Industrial Multi-Beam Klystrons

Rodolphe MARCHESIN

ICWS2011 Granada
29/09/11

THALES

Contents

- THALES L-Band MBK description
- Key parameters for reliable operation
- Klystrons test results
- Upgrade of MBK performance for new projects
- Conclusion

THALES L-Band MBK heritage

Multi-beam klystrons on DESY programs

- TH1801: 10 vertical MBKs have been built for DESY since 2000
  - 10MWp, 1.5ms – 10 Hz, 63 to 65 % efficiency
  - Klystrons in use at FLASH, PITZ and MBK test stand
  - > 60 000 hours of operation at different conditions
  - Tube stability has been secured thanks to several design improvements

- TH1802 : horizontal L band Multibeam klystron
- 27 RF stations in the XFEL tunnel layout
  - Tunnel components : klystrons, pulse transformers, aux power supplies etc …
  - Horizontal position
  - Waveguide distribution filled with dry air
  - Components are not accessible during accelerator operation

THALES

THALES L-Band MBK specification

TH1801 & 1802

Parameters	Specification
Frequency	1300 MHz
RF Peak output power	10 MWp min
RF Av output power	150 kW min
Beam voltage	116 kV typ
Beam current	137 A typ
RF pulse length	1.5 ms
Repetition rate	10 Hz
Efficiency	63 % min
Tube stability	Stop event < 1 per day
Waveguide pressurization	Dry air
Life time	> 40 000 h

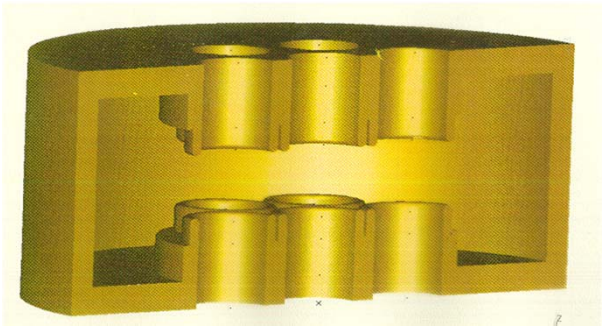
22 TH1802 will be delivered to DESY from March 2012 to June 2014

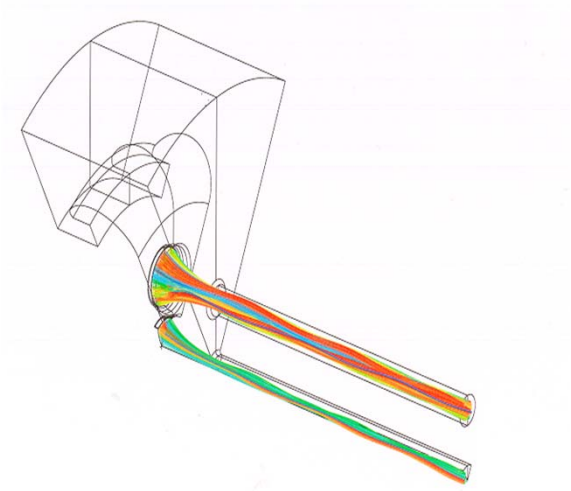
THALES

THALES L-Band MBK design

Main design parameters

- 7 low perveance per beam μK = $I/V^{3/2}$ = 0.5
- Long pulse diode gun design 1.7 ms
- 6 cavities interaction structure
- 2 output wave guides WR650
- Cylindrical multi-gap cavity, TM01 mode
- Tunable cavities
- Single collector
- Same technology as conventional klystron





THALES

Key parameters for reliable operation

- Good vacuum is required to keep excellent beam transmission, RF performance and cathode lifetime.
- Gun arcing : avoid micro-discharges in the gun region, high attention has been paid to the electrodes geometry
- Off axis-beam transmission : avoid beam interception
- Cavity design : avoid mode competition and oscillations
- Collector design : limit the reflected electrons and avoid line oscillation
- Output circuit design : avoid RF breakdown (cavity and window)

High stability of Multi Beam klystrons is required on particles accelerators

THALES

Key parameters for reliable operation

RF instabilities signature before gun spark (DESY test stand)

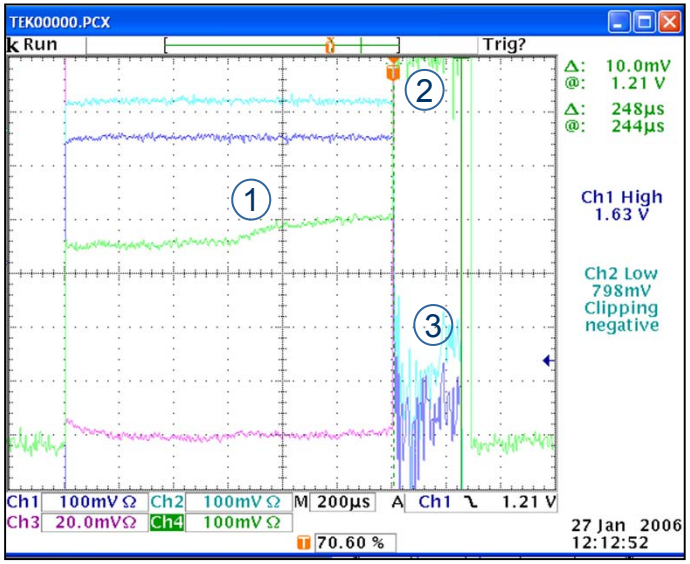
① ◆ Variation of the drive reflected power, 600 µs after beginning of the pulse.

