

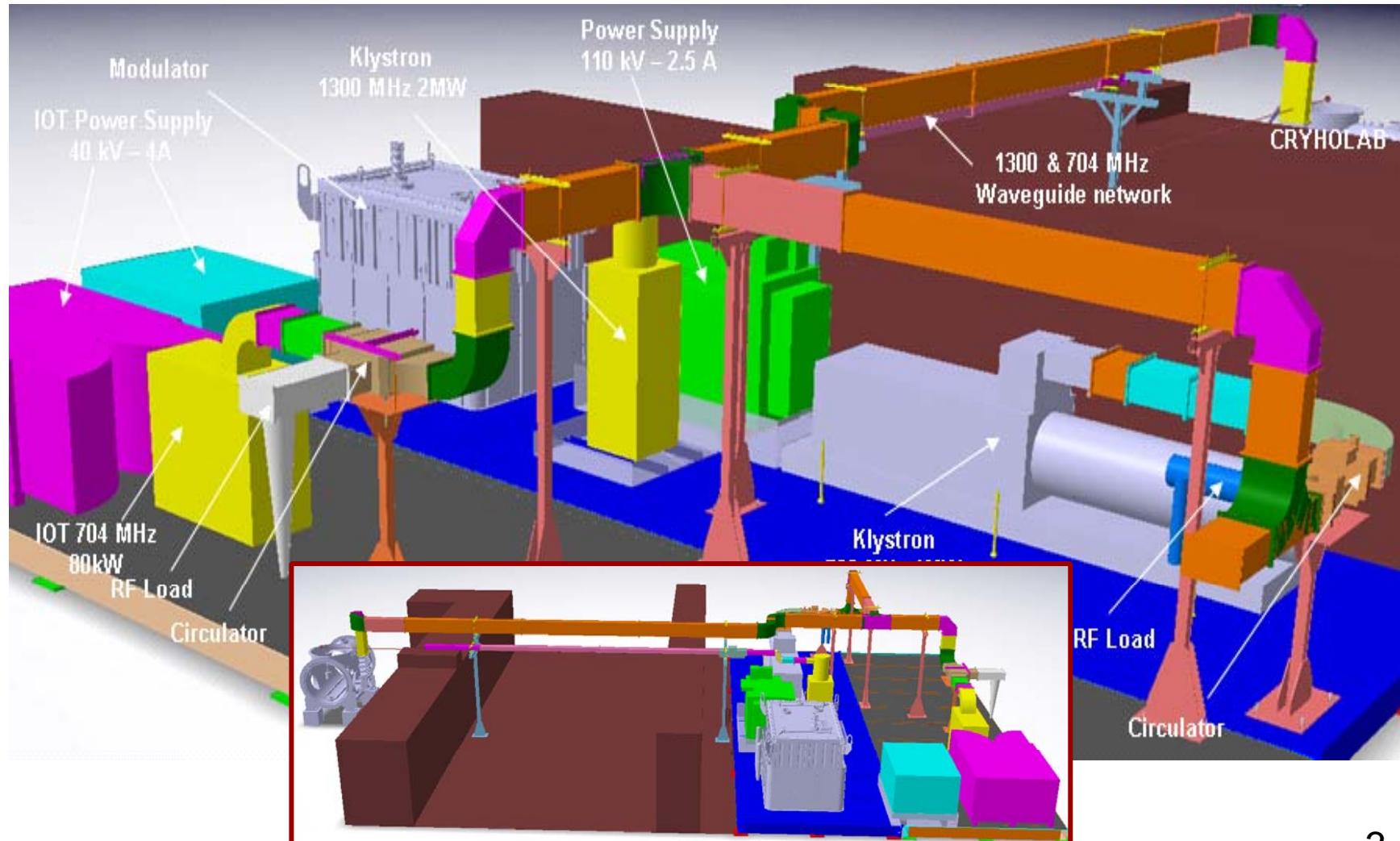
# CEA-SACLAY HIGH VOLTAGE MODULATOR FOR PULSED KLYSTRONS

- ✓ CEA Saclay RF teststand
- ✓ MODULATOR first design
- ✓ HV and RF tests with the first design
- ✓ MODULATOR new design
- ✓ HV and RF tests with the new design
- ✓ Conclusions

# CEA Saclay RF teststand

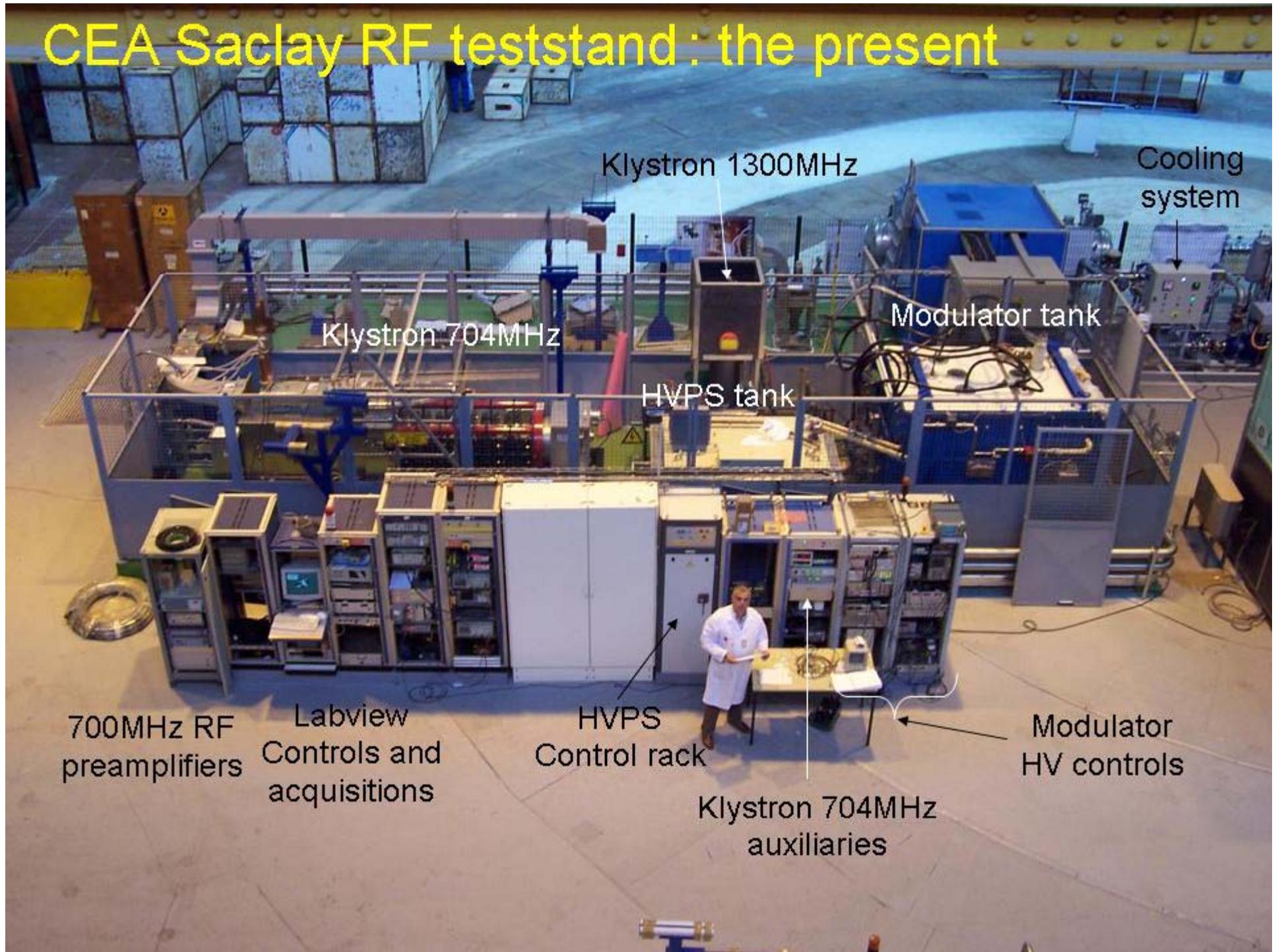
- Movement of the whole SEA (Service d'Etude des Accélérateurs) infrastructures from l'Orme des merisiers to Saclay center 2005-2006
- New power supply (300KVA) , new cooling etc... and their comissioning

# CEA Saclay RF teststand : the goal



3

# CEA Saclay RF teststand : the present



## Modulator first design : **CEA 1300MHz Test Stand**

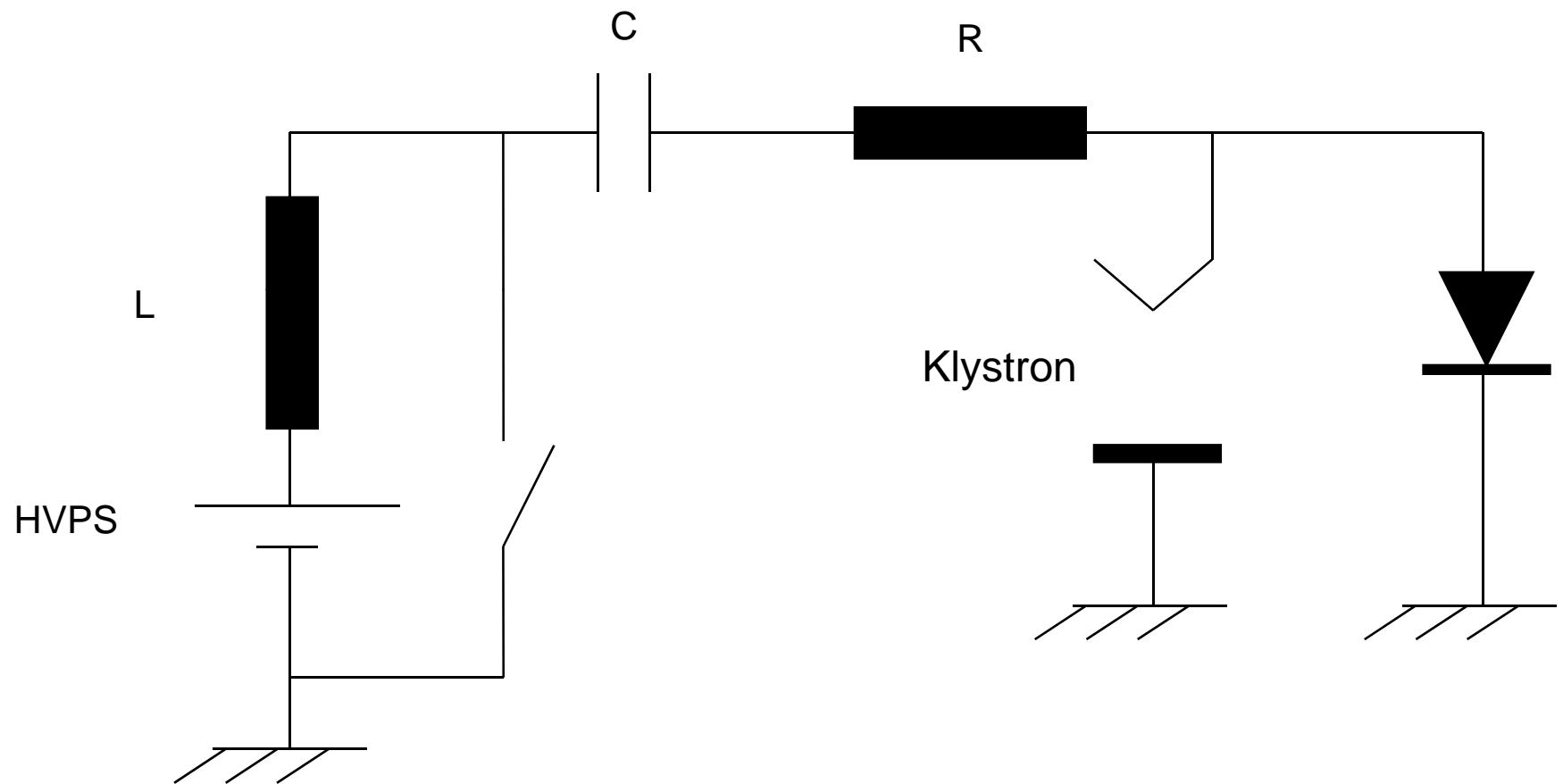
- ❑ 1995 : First design at low duty cycle ( 1ms, 0.1 Hz ) for HPPP conditioning of SRF cavities
  - improvement of maximum accel. Gradient
  
