THALES ELECTRON DEVICES

For now three months ,

THOMSON-CSF

changed its name for

THALES

THOMSON TUBES ELECTRONIQUES

is now

THALES ELECTRON DEVICES

RF High Power CW Sources for the VLLC Project

Philippe J. GUIDEE

Marketing for Scientific Applications

THALES ELECTRON DEVICES (TED)

----

with the contribution of

the R&D teams of the Microwave and Gridded tubes

TED Strategic Business Units

IIT - Chicago - **March 9 - 11 , 2001**

RF Sources for VLLC - Design criteria (1)

- Large RF power facilities require a precise analysis of the

  Life Cycle Cost (LCC)

  for giving the most advantageous balance of technical performances vs overall price .

- Fundamental RF criteria for design at optimized cost are :
  - the unit RF power
  - the efficiency
  - the reliability
  - the possibility to feed several RF sources with the same HVPS
  - the VSWR withstanding .

RF Sources for VLLC - Design criteria (2)

- Other important criteria are :
  - the RF frequency : standard or specific
  - the beam parameters (i.e. cathode voltage & current)
  - the gain of the end power stage
  - the flexibility of operation

- RF power transmission to the accelerator (length & size of the lines , transmission losses ,circulator , RF window , RF coupler limitations and so on) is another major design factor .

RF Sources for VLLC - Possible candidates

- Klystron
- Multi-Beam Klystron (MBK)
- Inductive Output Tube (IOT)

RF Sources for VLLC - Parameters for design (1)

RF frequency

- 400 MHz suggested : Why not ?
- Other possible close frequencies : 350/352 , 500 , 700 MHz .

But a specific RF frequency affects only the development cost of the RF source (klystron or IOT 's cavity) and has minor effect on total cost in case of large series number .

Efficiency

- **Klystron** efficiency in excess of 70 % is problematic because of :
  - required high cathode voltage
  - RF signal instabilities

  or:
  - technological complexity

  A reasonable objective should be around **65 %**
- Expected **IOT** efficiency ranges around **65** to **68 % .**

RF Sources for VLLC - Parameters for design (2)

RF unit power

- Possible values ranging from 300 kW to 1.3 MW CW .
- For 100 MW total RF power , the number of sources goes from 330 to 80 .
- Reliable operation of hundreds of high power RF sources is realistic , as CERN proved it with 44 klystrons implemented on LEP with high figures of operating hours .

Reliability

- Reduced down-time is mandatory to justify the investment cost .
- It concerns not only the RF source itself , but also the RF equipments in general (RF transmitters).
- Return of experience is very important for setting the expected availability figures .
- Klystron operation slightly below its nominal power of conditioning is an efficient way of reliability improvement .

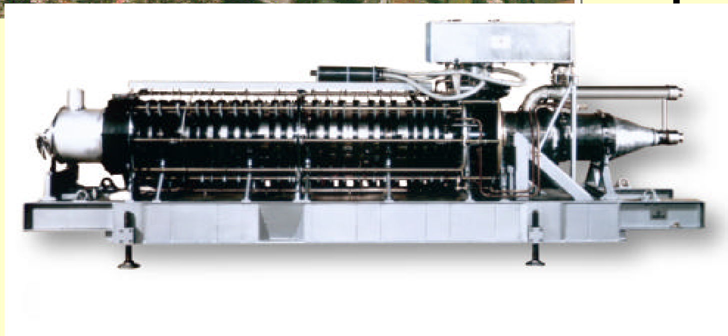
RF Sources for VLLC - Klystron option (1)

- Well known device with proven feasility
- Coverage of the whole frequency-power range
- Its size explains its high reliability

Really a conservative option for the peace of mind of a project leader .

RF Sources for VLLC - Klystron option (2)

Reliability operational data - TH 2089 at CERN



TED supplied to CERN for LEP operation 2 TH 2089 prototype klystrons and 27 series tubes (of which 6 were repaired once) .

The klystron operation period (from the 1st delivery to the facility shutdown) lasted around 17 years .