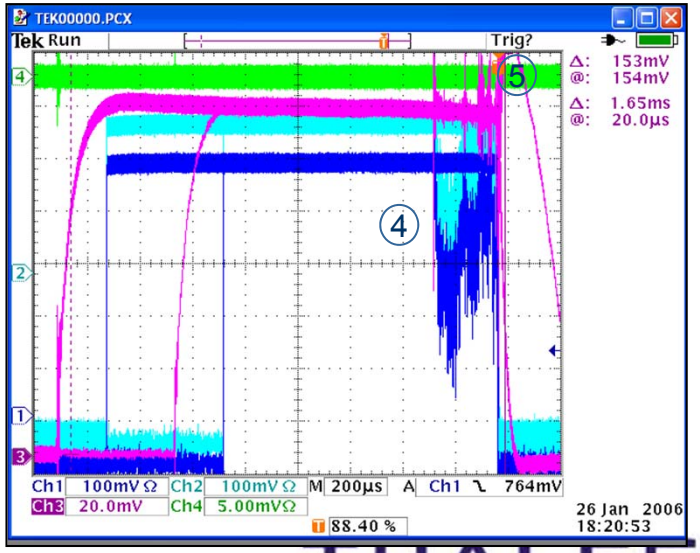
② ◆ High level of reflected drive power increase at the end of the pulse.

③ ◆ Simultaneously, output power decrease in both waveguides.

④ ◆ Variation on the reflected power signal from the RF loaded, end of the pulse.

⑤ ◆ Interlock by gun spark, 250µs between beginning of the instability end the over current.





Vacuum level increases during this event and total beam perveance decreases

THALES

Key parameters for reliable operation

Gun geometry for HV pulse length > 1.5 ms

- Maximum electric field x HV product < 800 kV²/mm
- Poor vacuum and arcing event consequences

Pre series tube after 5 000 h

Improved design since 2004

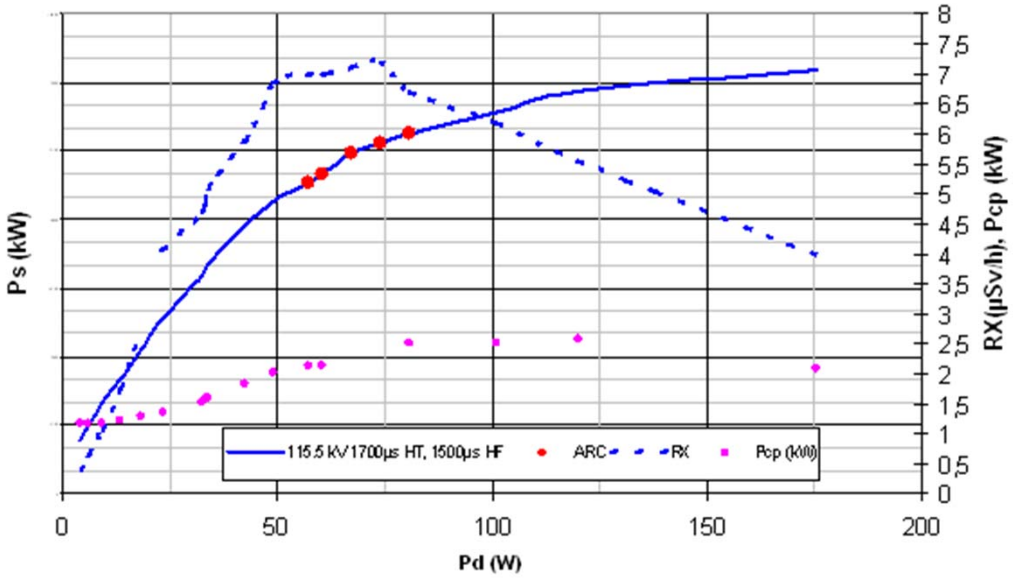
High level of safety margin on E field must be kept to avoid arcs on the gun electrodes

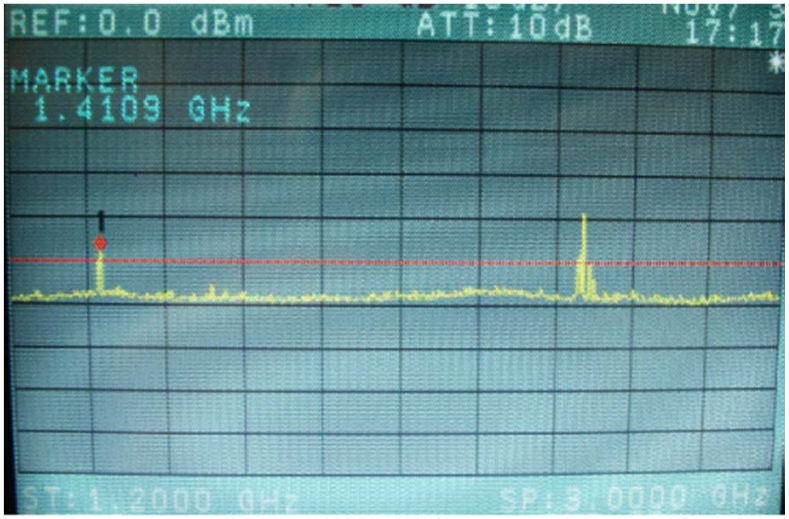
THALES

Key parameters for reliable operation

Example of line oscillation & RF instabilities

- Reflected electrons from output circuit & collector
- Interaction with parasitic mode