- ❑ 1999 : new design to get 1ms 10Hz pulse for High power tests of Main Power Coupler parts
  - R&D of RF windows and waveguide to coax transitions

Coupler RF Power Test Stand Parameters

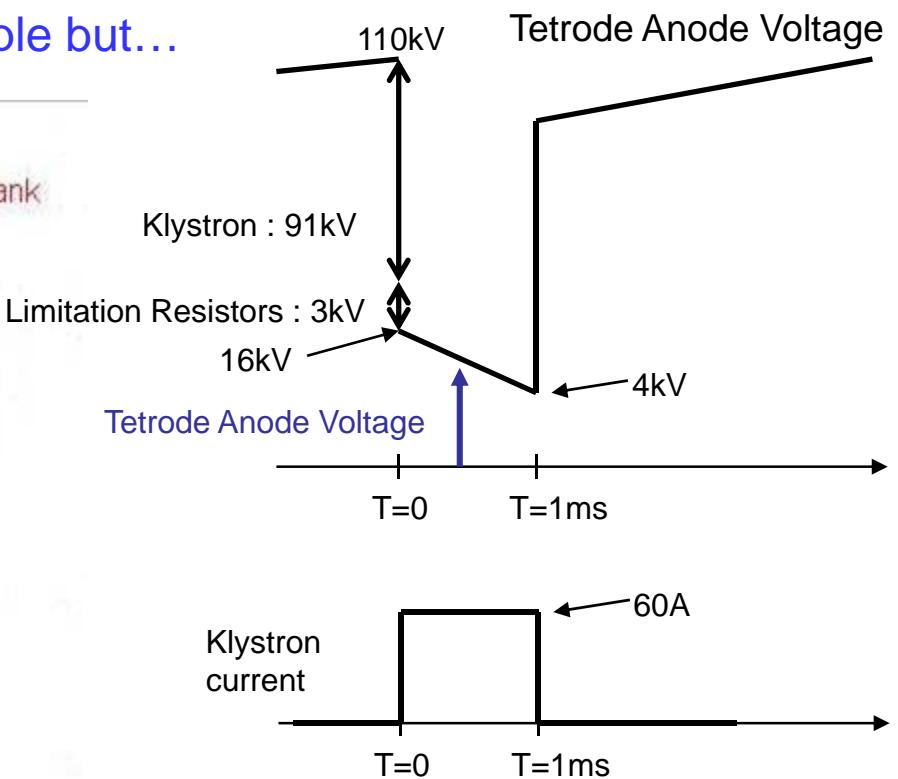
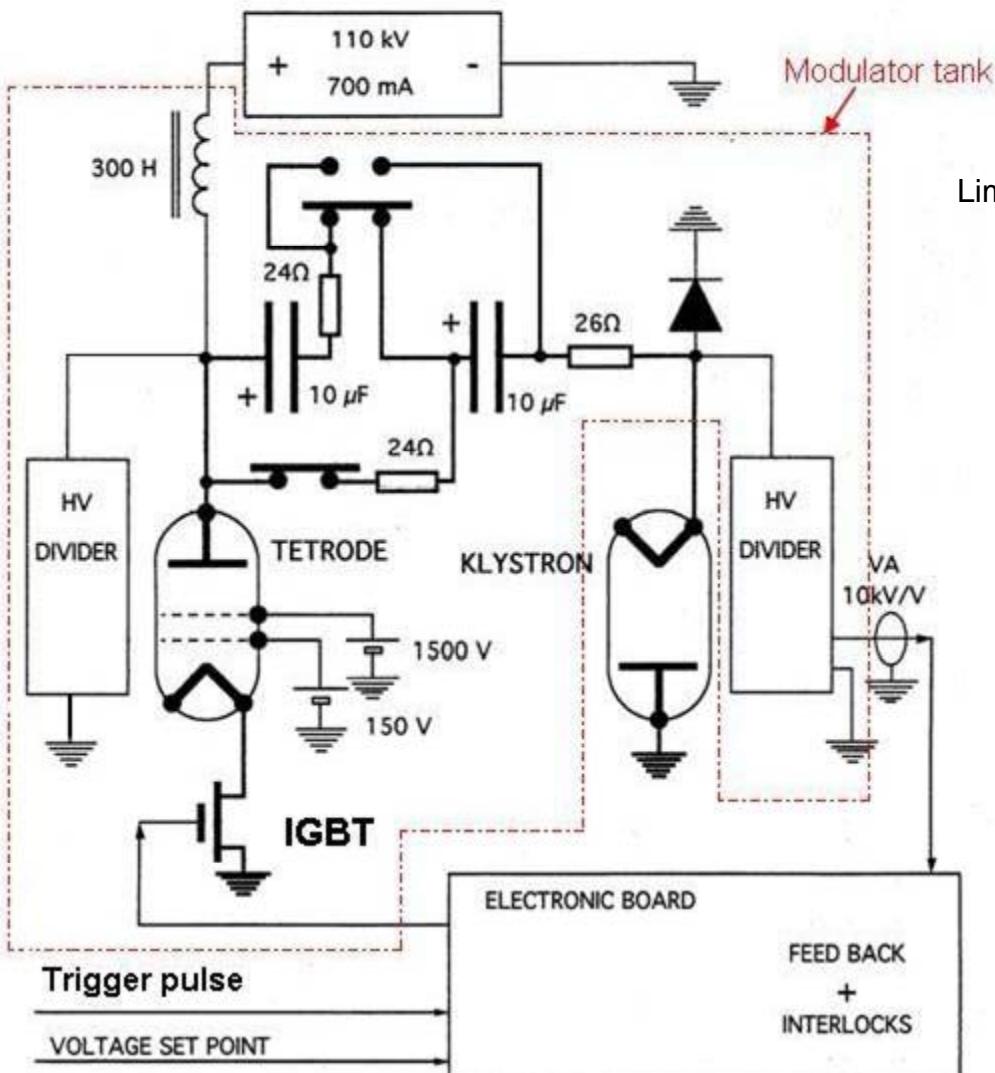
RF source :

- ❑ Frequency : 1300 MHz
  - ❑ peak RF power : 2 MW
  - ❑ pulse length : 1 ms
  - ❑ repetition rate : 10 Hz
- TH2086 THOMSON klystron  
2MW @ 90kV 60A  
Drive power 100W max  
heater 18V 22A  
focusing coil 16A 150V max  
ion pump 5kV 30W max

