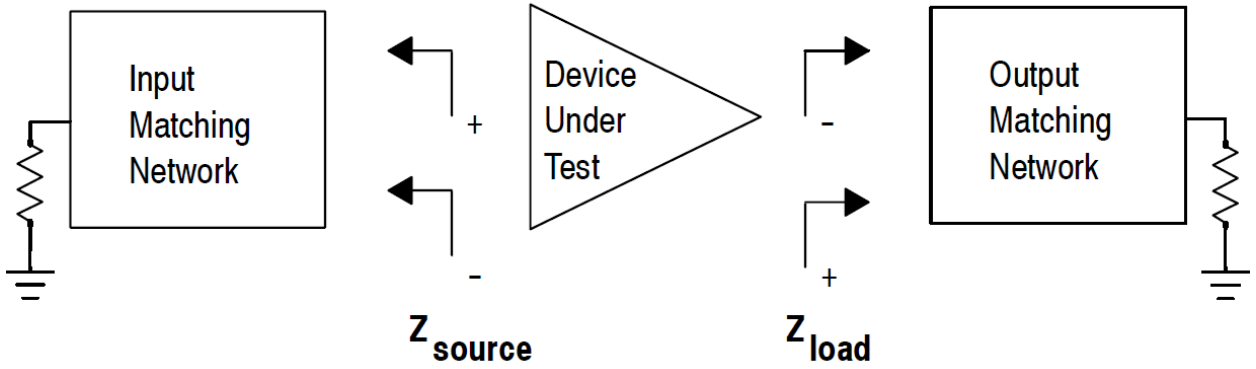
Table 1. Application information

RF performance at V_{DS} = 50 V unless otherwise specified.

Mode of operation	f (MHz)	$P_{L(AV)}$ (W)	$P_{L(M)}$ (W)	G_p (dB)	η_D (%)	IMD3 (dBc)	IMD_{shldr} (dBc)	PAR (dB)
RF performance in a common source 860 MHz narrowband test circuit								
2-tone, class-AB	f_1 = 860; f_2 = 860.1	250	-	21	46	–32	-	-
pulsed, class-AB [1]	860	-	600	20	58	-	-	-

Load pull measurement

RF base Module 400CW @ 700MHz



Z_{source} = Test circuit impedance as measured from gate to gate, balanced configuration.

Z_{load} = Test circuit impedance as measured from drain to drain, balanced configuration.

Measurement

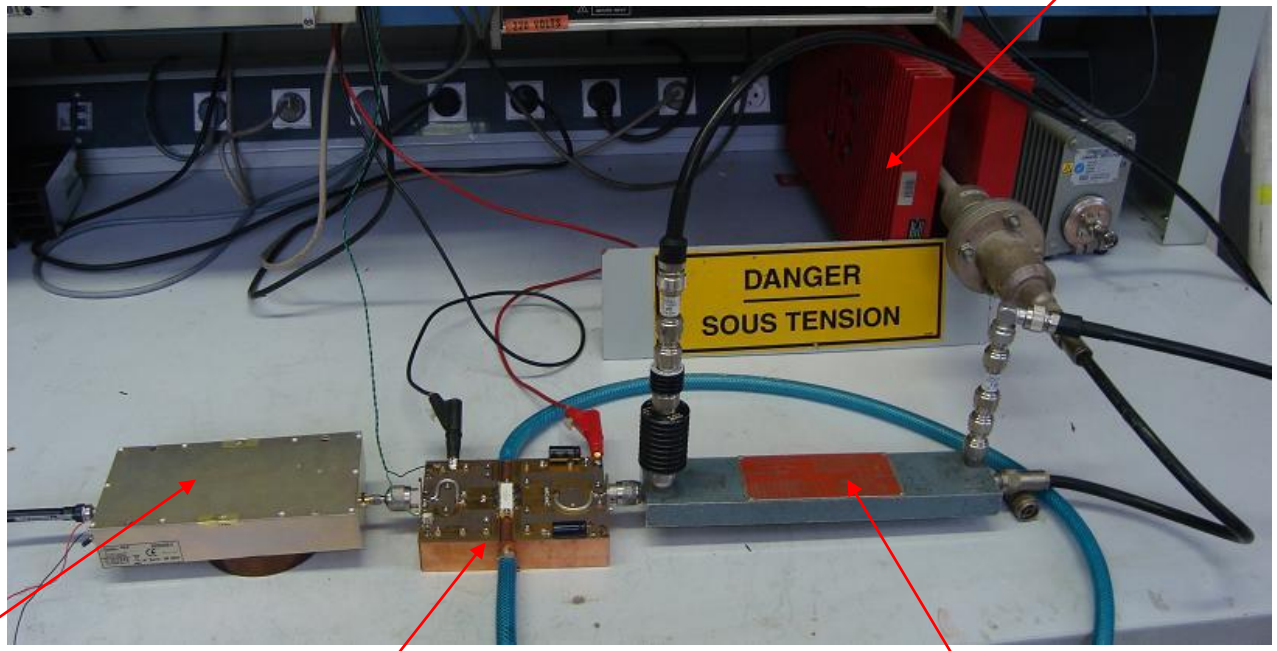
Frequency	Zsource (ohm)	Zload(ohm)
700	2,2+J0,1	5,6+J1,2