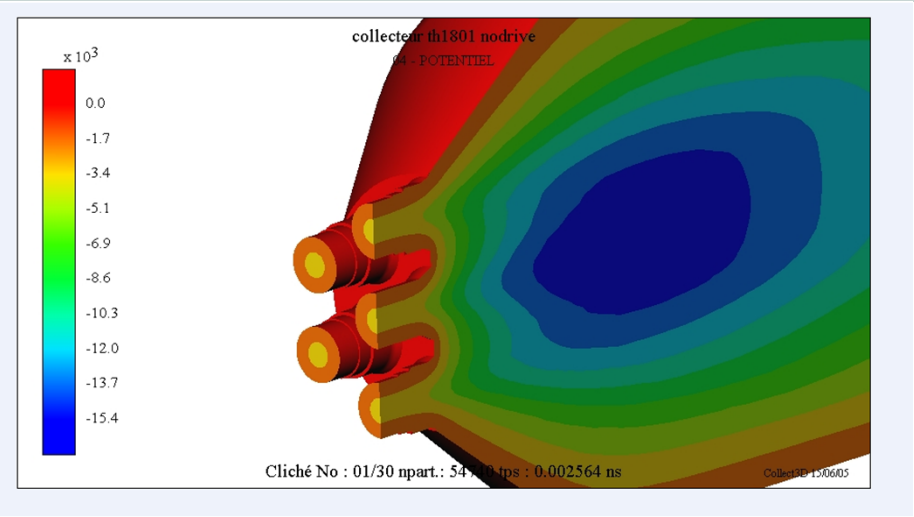
Collector and output cavity design are directly correlated with high efficient tube stability when is used in back off regime

THALES

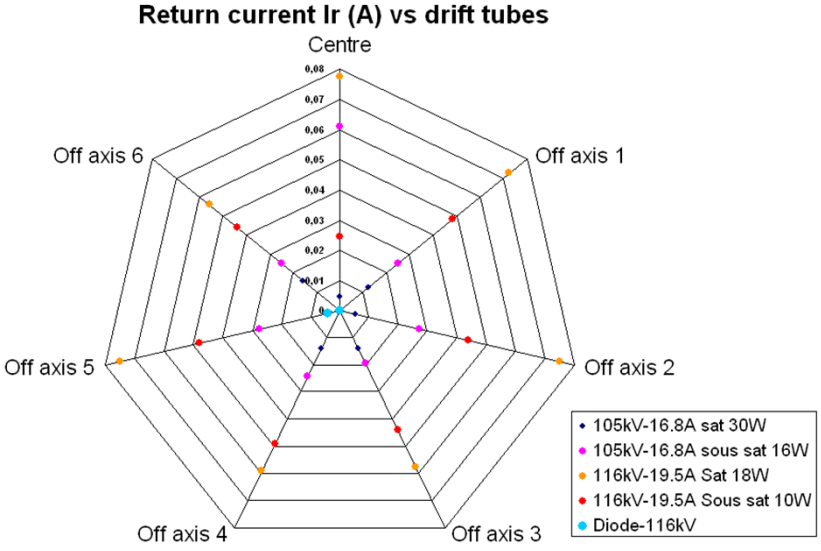
Key parameters for reliable operation

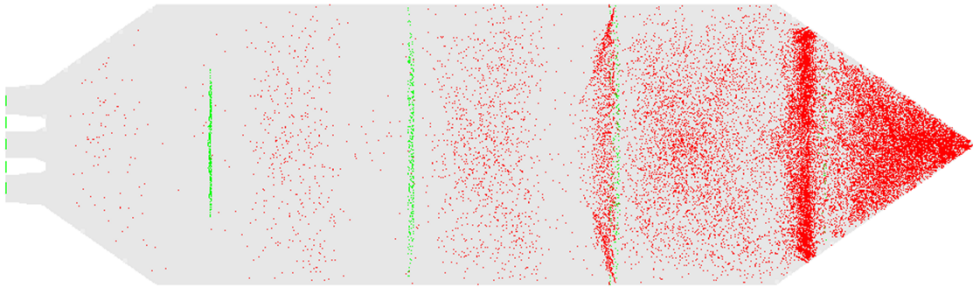
Collector design

- Thermal aspect
- Electrostatic aspect



collecteur th1801 nodrive





Cliché No : 01/30 npart.: 54740 tps : 0.002564 ns Collect3D 15/06/05

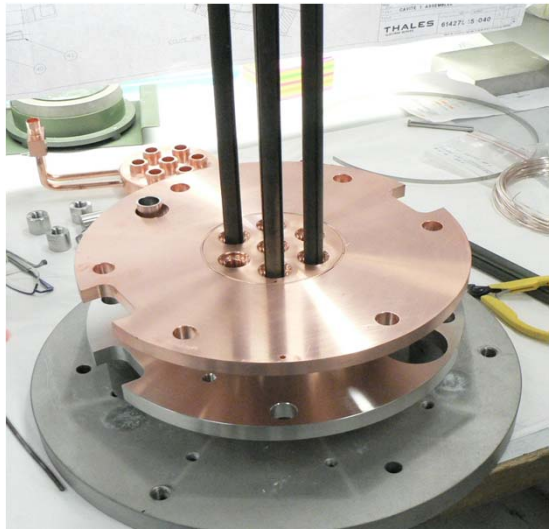
Collector design is directly correlated with high efficient tube stability when is used in back off regime