## Modulator first design : simple principle

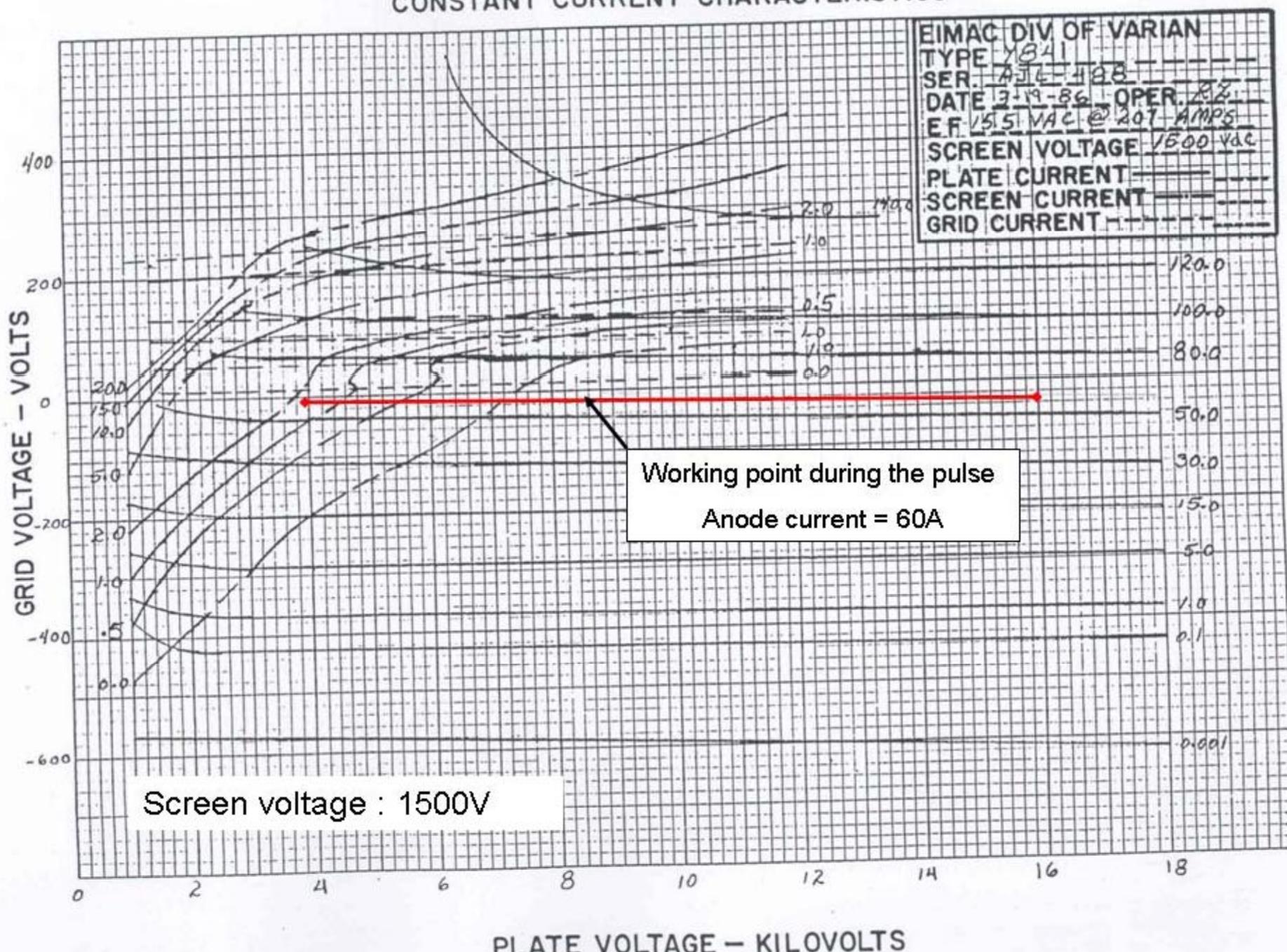


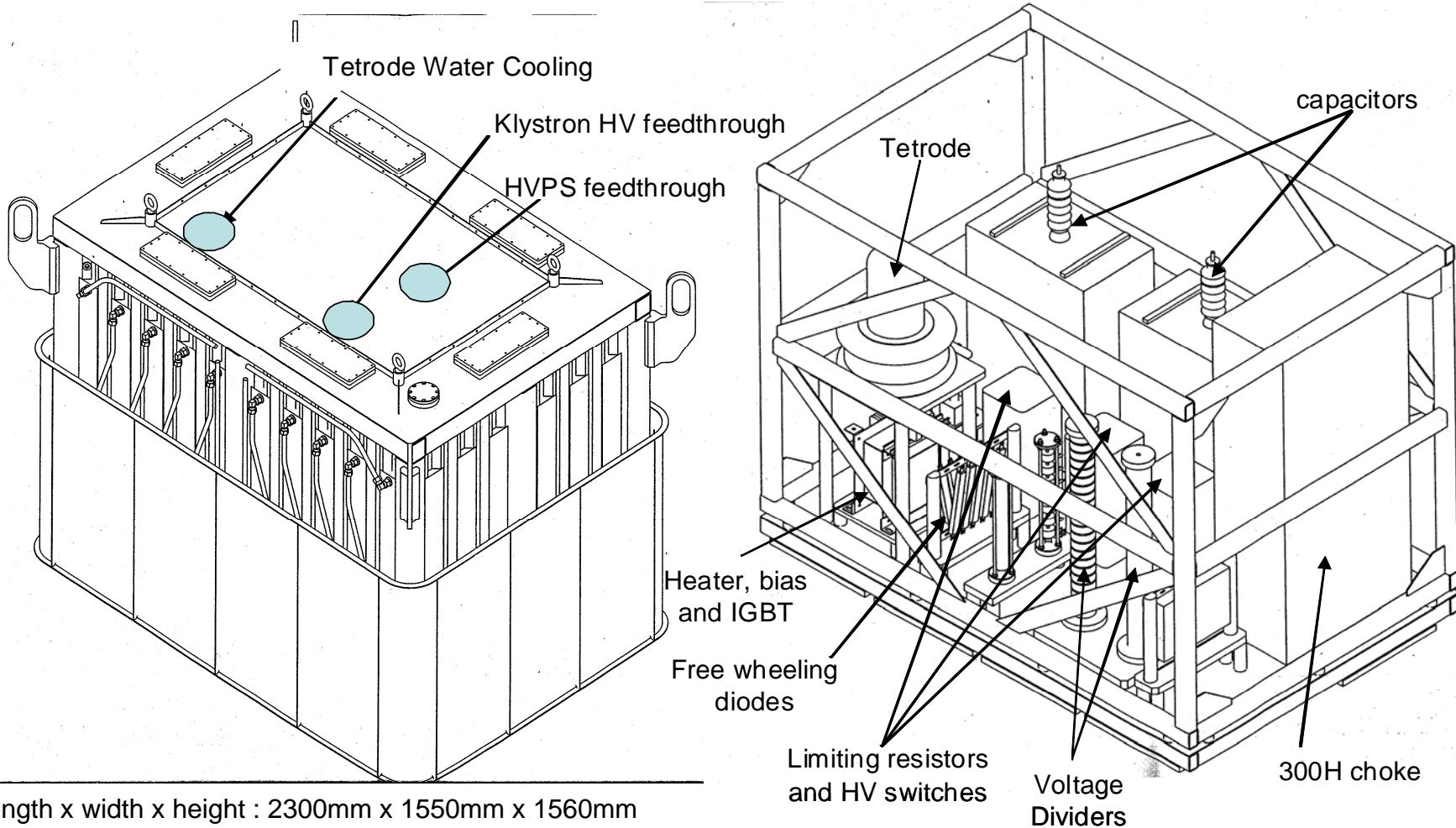
## Modulator first design : simple but...



- 300H choke to limit  $di/dt$  during 1ms on HVPS
- 2 modes : - 1 ms pulse @ 91 kV 60 A  
- 2 ms pulse @ 56 kV 31 A
- 2 HV dividers : 10kV/V
- 1 toroid in the tetrode cathode (ground) : 30A/V
- Tetrode selfbiased
- Tetrode current driven by IGBT
- HV feedback

GROUNDED CATHODE  
CONSTANT CURRENT CHARACTERISTICS





Length x width x height : 2300mm x 1550mm x 1560mm

Oil volume : 4500 liters

**MOBILECT 35**

CP ( J/g/ $^{\circ}$ C )= 1.84

Density ( g/Cm<sup>3</sup> ) = 0.87

K ( W/m/ $^{\circ}$ C ) = 0.14

Viscosity ( mm<sup>2</sup>/s ) = 66 @ 0 $^{\circ}$ C, 9.3 @ 40 $^{\circ}$ C, 2.6 @ 100 $^{\circ}$ C

Expansion coeff ( / $^{\circ}$ C ) = 7.5 E-4

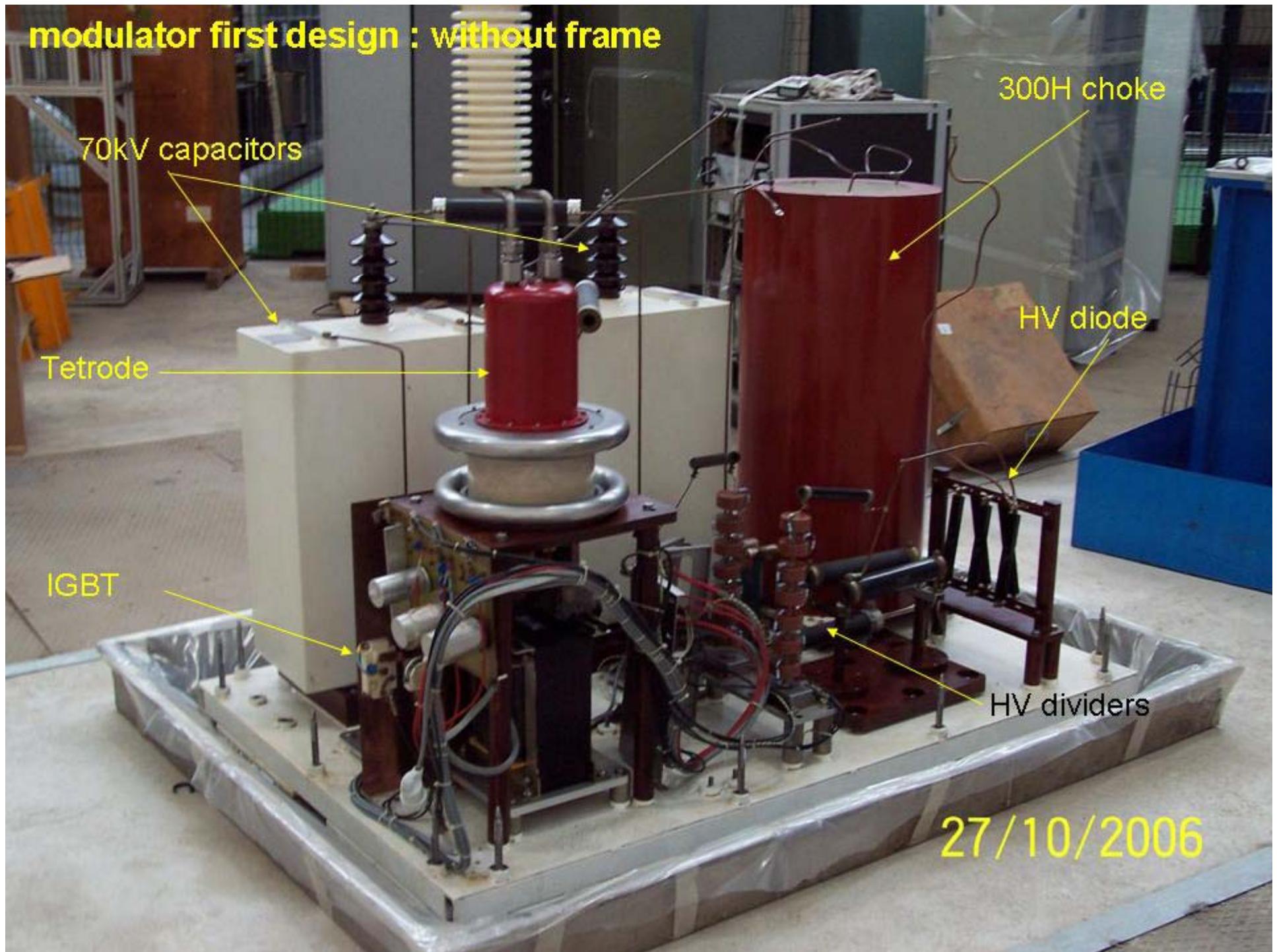
Epsilonr = 2.3 @ 25 $^{\circ}$ C

## Modulator first design



10

## modulator first design : without frame



## EIMAC TETRODE 4CPW100KA characteristics

Maximum ratings / ( 1ms 10Hz modulator operation )

- Max DC anode voltage : 110kV / ( 110 )
- Max anode dissipation : 100kW / ( 6 )
- Max screen dissipation : 1750W / ( 10 )
- Max grid dissipation : 500W / ( 0 )
- Max DC cathode current : 16A / ( 0.6 )
- Max peak cathode current : 140A / ( 60 )
- Net weight : 22.7kg
- Filament voltage : 15.5V +/- 0.75V
- Filament current : 215A @ 15.5V

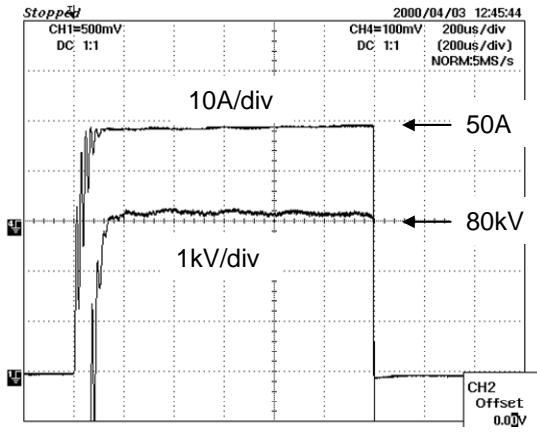
Average dissipations @ 1ms 10Hz

- Tetrode Anode : 6kW
- Limitation Resistors : 1.8kW
- 300H Choke : 1.2kW
- Tetrode Heater : 3.4kW