Gain	Pout	Compression	efficency
19dB	575 pulse (duty 20%)	1 db	55%

Gain	Pout	Compression	efficency
20dB	400 W CW	0,1dB	55%

Physique measurement

Load 50Ohm
1KW

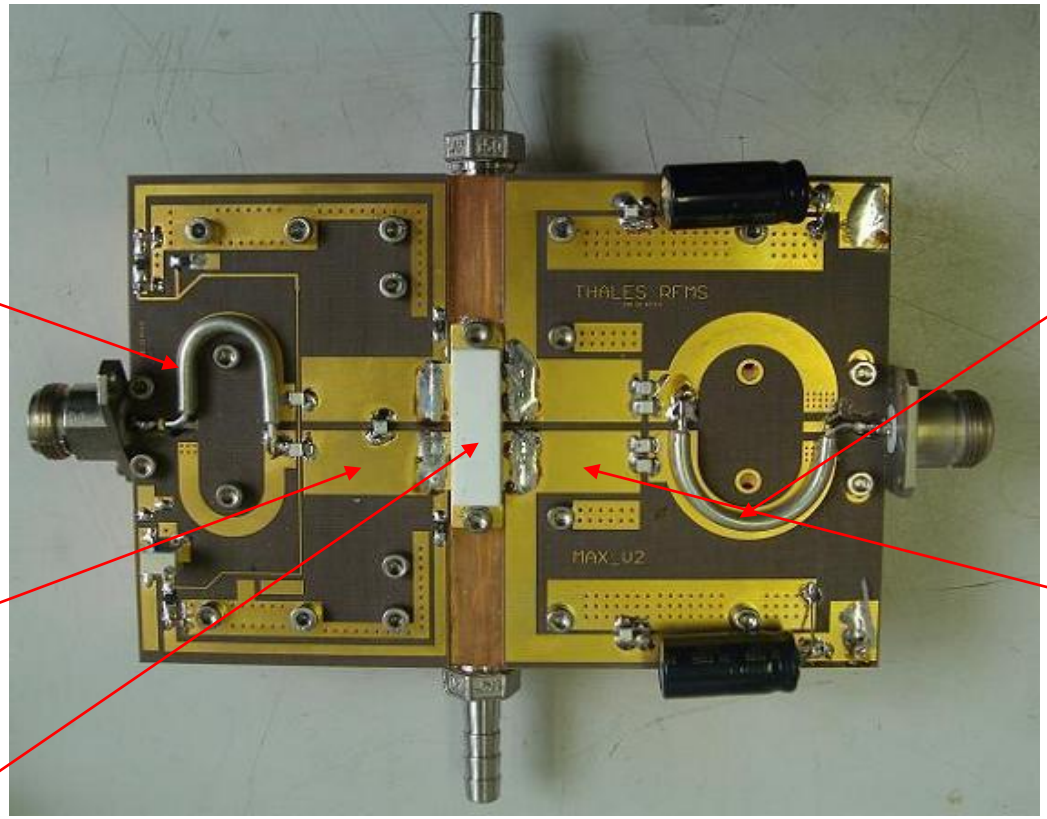