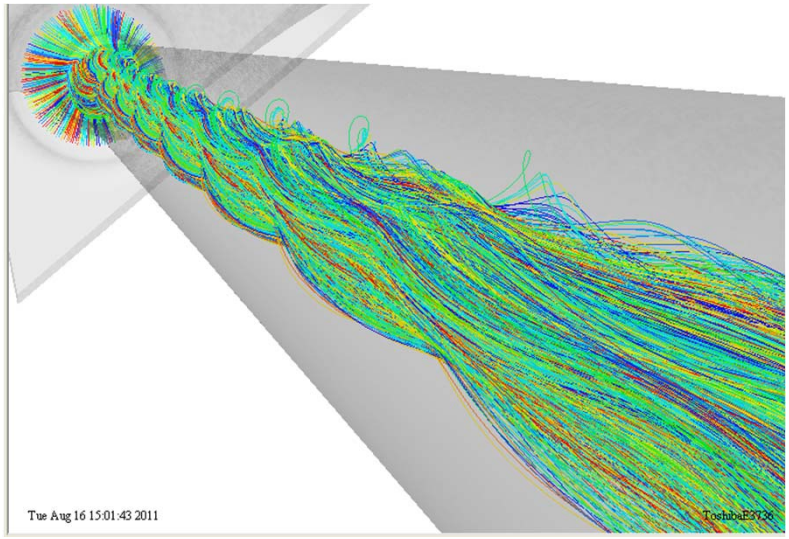
THALES

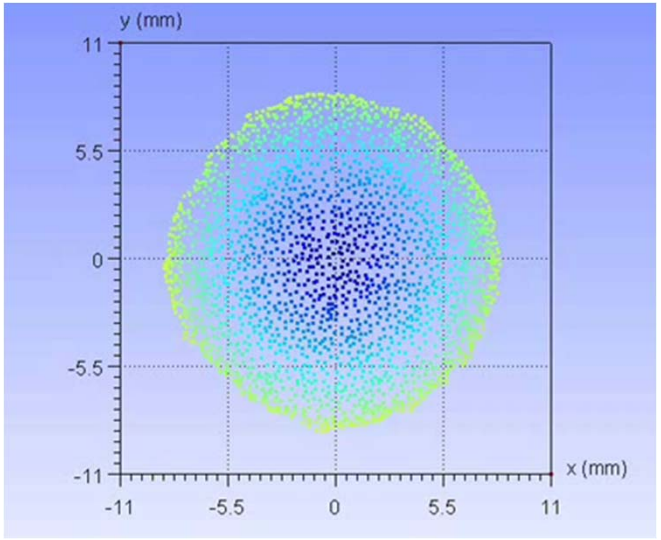
Key parameters for reliable operation

Beam transmission along klystron axis

- High optic quality
- 2D & 3D simulations are required
- Magnetic field profile
- Off axis beam analysis
- Mechanical alignment







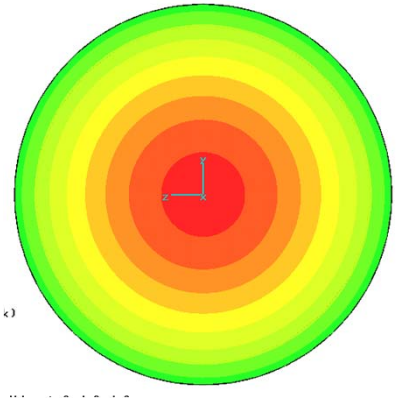
Off axis beams must be under control all along the klystron

THALES

Key parameters for reliable operation

RF cavity design and stability

- Choice of the cavity geometry and interaction mode
  - **TM01 in pillbox cavity**
  - **Compact geometry**
  - **Efficient beam modulation (high shunt impedance)**
- Mode competition has to be suppressed
  - **Large frequency gap between operating mode and HOM**
  - **Evaluation of the HOM oscillations conditions**



TM01

Heated cavity after HOM oscillation

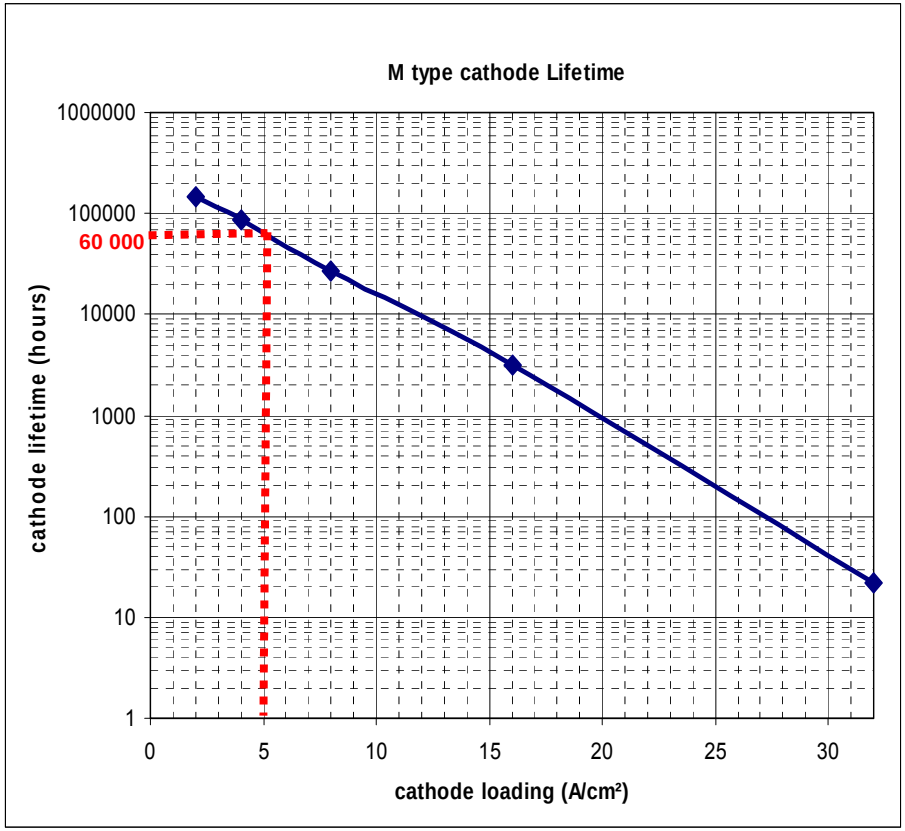
Stable operation on TM01 mode provided damping of the critical HOM