The MTBF figures are :

Probability	MTBF	
of occurrence	Heater hours	HV hours
90%	36 684	31 381
60%	48 504	41 493

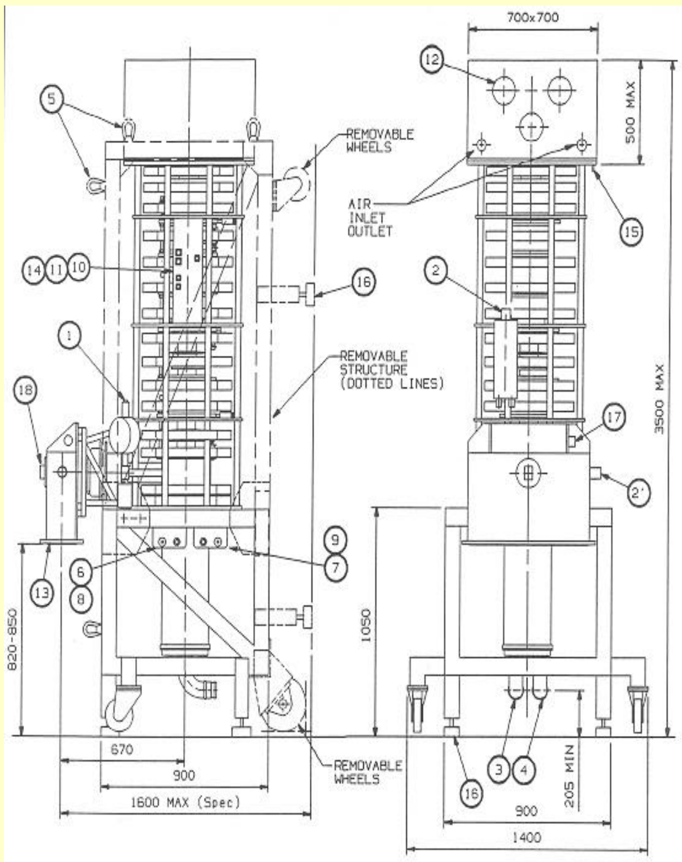
RF Sources for VLLC - Klystron option (3)

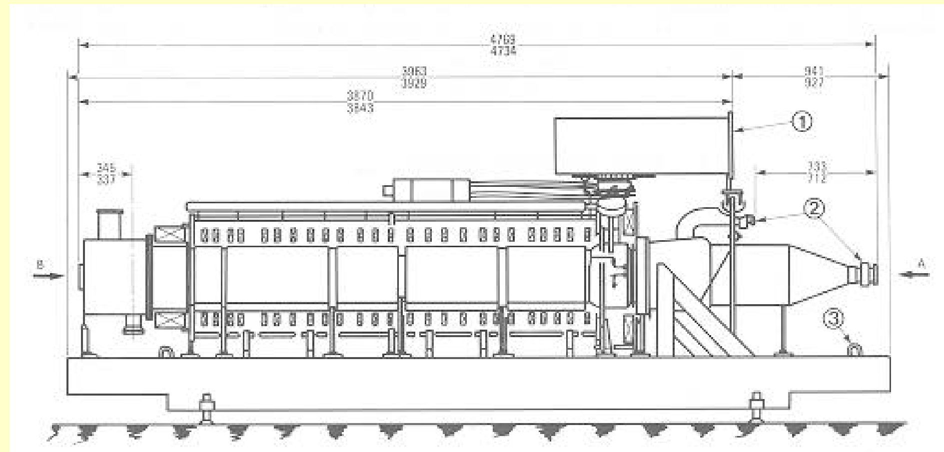
	TH 2089	LEP Klystron	TH 2167 LHC Klystron	VLLC Klystron
RF Frequency	352 MHz	352 MHz	400 MHz	400 MHz
RF Power	1 MW	1.3 MW	0.3 MW	1 MW
Beam Voltage	85 kV	100 kV	54 kV	85 kV
Beam Current	18 A	20 A	9 A	18 A
Efficiency	65%	65%	62%	65%
Gain	41.5 dB	42.7 dB	38 dB	41.5 dB
Length	4.8 m	4.8 m	3 m	4.6 m
Operating position	Horizontal	Horizontal	Horiz.or Vert.	Horizontal