driver

amplifier

Measurement coupler

RF module V2



Input balun
Zc=25ohm

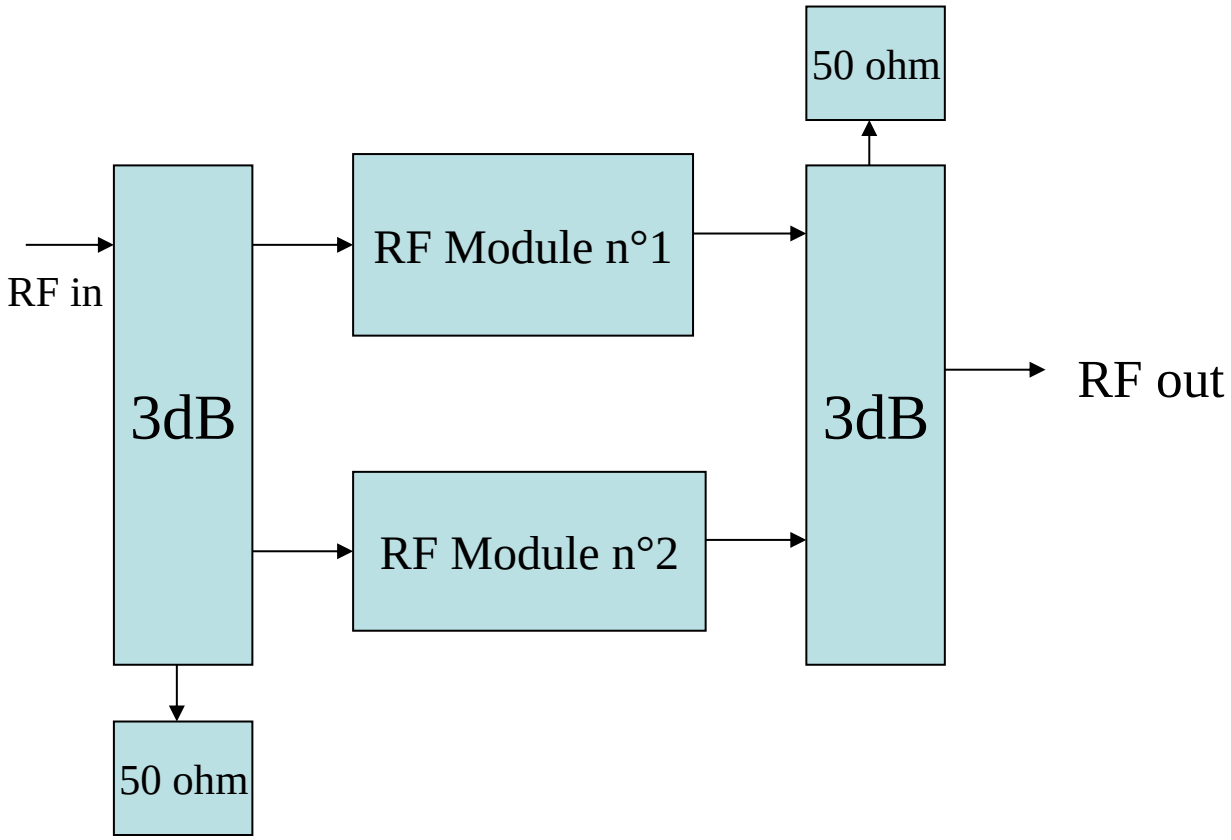
Output balun
Zc=25ohm

Input
matching

Output
matching

RF transistor