Oil T° = 45 °C @ 6.4 kW average dissipation

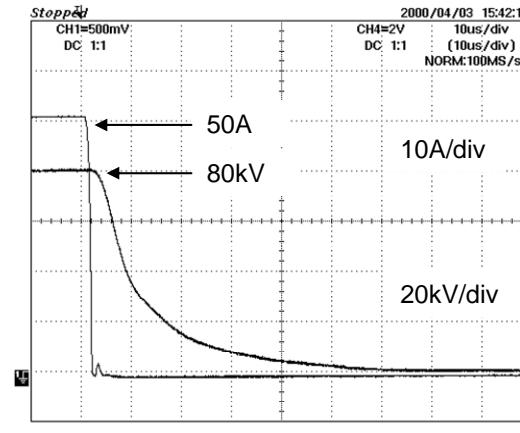
Anode Dissipation kW	Minimum Water flow L / mn	Pressure Drop bar
20	18.9	0.35
40	34.1	0.71
60	47.3	1.20
80	62.5	1.83
100	75.7	2.46

## Modulator first design : 1300 MHz scope curves

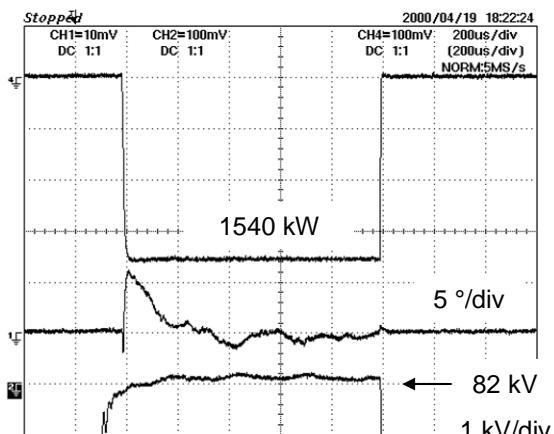


Settling Time = 120us

Klystron Voltage Flat Top Ripple = 200V p-p ( 0.25% )



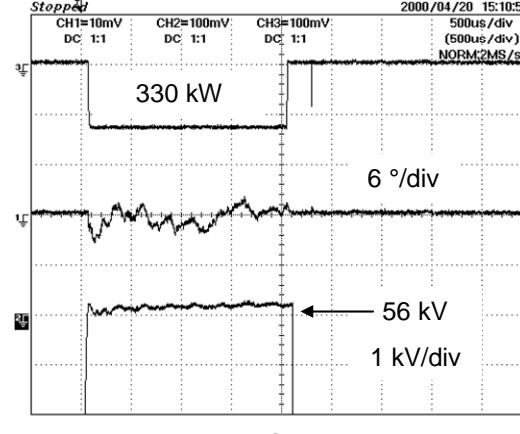
Klystron Current Turn-Off time = 2us



CH4 : RF Power

CH1 : RF Phase Shift

CH2 : Klystron Voltage



2 ms pulse @ 330 kW 6 °/div

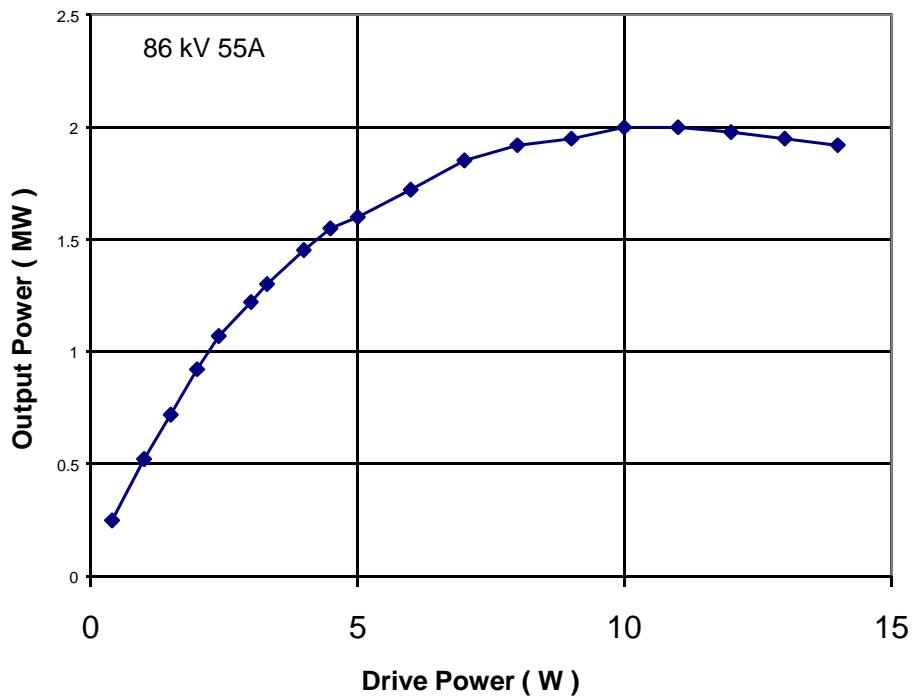
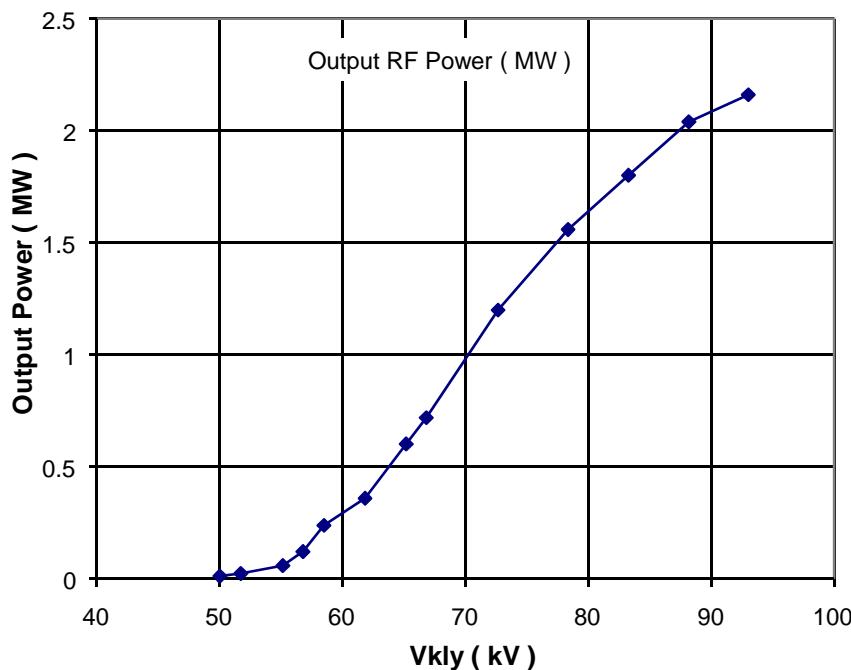
with 2 capacitors connected in parallel

## Modulator first design : RF tests

### TH2086 Klystron AMPLIFIER( THALES )

#### Main Parameters

- 2 MW 1300MHz
- Pulse Operation ( 1ms pulse width, 10Hz repetition rate, 1% duty cycle )
- 40% efficiency ( Losses = 650 kW Collector + 13 kW Body )
- 86 kV 55A
- 53 dB RF Gain ( 10W Input Power @ 2000 kW Output Power )
- 20 MHz @ -1dB Bandwidth



## Modulator new design : goal

In the frame of the CARE/HIPPI programme, CEA-Saclay built and ordered the necessary RF equipments to make a platform for high power tests in a cryogenic environment available. Only few similar platforms are existing in Europe (at CERN for tests at 352 and 400 MHz, at DESY and BESSY for tests at 1300 MHz) but not any was equipped to perform RF power tests at 704 MHz. This RF frequency was chosen in the reference design of the CERN-SPL-II [1]

for the medium and high energy parts of the superconducting linac

### HIPPI RF Power Test Stand Parameters

- ❑ Frequency : 704 MHz
- ❑ peak RF power : 1 MW
- ❑ pulse length : 2 ms
- ❑ repetition rate : 50 Hz
- ❑ Average power : 100 kW

In 2005, one existing source

➤ klystron CPI VPK-7952A

## Existing RF source

### VKP-7952A Klystron



CPI/Microwave Power Products (MPP) offers super-power klystrons for particle accelerator applications. Typical performance for these devices are operating frequencies of 350 to 700 MHz and output power up to 1.3 MW CW. The VKP-7952A is a 700 MHz, 1 MW CW klystron developed for Los Alamos National Laboratory in support of the Accelerator Production of Tritium (APT) Project.

#### Key Features

- Electron Gun with Modulating Anode
- 6-cavity rf circuit, including one 2<sup>nd</sup> harmonic cavity for enhanced efficiency
- Single coaxial output window
- Collector capable of dissipating the full beam power

#### Typical Operating Parameters

Power Output	1,000	kWatts (min)	Electromagnet:		
Beam Voltage	95	kV (max)	Gun Coil Current	20	Amps dc
Beam Current	21	A (max)	Gun Coil Voltage	8	Volts
Mod Anode Voltage	75	kV	Main Coil Current	22	Amps dc
Frequency	700	MHz	Main Coil Voltage	180	Volts
1dB Bandwidth	± 0.7	MHz (min)	Size with Accessories:		
Saturated Gain	40	dB (min)	Length	186 / 472	inches / cm
Efficiency	65	% (min)	Width	37 / 94	inches / cm
Collector Coolant Flow	380	gpm	Height	60 / 152	inches / cm
Body I Coolant Flow	10	gpm	Weight	5,200 / 2,360	Pounds / kg
Body II Coolant Flow	10	gpm			
O/P Window Cooling (Air)	35	cfm			



### VKP-7952A Klystron

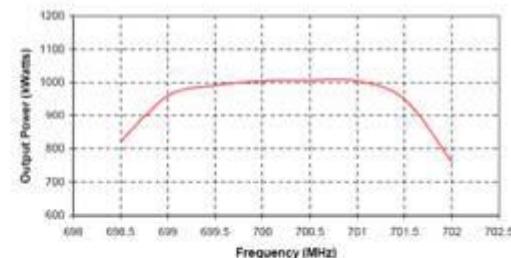


#### Typical Performance Characteristics

Measured data for the VKP-7952A serial number 001.