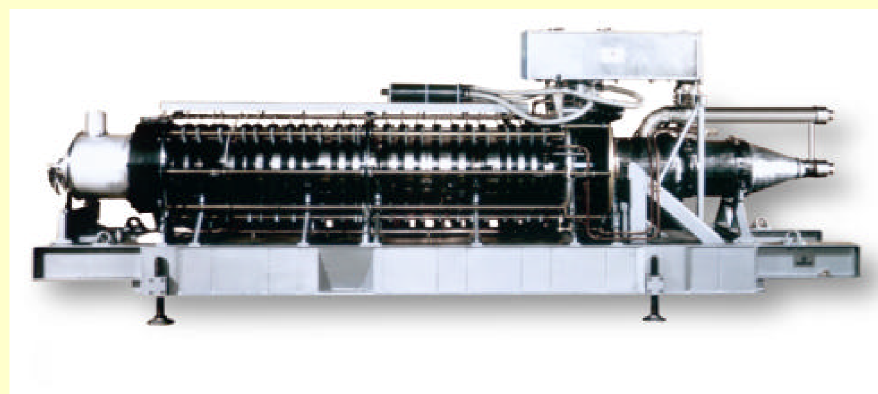
* : Operational data for TH 2089 klystron - Tentative typical data for TH 2167 and possible VLLC klystron .

** : All tubes fitted with modulating anode .

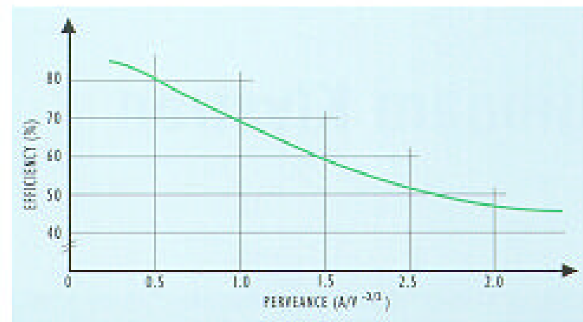
RF Sources for VLLC - Klystron option (4)







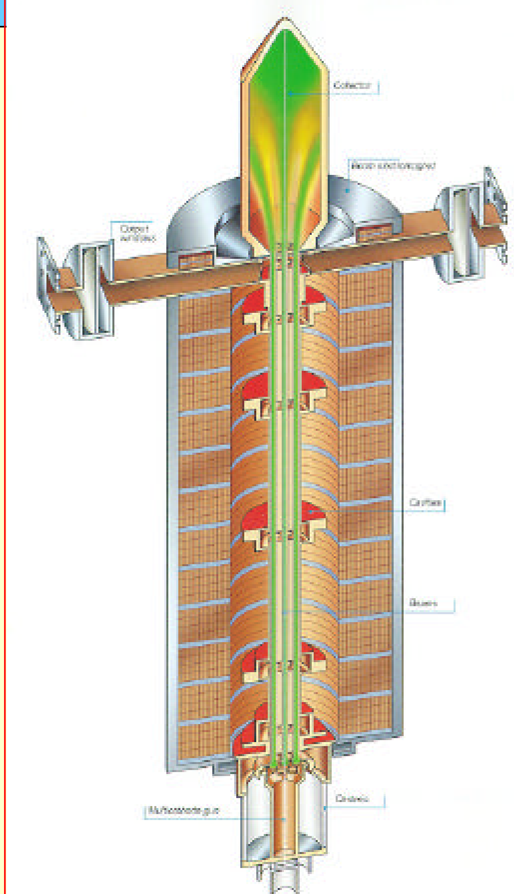
RF Sources for VLLC - MBK option (1)



Efficiency / Perveance

- **Klystron efficiency is mainly affected by the beam perveance = $I/V^{1.5}$.**
- **Lower is the perveance, higher is the efficiency.**
- **But it means to operate at higher voltages :**
  - ➡ **Higher costs of the RF power system**
  - ➡ **Reduced reliability**
- **MBK permits to combine an high efficiency with low applied voltages by having :**
  - **- a low perveance of each individual beam**
  - **- an high perveance of the tube .**

RF Sources for VLLC - MBK option (2)