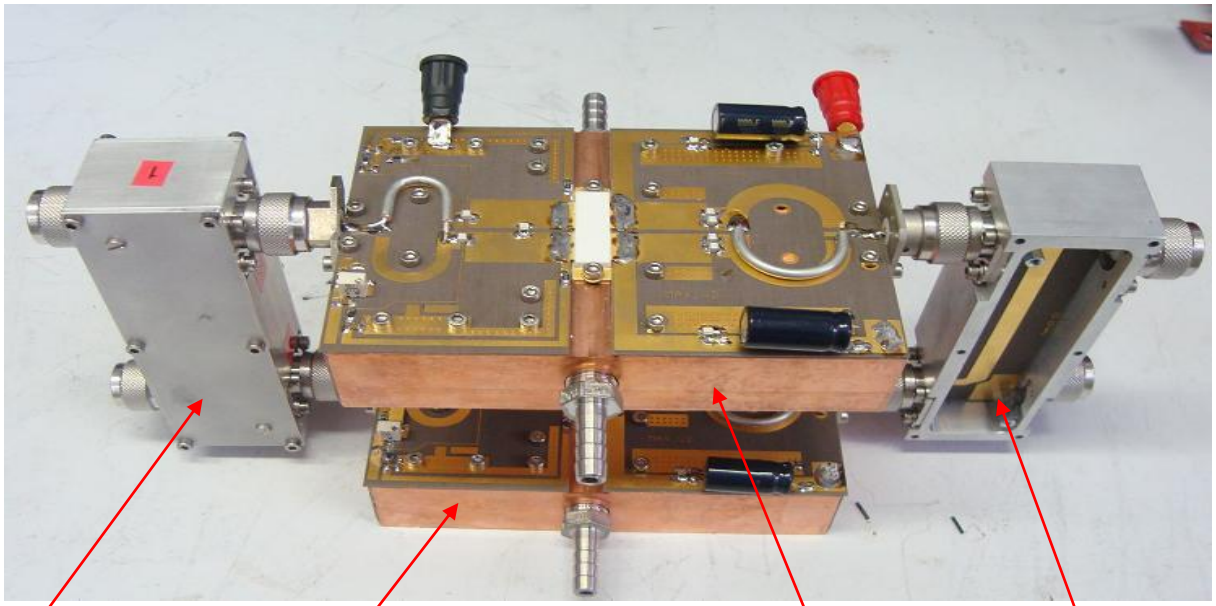
RF base Module 2x400CW @ 700MHz



3 db micro-strip (prototype)

lost(S23,S13)	coupling (S23,S13)	Adaptation(S11,S22,S33,S44)	isolation (S12)
-0,23dB	-3,2dB	> -18 dB	>-20dB