Beam voltage: 92 kV  
Beam current: 16.7 A  
Mod Anode Voltage: 75 kV

#### Frequency Response



#### Transfer Curve

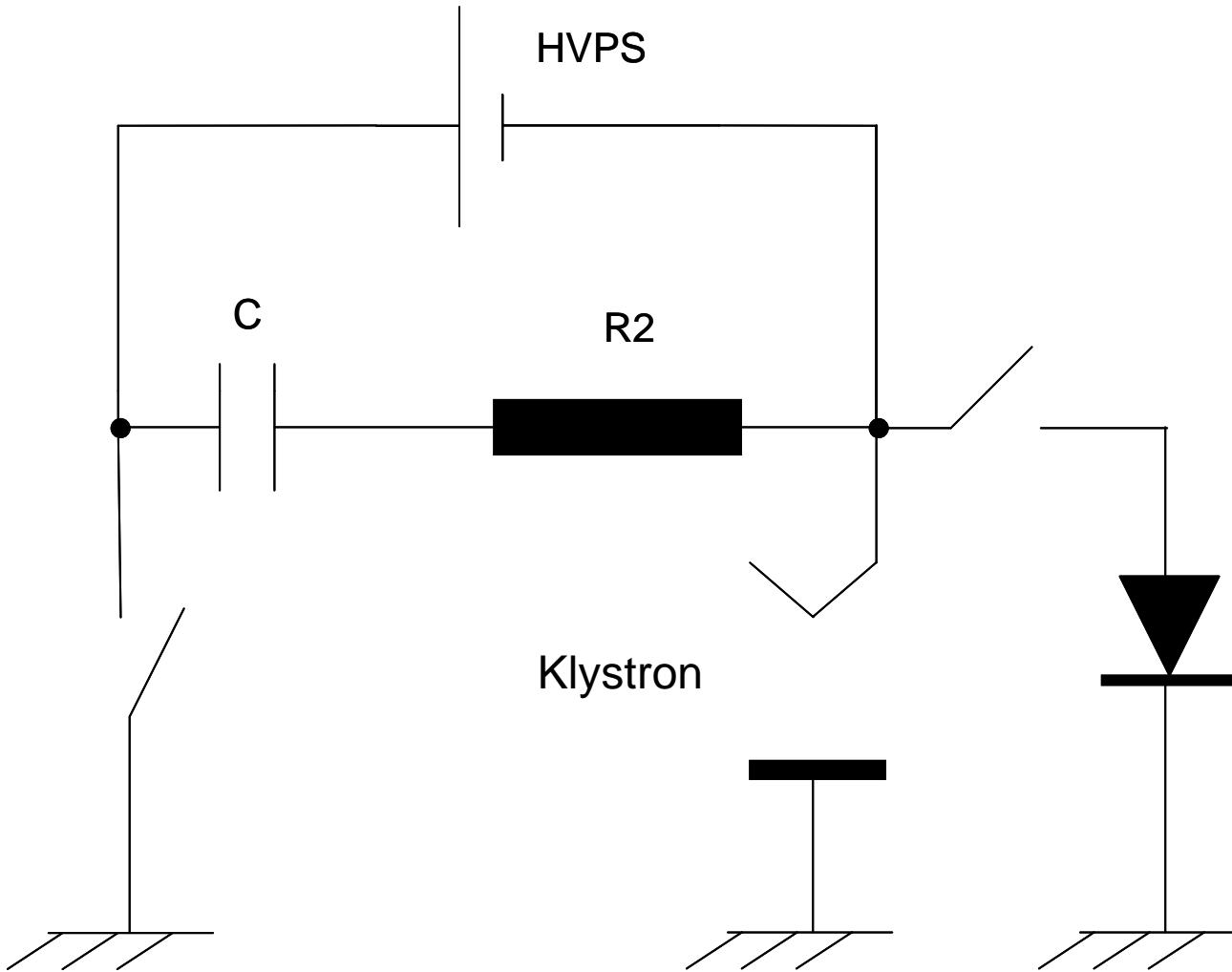


May 2002

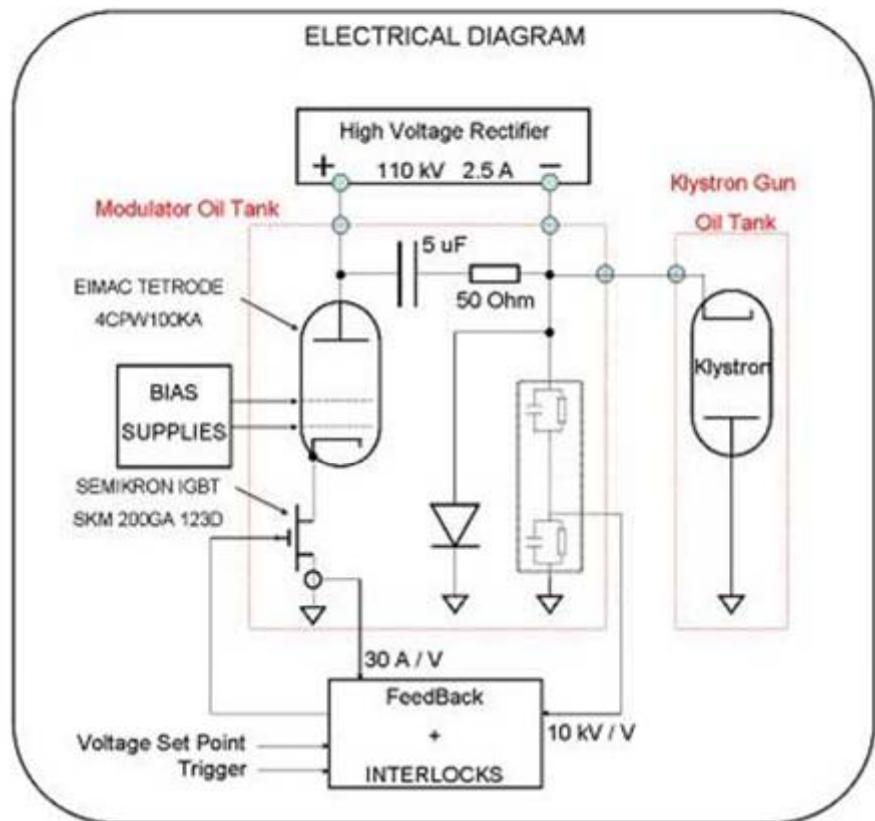
For information on Super Power Klystrons and other CPI/MPP products, visit our website at [www.cpi.com/mpp](http://www.cpi.com/mpp), or contact:

CPI Microwave Products Division, 811 Hansen Way, Palo Alto, CA 94303-0750  
Telephone: 650-846-3900, Fax: 650-856-0705, Email: [marketing@cpi.com](mailto:marketing@cpi.com)