THALES

Key parameters for reliable operation

Gun geometry & cathode loading

- Cathodes life time versus current density



Cathode loading = 5.0 A/cm²

THALES

Key parameters for reliable operation

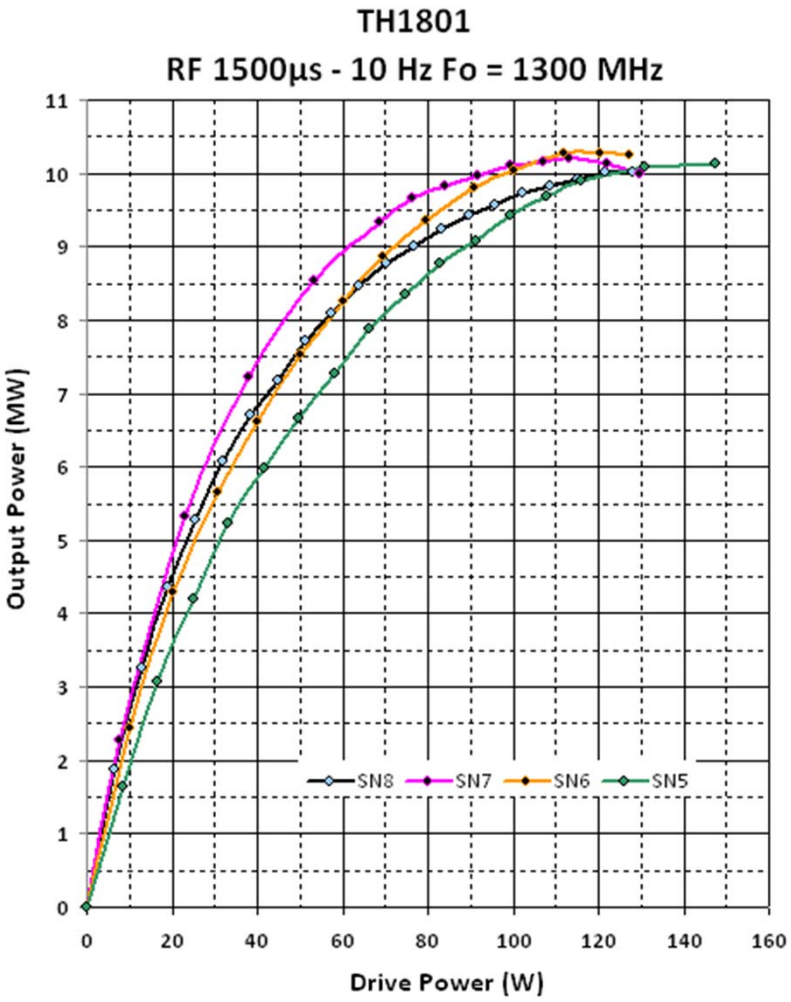
- Lessons learnt during 10 years of MBK manufacturing in Vélizy and operation at DESY enabled to improve the MBK design for good stability and reliability (> 60 000 hours of cumulative RF operation)

- All L-Band MBK produced since 2005 demonstrate a high degree of stability under all operating condition

Thanks to DESY for the continuous support to MBK technology

L-Band test results

TH1801 MBK



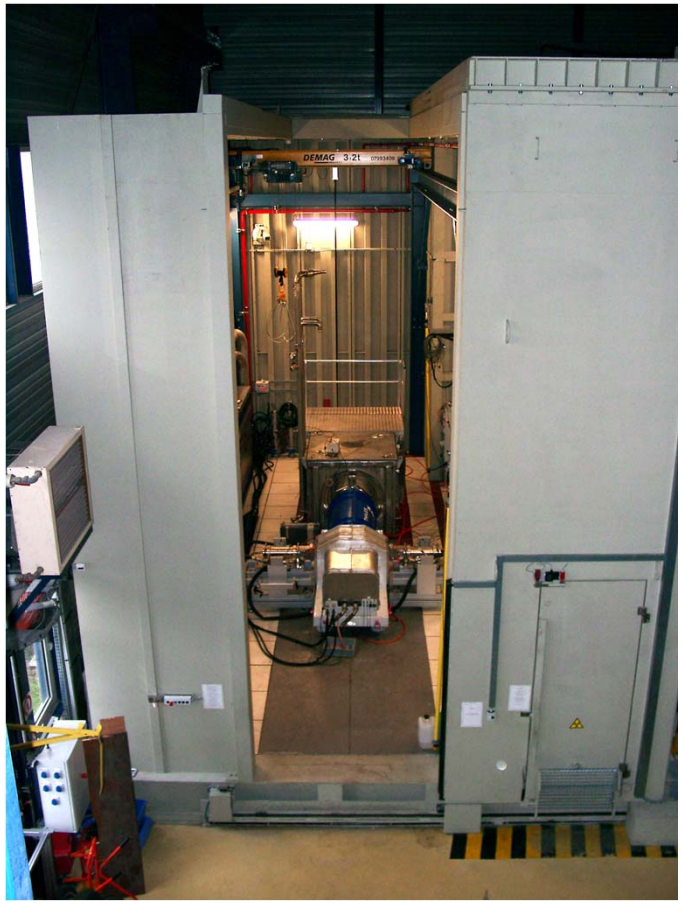
More than 10 vertical MBKs have been delivered by THALES