2 RF modules coupled (prototype)



3dB coupler
Input printed

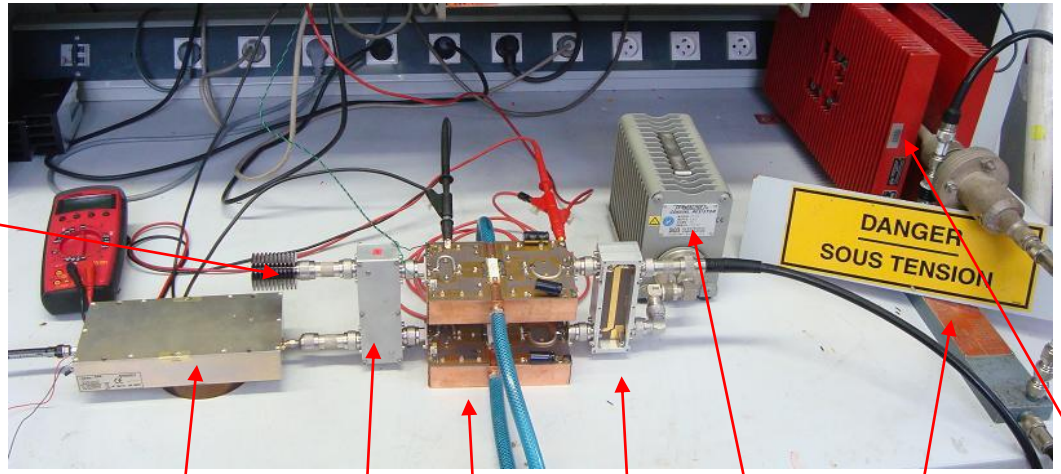
Amplifier N°1

Amplifier N°2

3dB coupler
Output printed

Gain	Pout	Compression	efficency
19,7dB	880 W pulse (duty 20%)	0,1 db	49%
19,7dB	800 W CW	0,3db	51%

Measurement



50ohm 10W

Driver

3dB coupler Input

2x 400W amplifier

3dB coupler Output

50ohm 500 W

Measurement coupler

50ohm 1KW

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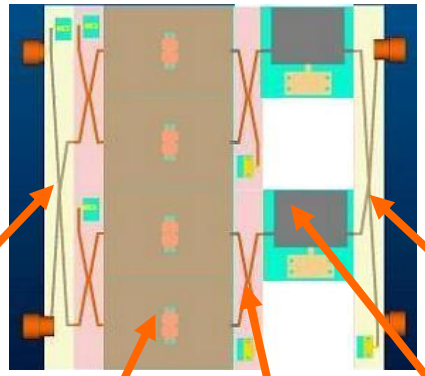
Next possible steps

Step N° 1

2 x 1.6 kW CW @ 700MHz base block



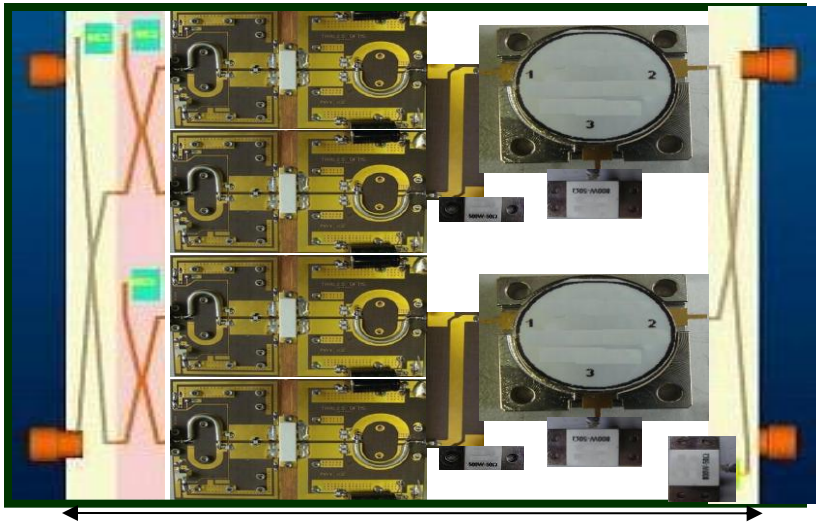
3 x spliters

4 x Base modules

2 x « 3dB coupler »