## Modulator new design : principle

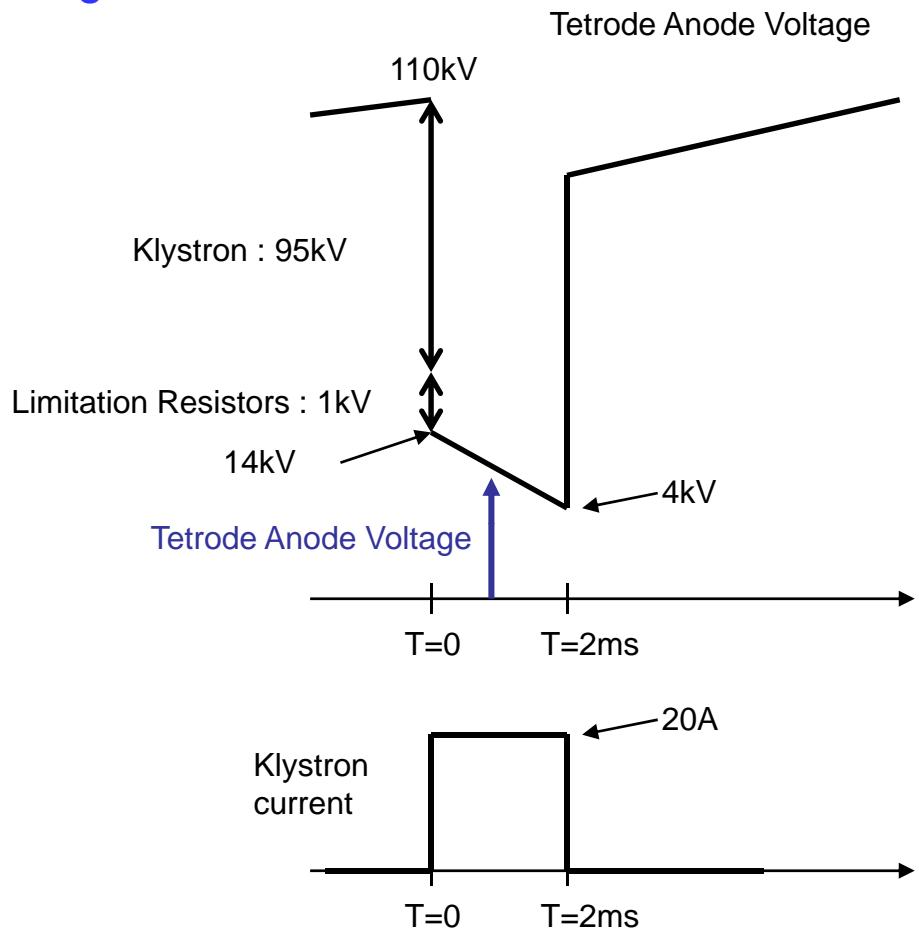


## Modulator new design : schematics

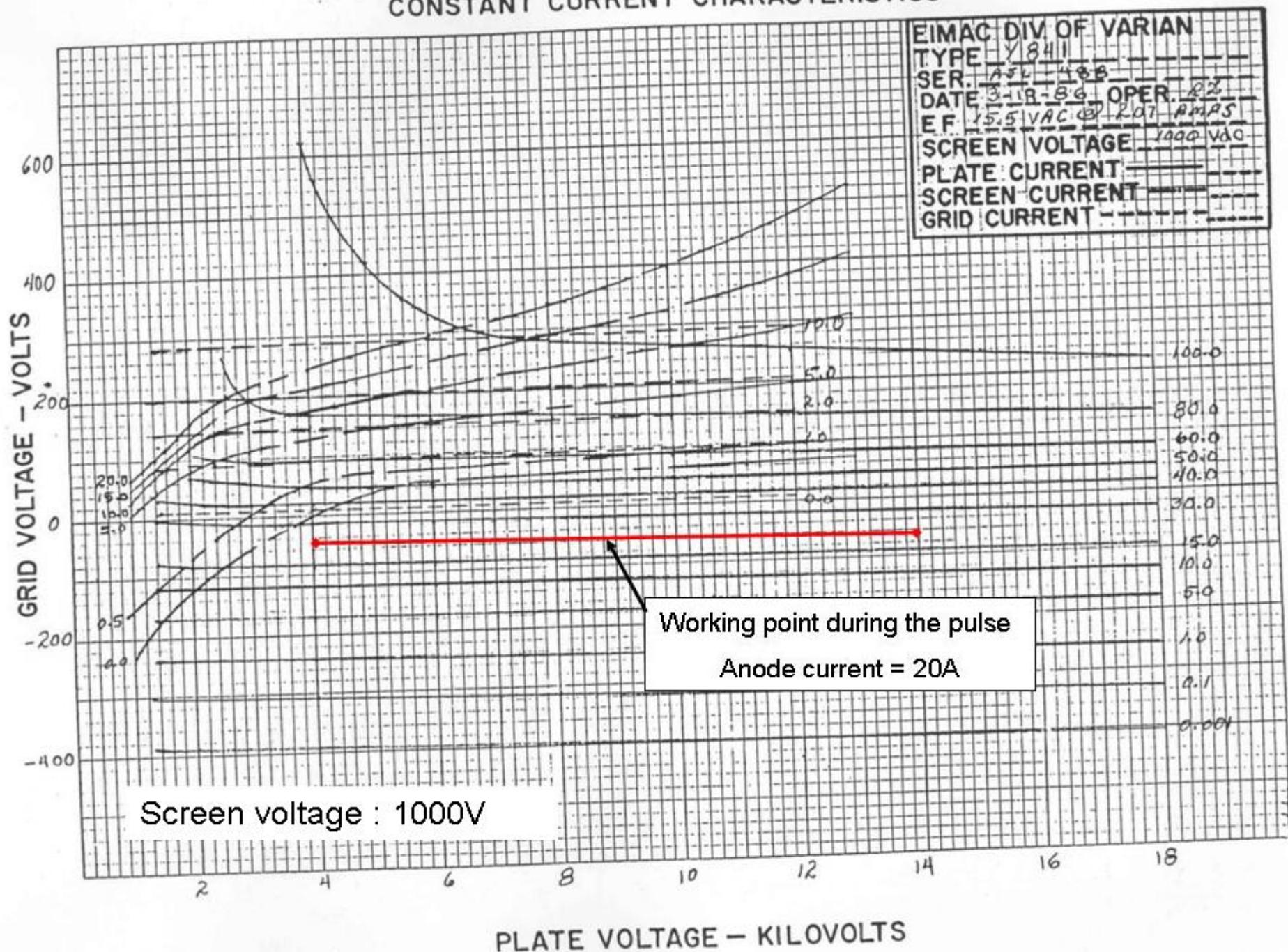


Average dissipations @ 2ms 50Hz

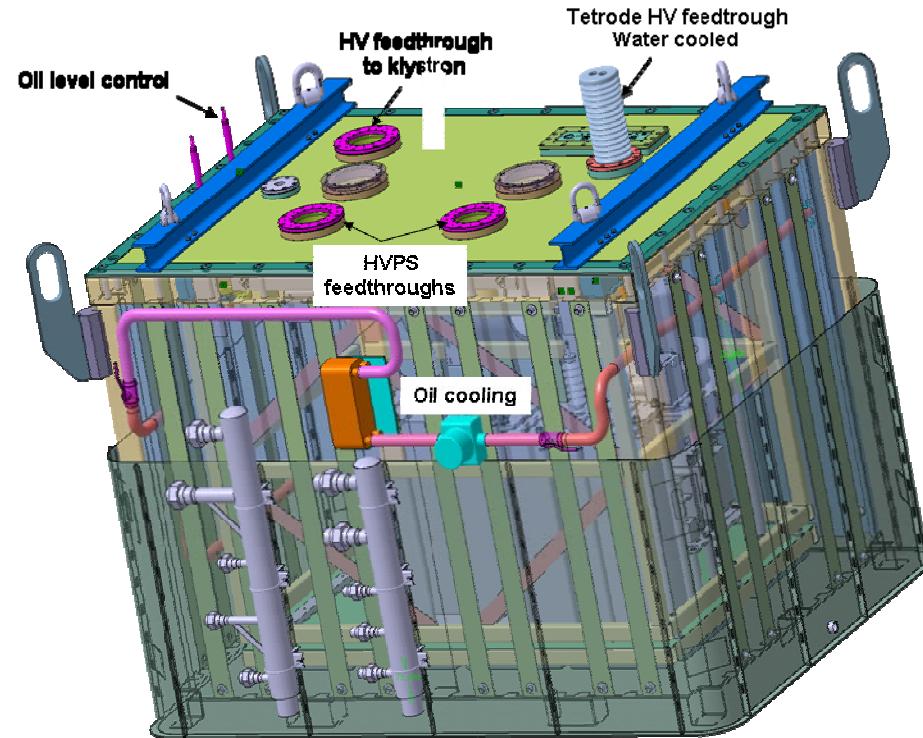
- Tetrode Anode : 22.5kW
- Limitation resistors : 3.2kW
- Tetrode Heater : 3.4 kW



# GROUNDED CATHODE CONSTANT CURRENT CHARACTERISTICS



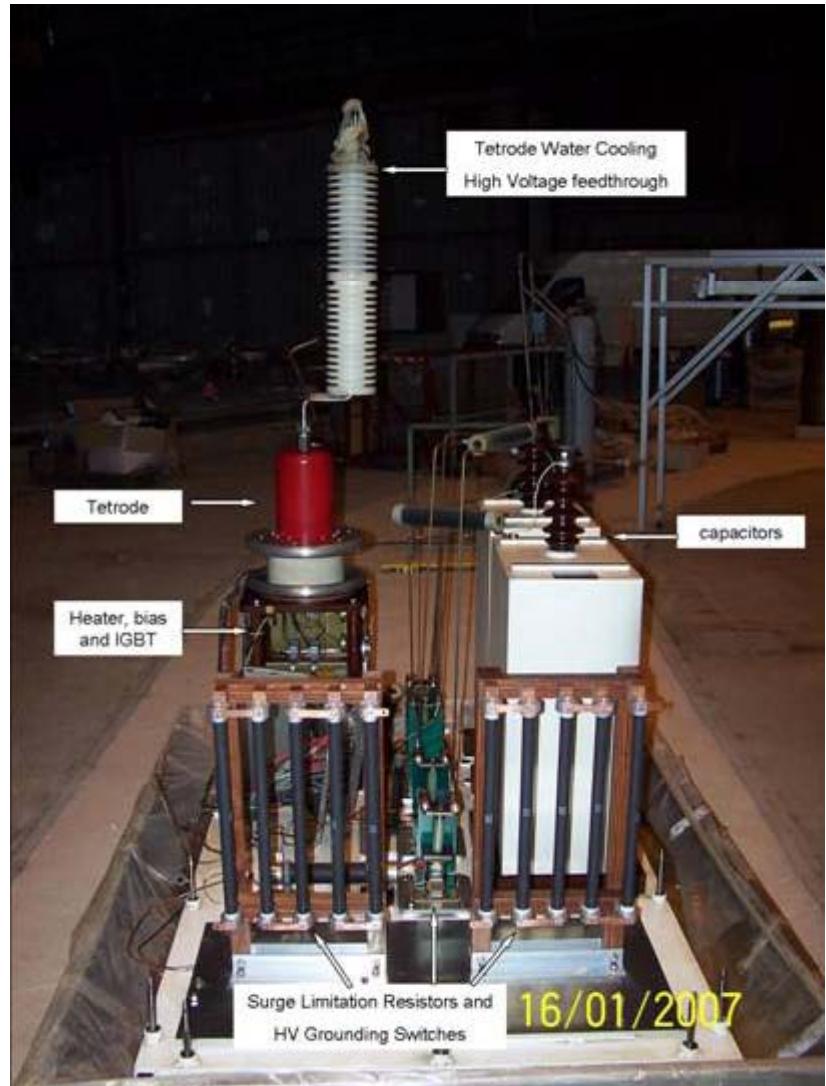
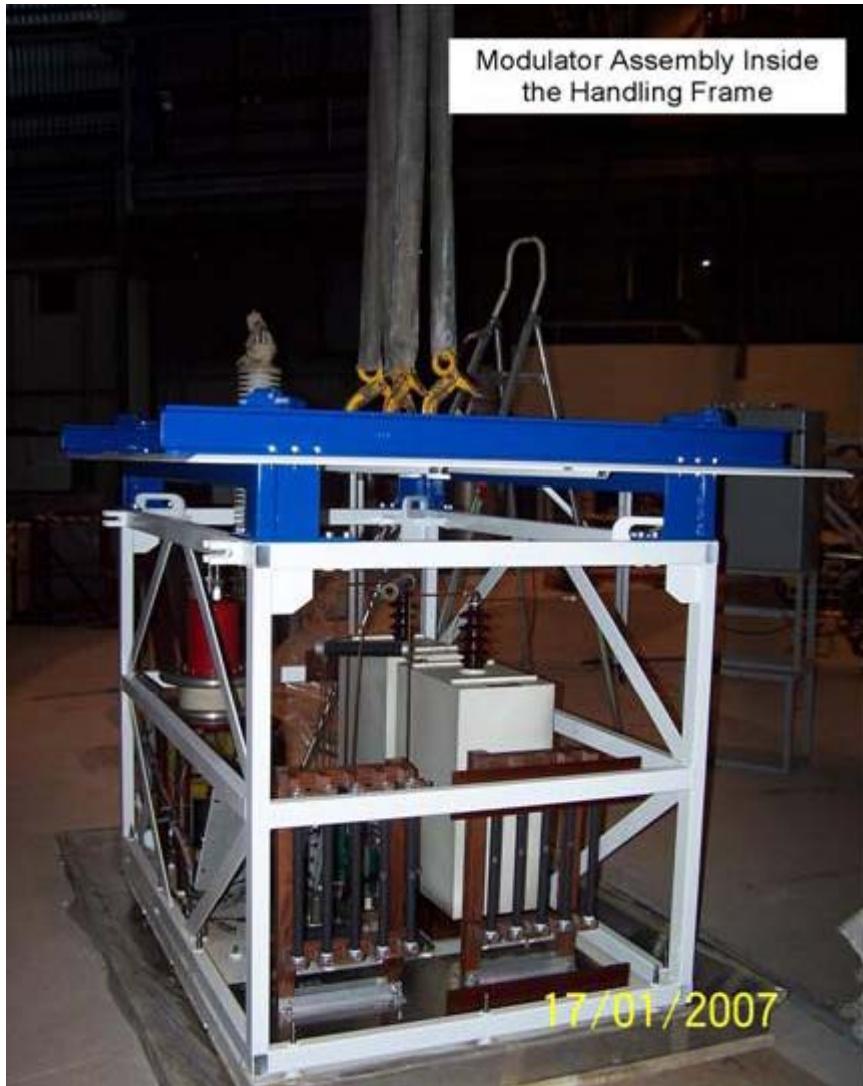
## Modulator new design



Some improvements :

- new mechanical frame to remove easily the electronics out of the oil tank,
- modulator is hanged to avoid fast paint deterioration
- new receptacle for the differential HVPS,
- new oil cooling system to sustain the full duty cycle,
- control window.