THALES

L-Band test results

TH1802 prototype tests

- X-Ray shielding qualified on KGP5 test stand < 10 µSV/h

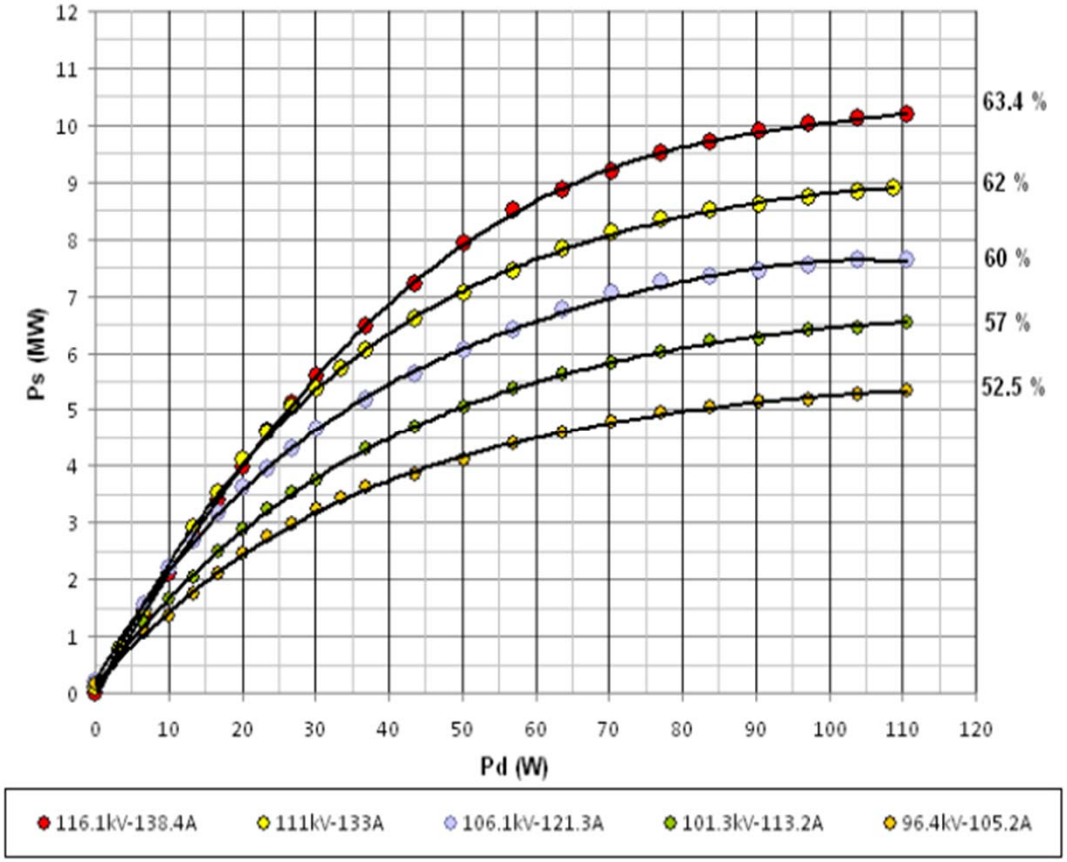


TH1802 prototype was fully tested at Velizy

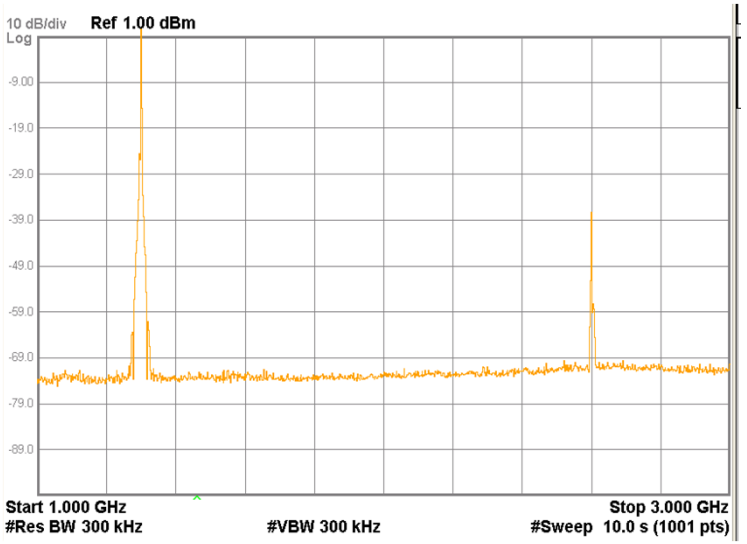
THALES

L-Band test results

TH1802 RF tests



- High tube stability in multiple operating modes (vs drive power and cathode voltage)
- No parasitic lines on the RF spectrum