2 x isolators

1x combiner



450mm

500mm

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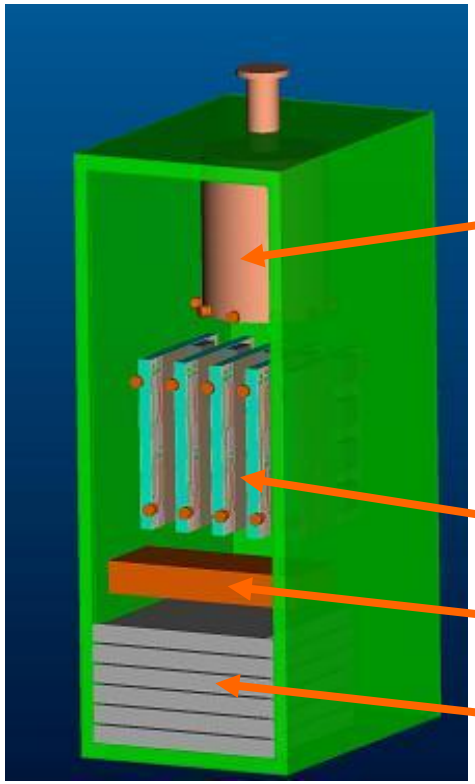
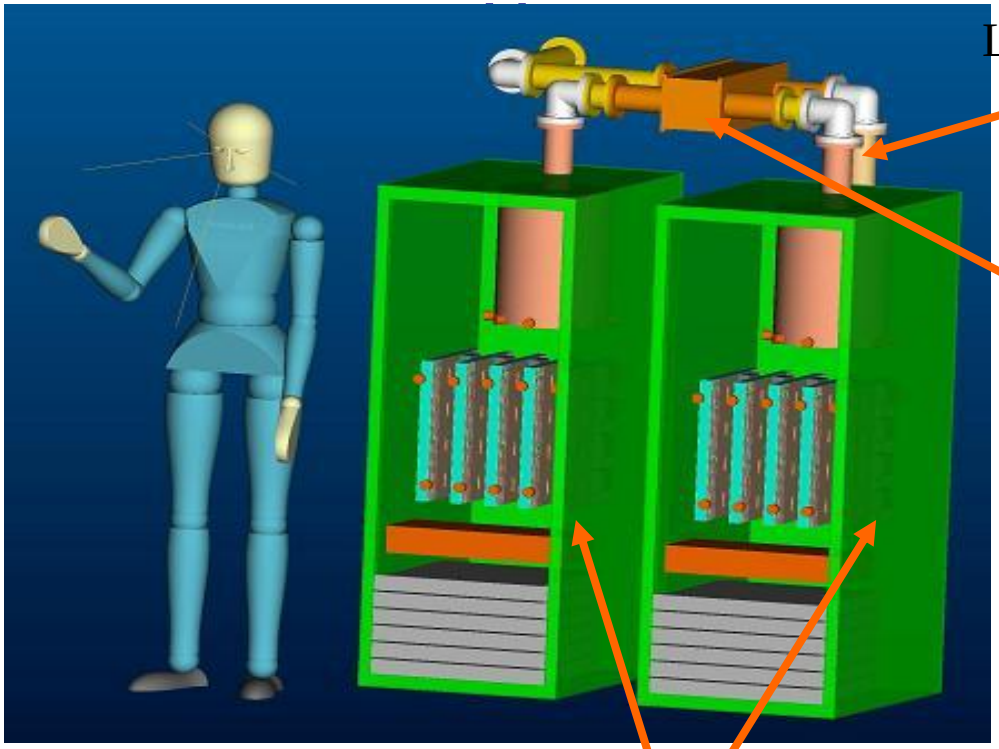
Step N°2