MBK cross-section

- **MBK principle and technology are the ones of a conventional klystron .**
- **For the same RF power and comparable efficiency , the beam voltage is half of the klystron one .**
- **Pulsed MBK is able to operate in working areas (RF peak power + RF pulse duration + Efficiency) not accessible to the conventional klystron .**
- **In CW operation the expected advantage lies in the reduced voltage .**

RF Sources for VLLC - MBK option (3)

TH 1801 MBK prototype for TESLA project

	Design objectives	*Test results at Desy*
RF Frequency	1300 MHz	1300 MHz
Peak RF Power	10 MW	10 MW
Avge RF Power	150 kW	75 kW *
RF Pulse Width	1.5 ms	1.5 ms
Beam voltage	115 kV	117 kV
Efficiency	70 %	65 %

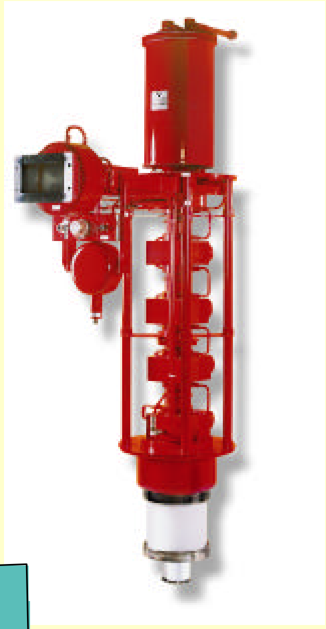
*: limitation by the modulator at 5 Hz (instead of 10 Hz nominal)

RF Sources for VLLC - MBK option (4)

The TESLA case : how to replace two tubes by one

TH 1801

TH 2104C



TH 1801		TH 2104C
1300 MHz	RF Frequency	1300 MHz
10 MW	RF peak power	5 MW
150 kW	RF avge power	75 kW
1.5 ms	RF pulse duration	1.5 ms
120 kV	Cathode voltage	122 kV
65 to 70 %	Efficiency	42 %

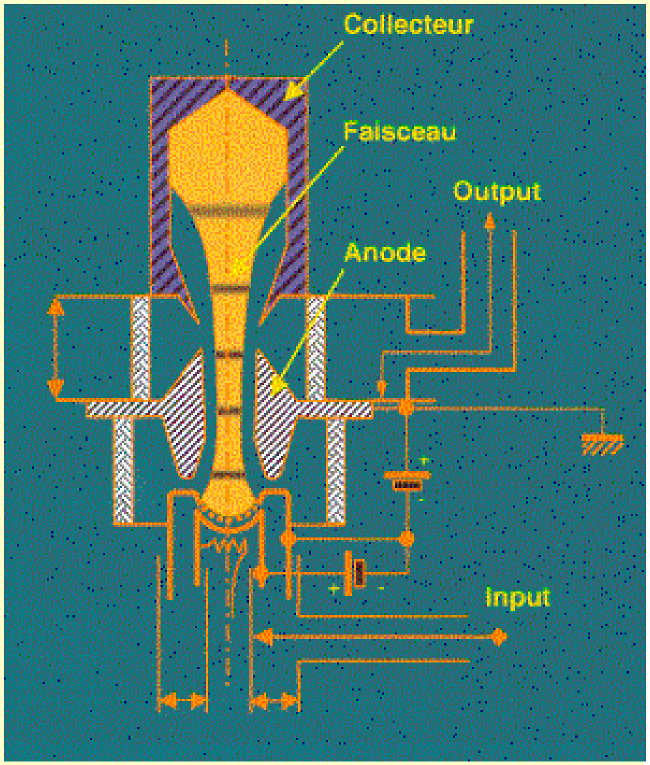
1 = 2

RF Sources for VLLC - MBK option (5)