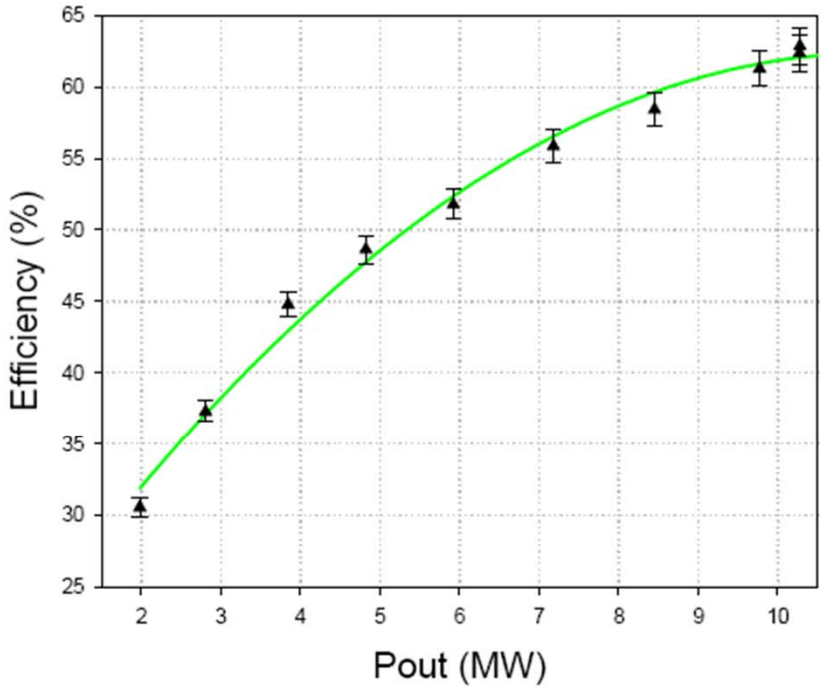


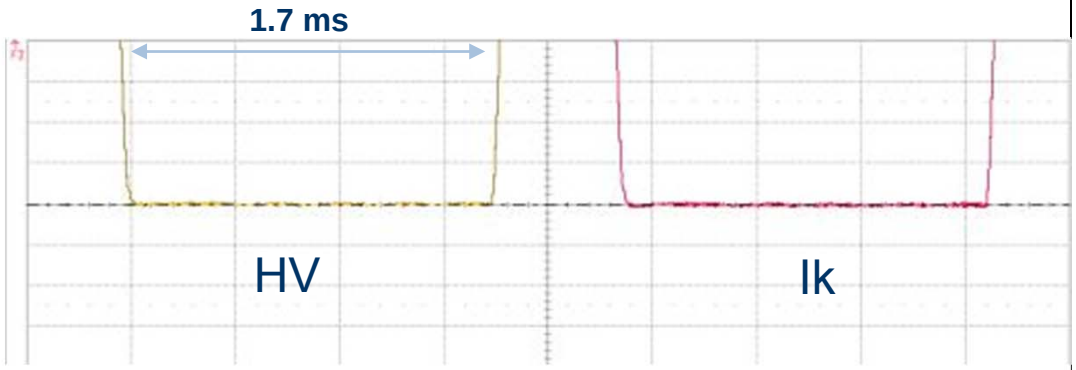
The MBK is perfectly stable in the full range of RF power and HV