16 kW CW @ 700MHz base block



Step N°3

Pout ≈32 kW CW @ 700MHz



Water
Load 50 Ohm/ 8Kw

3dB coupler

2 x 16Kw bloc

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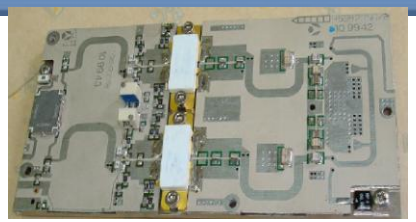
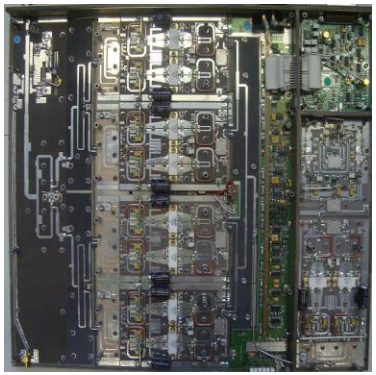
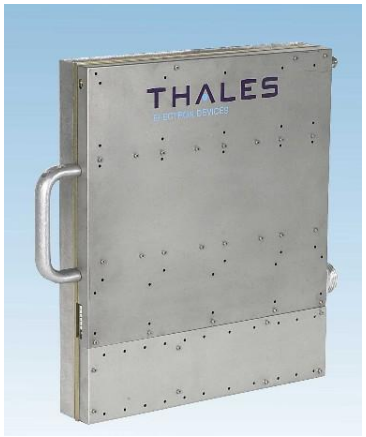
Similar realizations



Individual module @ 500MHz to 800 MHz



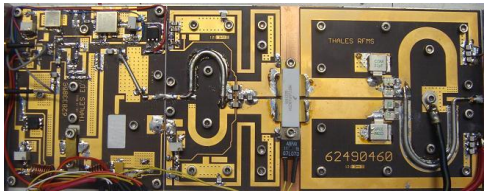


Core module 500MHz up to 800 MHz

Complete amplifier 500MHz à 800 MHz
(10KW à 30Kw)

Cavity coupler

Bloc 16Kw to 32Kw



RF bloc 1Kw @ 352MHz
(RF generator integrated)

50 kW cabinet

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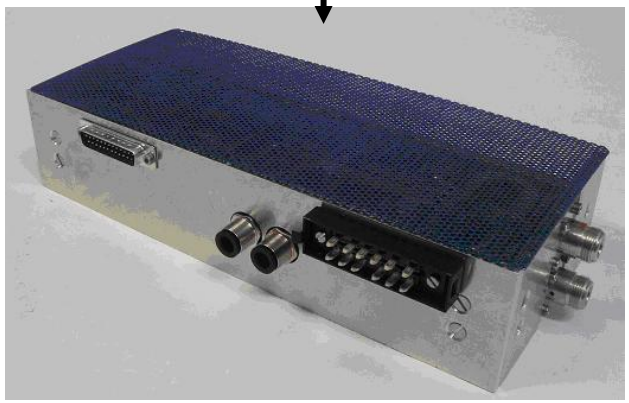
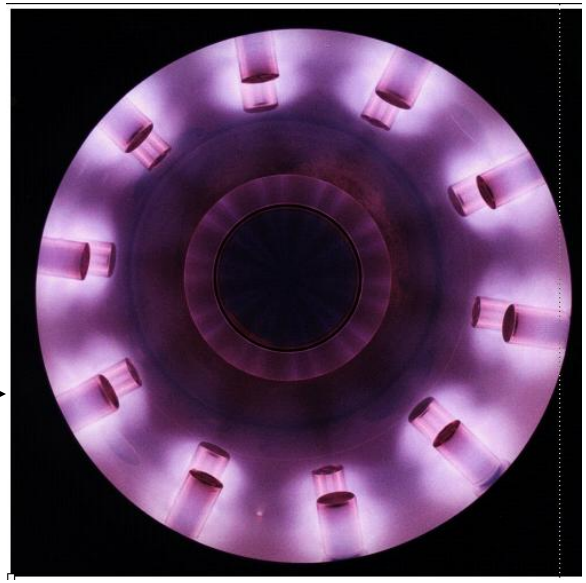
RF module 1kW @ 352MHz

Rf generator integrated



Rf module 2 x 1Kw @ 352MHz

2 x 10 channels repartition



2x10 applications

THALES

Thank You