## Modulator new design



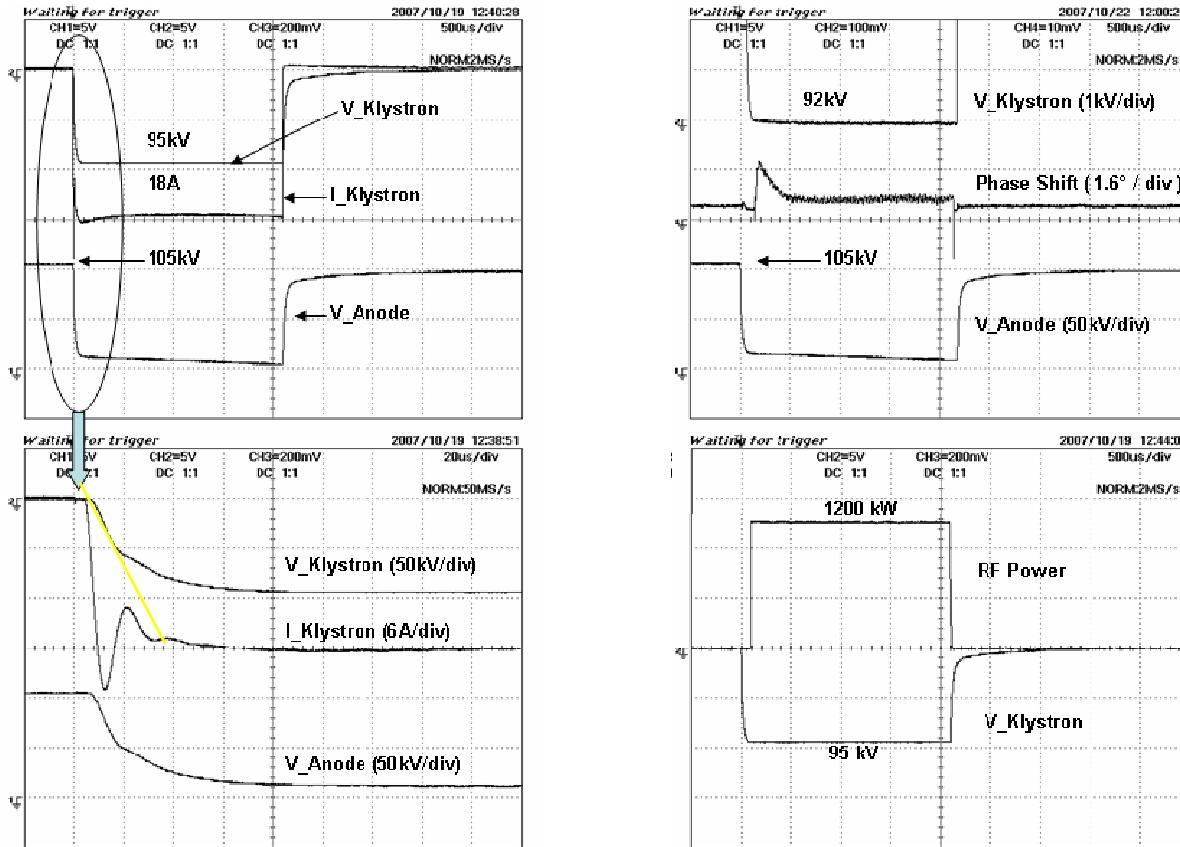
## EIMAC TETRODE 4CPW100KA

Maximum Ratings / ( 2ms 50Hz modulator operation )

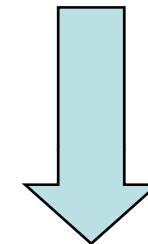
- Max DC anode voltage : 110kV / ( 110 )
- Max anode dissipation : 100kW / ( 22.5 )
- Max screen dissipation : 1750W / ( 0 )
- Max grid dissipation : 500W / ( 0 )
- Max DC cathode current : 16A / ( 2.5 )
- Max peak cathode current : 140A / ( 20 )

Anode Dissipation kW	Minimum Water flow L / mn	Pressure Drop bar
20	18.9	0.35
40	34.1	0.71
60	47.3	1.20
80	62.5	1.83
100	75.7	2.46

## Modulator new design : 704 MHz scope curves



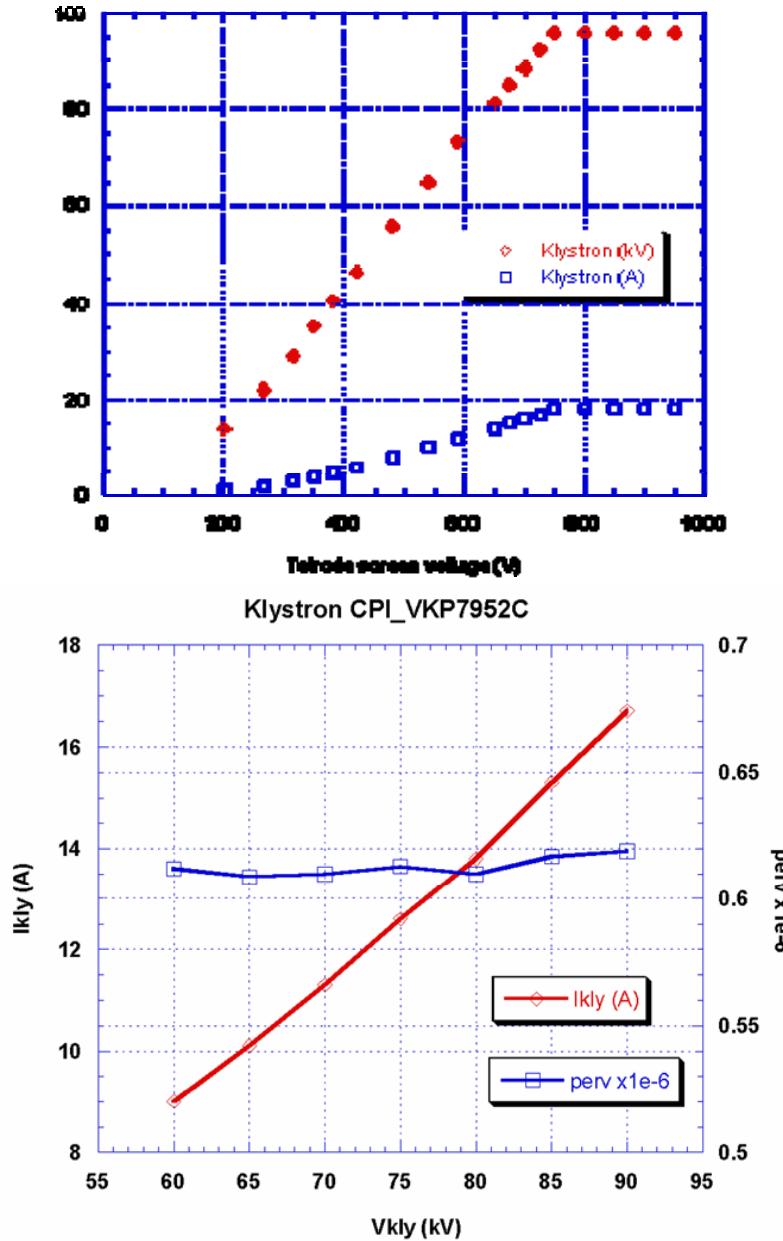
The klystron phase shift is about  $10^\circ/\text{kV}$  at 92kV gun voltage.



The HV ripple is lower than 100V from  $t=0$  to  $300\mu\text{s}$ , and lower than 10V for  $t>300\mu\text{s}$ .

The undershoot appearing when zooming the klystron current signal trace is due to the parasitic capacitor of the 3 -7m each - HV cables(3nF) and 100pF heater transformer . To reduce this effect, we could reduce the HV cable length. This imply also to increase the threshold on the Ikly interlock to about >24A.

## Modulator new design : HV tests on klystron in diode mode

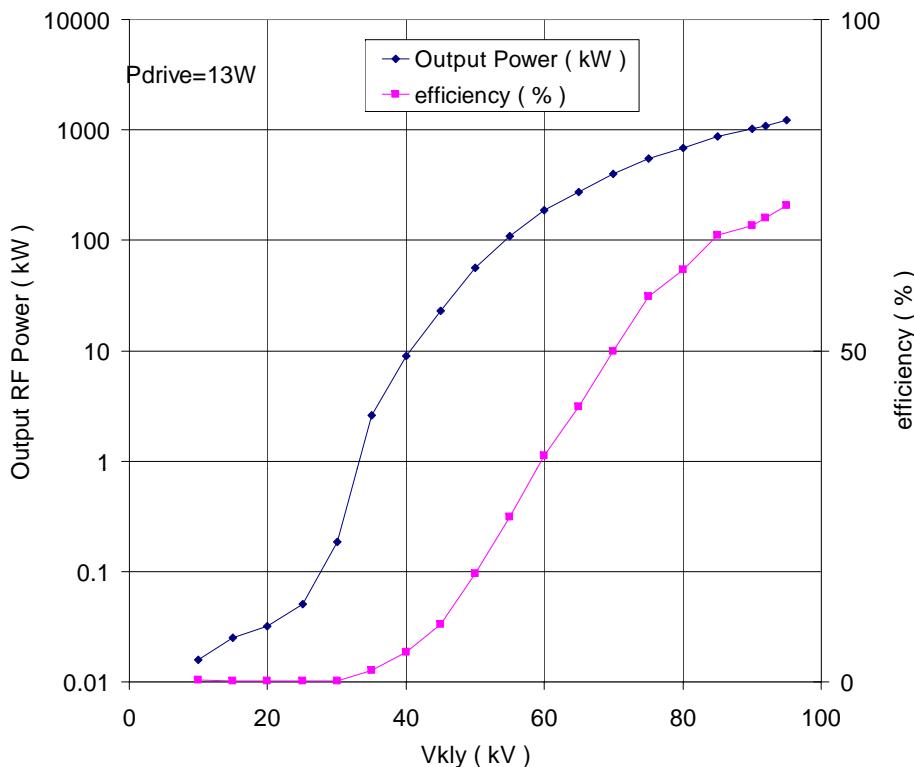


Current and Voltage modulator output vs. tetrode screen grid voltage with  $V(\text{anode\_tetrode})=5\text{kV}$  and  $V(\text{gate\_IGBT})=25\text{V}$

In order to safely increase the duty cycle up to 10%, great care must be taken to avoid an excess of dissipating power in the tetrode and the IGBT: The tetrode screen grid voltage has to be carefully optimized. After preliminary measurements, the nominal current and voltage values required for generation of a 1 MW pulse at the klystron output have been reached with appropriate settings of the tetrode screen grid voltage.

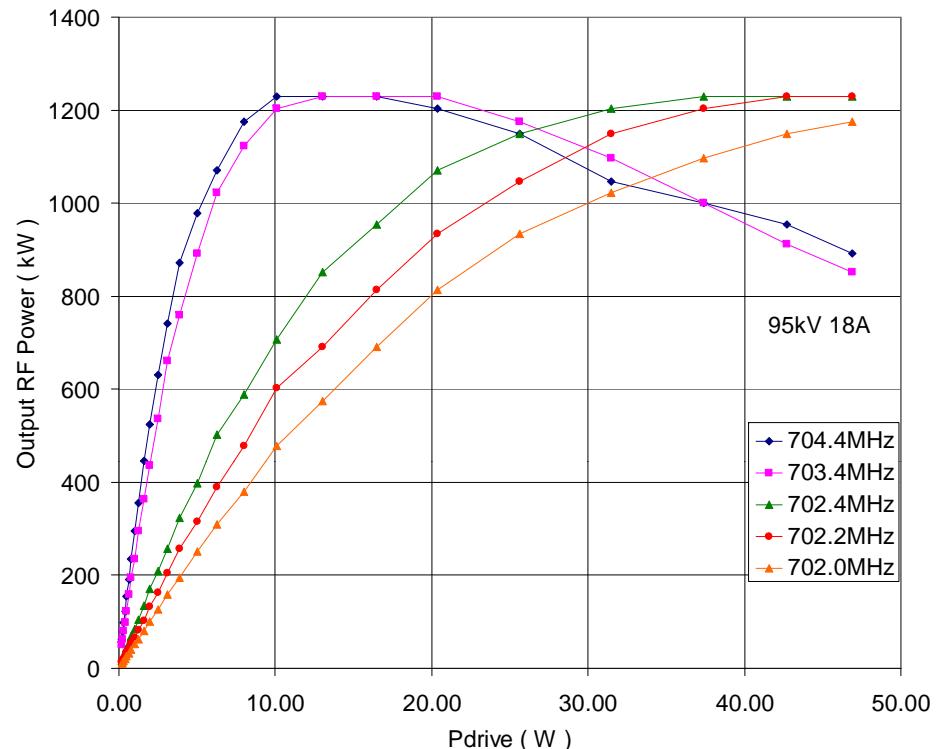
The first tests of the klystron cathode have shown that the current density from the cathode is stable when HV is increased, which is characterized by the constant microperveance