THALES

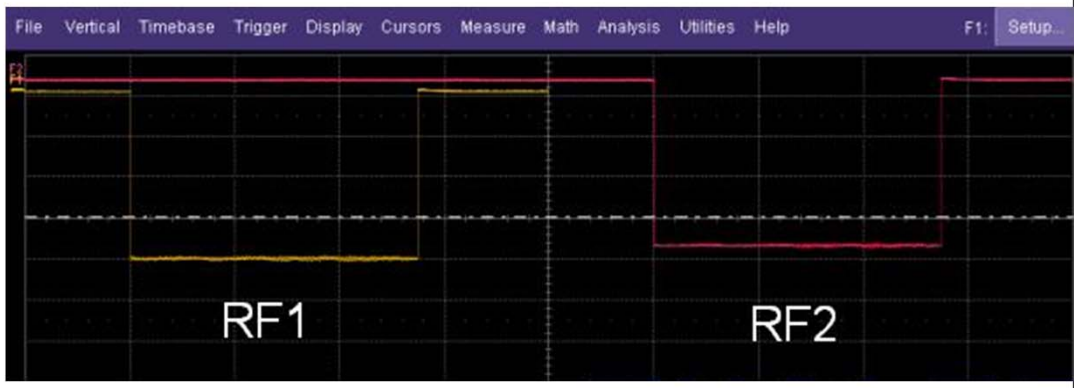
L-Band test results

TH1802 RF performances





KGP5 modulator high voltage pulse



10 MWp Output power at 116 kV in long pulse (1.5 ms RF)

THALES

L-Band test results

TH1802 operating statistics done at DESY test stand

- RF = 1,5 ms 10 Hz ; 10 MWp

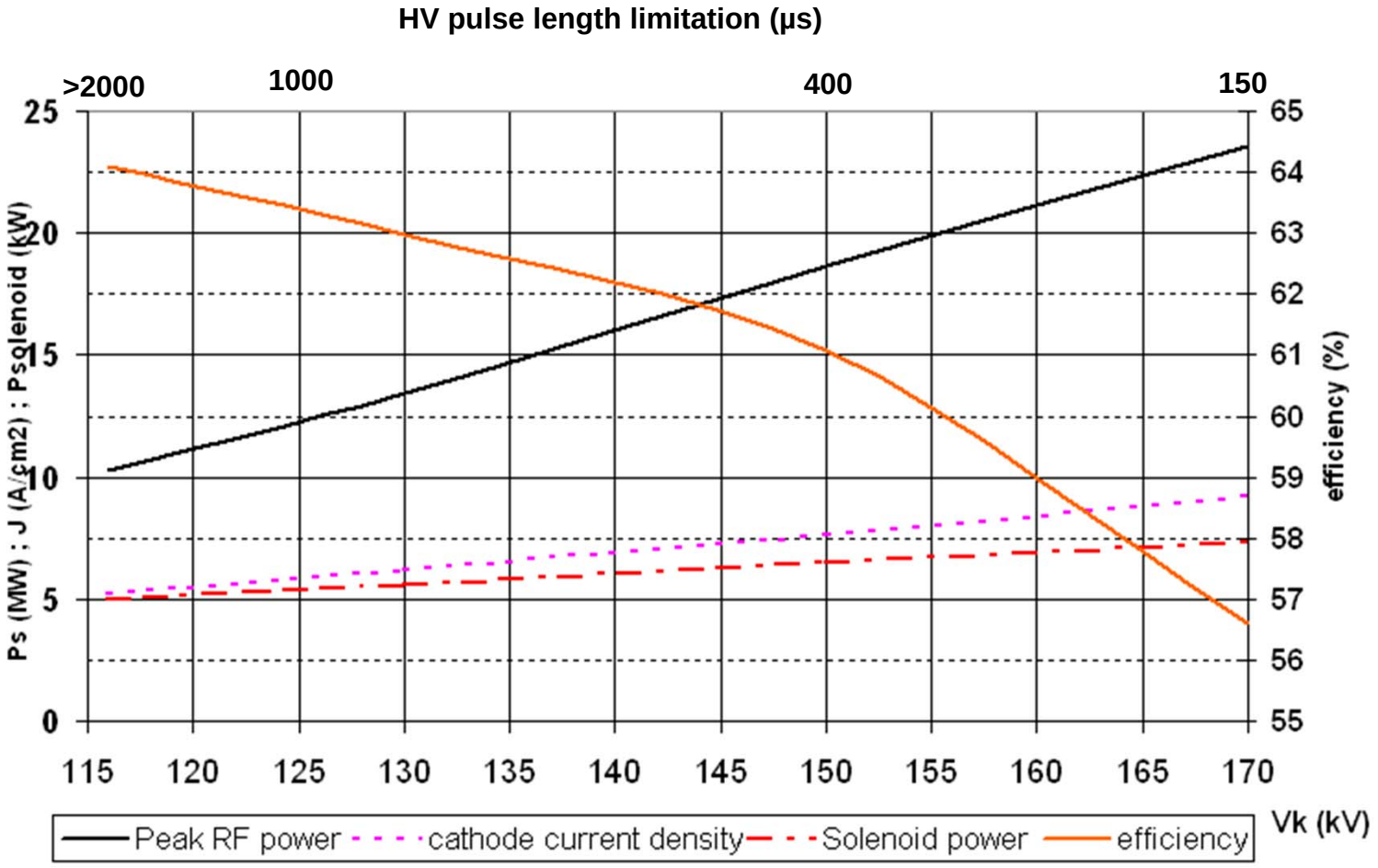
	Operating time (hours)	Gun arcing	Breakdows in klystron output circuit	Arcs in waveguide (1,3 bar of dry air)
From Feb to Dec 2010	820	4	4	7
From Jan to April 2011	1000	2	1	0

Average rate of stop events due to the klystron less than 1 per 100 hours

THALES

Klystron performance upgraded

Performance evolution of the existing MBK versus high Voltage at constant beam perveance

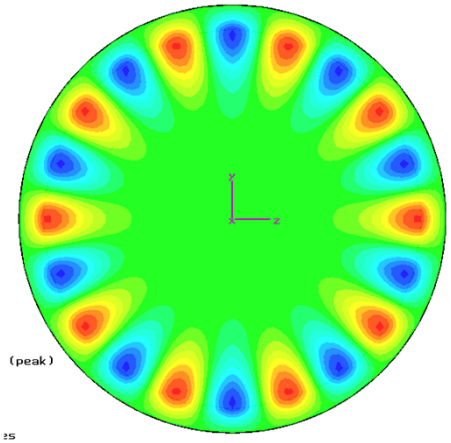


THALES

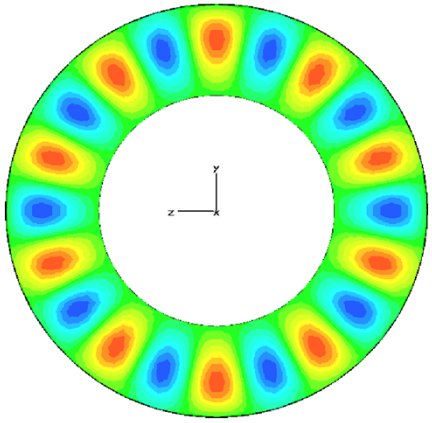
Klystron performance upgraded

How to obtain 20 MWp and efficiency > 68 %

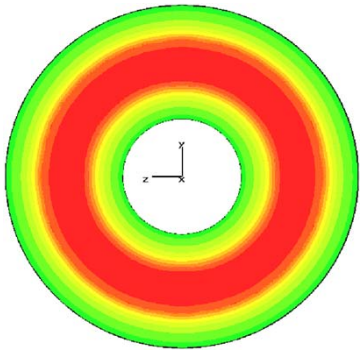
- Decrease the individual beam perveance (0.5 to 0.2)
- Allowed higher efficiency tube capability : $\eta = 78 - 0.16 x \mu K$
- Increase the number of beam from 8 to 20
- Depending the HV (115 to 140 kV)
- Determination of the best cavity geometry and interaction mode
- Off axis beam transmission and associated focusing system
- Interaction structure stability for all klystron regime



TM 10 1



TM 10 1



TM 0 1

THALES

CONCLUSION

- TH1802 L-band horizontal MBK shows very good reliability after mores than 1 year operation on DESY test stand
- MBK design is proven and performances have been qualified for XFEL facility, 22 tubes are under fabrication
- Development of a new high power and efficient L-band MBK
  - **Requires support from Accelerator people community; especially CLIC team**
  - **Breadboard and prototype fabrication are needed to obtain experimental results**
  - **Several thousand hours of operation is necessary to validate the design and improved the tube stability**