## Modulator new design : RF tests



**1 MW 704MHz**

- Pulse Operation : 2ms pulse width, 50Hz repetition rate, 10% Duty Cycle
- 66% efficiency ( Losses = 500 kW Collector + 13 kW Body )
- 92 kV 17A
- 49 dB RF Gain ( 13W Input Power @ 1 MW Output Power )
- 4 MHz @ -1dB Bandwidth



## Summary of Modifications

❑ modulator tank :

- oil cooling connections
- one more HV feedthrough
- Limitation resistors dissipation upgrade
- 300H choke removal

❑ new High Voltage Power Supply with two poles isolated at full rated voltage

❑ auxiliary power supplies :

- klystron focusing coils
- klystron ion pump
- klystron heater
- interlocks

❑ klystron water cooling

## Modulator efficiency comparison

Modulator first design : Modulator efficiency : for 55A, 1.1ms  
10Hz, with a Tetrode voltage=12.1kV,  
( $55\text{A} \times 1.1\text{ms} / 5\mu\text{F} = 12.1\text{kV}$ ), The dissipated power is 7.74kW

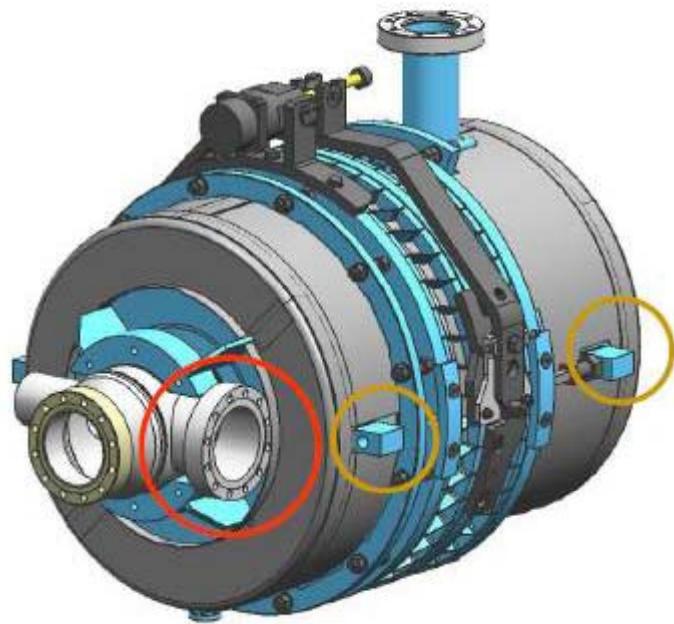
For  $90\text{kV} \times 55\text{A} \times 1.1\text{ms} \times 10\text{Hz} = 54.5\text{kW HV}$   
Hence an efficiency of  $54.5 / (54.5 + 7.74 + 3.3) = 83\%$

Modulator new design : Modulator efficiency : for 20A, 2.1ms  
50Hz, with a Tetrode voltage=12.1kV,  
( $20\text{A} \times 2.1\text{ms} / 5\mu\text{F} = 8.4\text{kV}$ ), The dissipated power is 19.3kW

For  $90\text{kV} \times 20\text{A} \times 2.1\text{ms} \times 10\text{Hz} = 189\text{kW HV}$   
Hence an efficiency of  $189 / (189 + 19.3 + 3.3) = 89\%$

## Conclusions

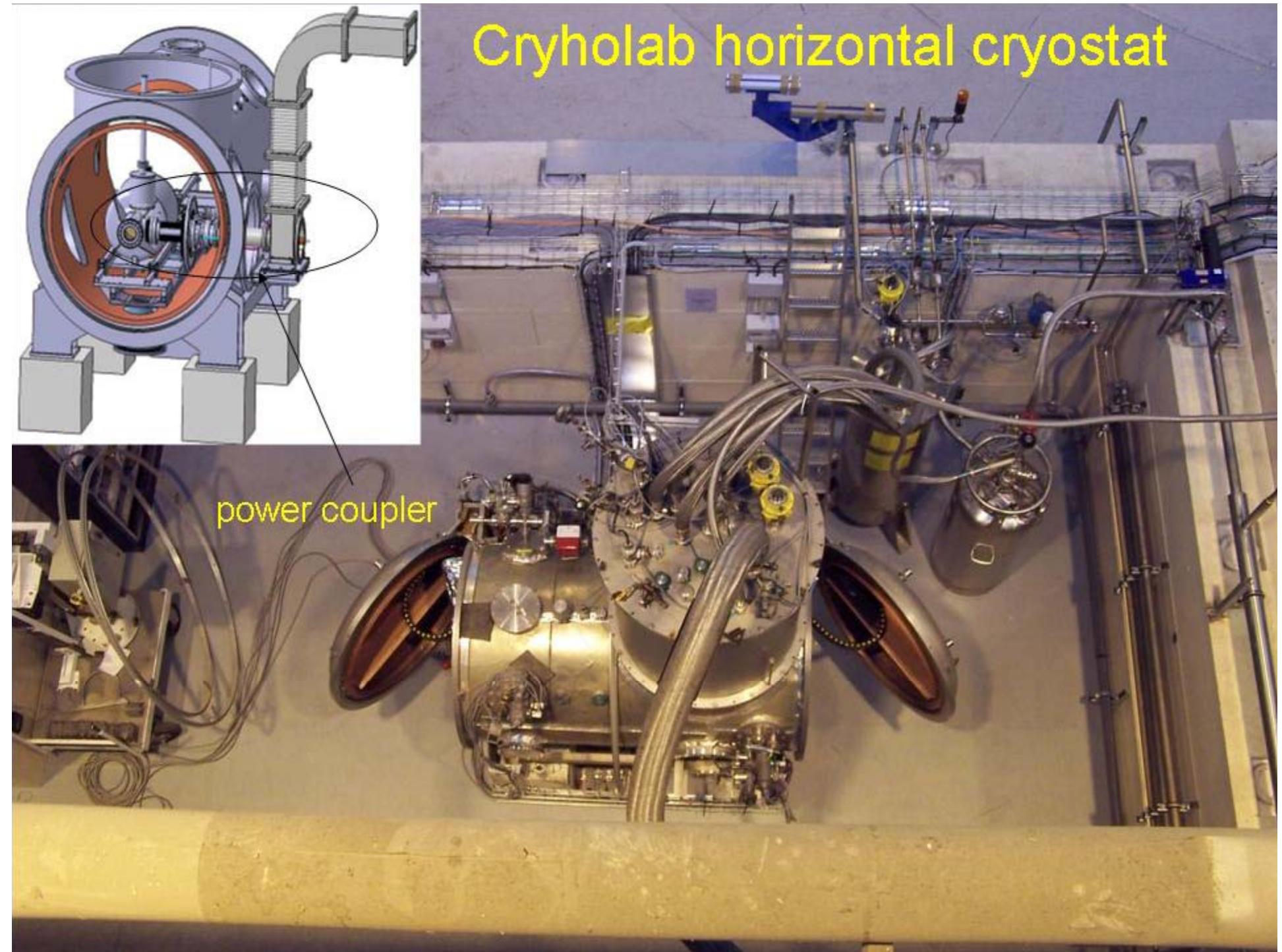
- ❑ The new 110kV 2.5A HVPS is the most expensive part of the HV modifications : 80K€
- ❑ The modulator has been modified successfully but still some “infant” problems to solve with the HVPS nevertheless efficiency is better even if it wasn’t the first goal.
- ❑ The modifications took account the shared operation of the two RF sources, 704 MHz and 1300MHz, with a short dead time (couple hours estimated)
- ❑ Measurements performed on the klystron VKP7952C show that the specifications (HV and RF power levels and duty cycle) have been met.
- ❑ 150kW Circulator under commissioning
- ❑ next step 1 : HIPPI power coupler conditioning and processing @T°room
- ❑ next step 2 : 704MHz HIPPI superconducting cavity with its power coupler test @Cryholab
- ❑ next step 3 : Retstart of the 1300Mhz source for SRF program (piezo tuner R&D, LFD)



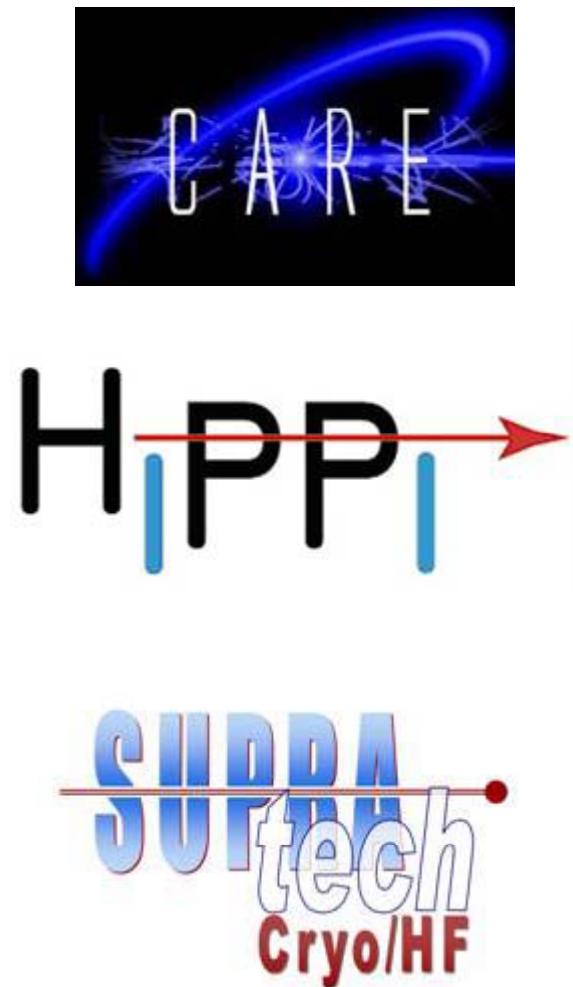
Cavity A , ready to be integrated in the CryHoLab environment for tests at Saclay.



Cavity B , delivered in march 07 at Saclay, has been measured (frequency, bead pull) and it is now ready to be integrated in the CryHoLab environment.



## Acknowledgements



## References

- M. Desmons, “Cryholab modulator modifications for HIPPI 704MHz 1MW pulsed RF source”, HIPPI -WP3 meeting - march 2005, LASA / INFN – Milan
- S. Chel, M. Desmons, A. Hamdi, J.-F. Denis, F. Ballester, D. Roudier, G. Monnereau, G. Bourdelle, “1MW - 704 MHz RF test stand at CEA-Saclay”, CARE deliverable November 2007
- G. Devanz, “HIPPI 704 MHz Power Coupler” - HIPPI WP3/5 meeting Juelich 27 Apr 06

Vielen Danke !

Merci de votre attention!

Thank you !

*Questions in French or Moroccan please?*

33