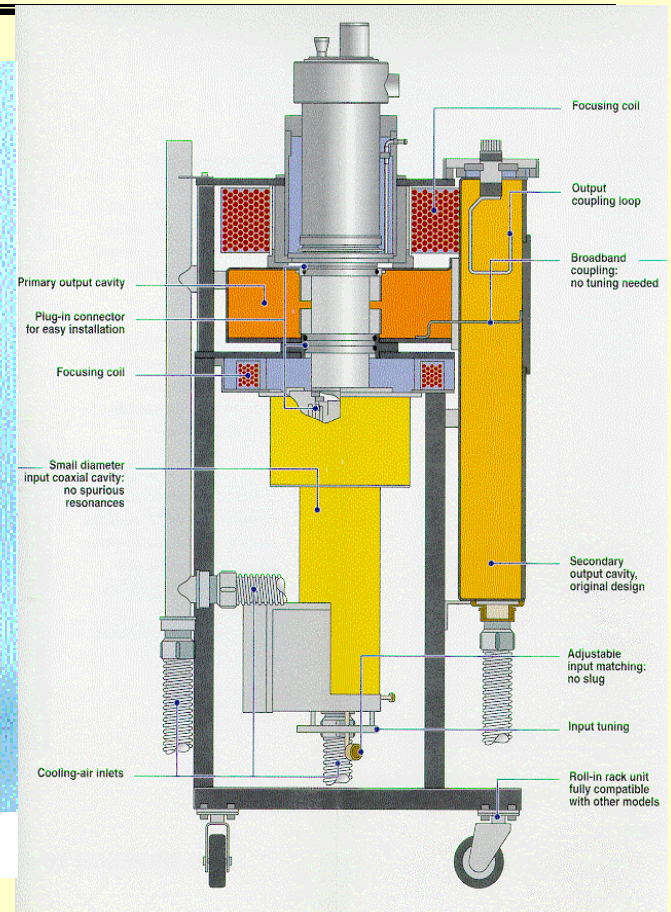
Conclusions

- The feasibility of high peak power MBKs is now proven with the tube developed for TESLA project .
- The 1.3 GHz RF frequency of TESLA was a real challenge for design .
- In this respect , the 350 to 700 MHz frequency range is much more accessible to MBK .
- The MBK requires additional development work for a complete technical benchmarking versus conventional klystron .
- The ideal case is the possibility to replace two tubes by one : all accelerator designs don ’t permit it .

RF Sources for VLLC - IOT* option (1)



The 18760 cavity



* : IOT means « Inductive Output Tube »

RF Sources for VLLC - IOT option (2)

- Return of experience from the TV application :

    - in CW operation
    - at lower power level (tens of kW) .

- 3OO-kW IOT seems feasible but requires a development effort to become an operational solution

- Some critical issues have to be addressed

- IOT offers attractive features (high efficiency , compact size) but its reliability at high power , i.e. hundreds of kW , is not proven .

RF Sources for VLLC - IOT option (3)

RF power	300 kW	600 kW	1.2 MW
Cathode size	Compatible with acceptable cathode loading	Could be too large for acceptable cathode loading (and inversely)	
Focus. difficulties	Moderate	High	High
Cathode voltage	Around 50 kV	> 50 kV	> 80 kV
HV decoupling capacitor	Feasible	More difficult	
Grid therm.behavior	Solvable	Questionable – To be verified	
Conclusion	Accessible objective through a R&D program	Too many issues without certainty of success : other devices to be considered	

RF Sources for VLLC
Comparison of the possible candidates

	IOT	Klystron	MBK
Advantages	• Reduced size • Replacement of tube only • Low group delay • Good efficiency in a broad power range • Grid modulation • Tube possibly Off between pulses	• Large return of experience • Certainty of feasibility • High gain • Possible anode modulation • High reliability & long lifetime	• Klystron technology with subsequent spin-offs & advantages • Low cathode voltage (half of klystron and IOT cathode voltage)
Drawbacks	• Gain : 22 to 25 dB • Grid power supply referenced to the cathode potential • Experience limited to lower power levels	• Relatively large size at 400 MHz	• The same as the klystron + still a limited return of experience

RF Power for VLLC - Budgetary Estimate (1)

- This difficult exercise requires some assumptions and guidelines for making sense .
- For VLLC , we suggest the following ones :
  - 1 MW CW , 400 MHz klystron (or MBK if feasible and developed)
  - 4 klystrons per 100 kV, 80 A HVPS
  - Supply limited to the RF source , the HVPS (of PSM solid state technology) and the RF amplifier (i.e. drive chain , auxiliaries PSU , low level RF circuits ,control-command).
  - Production rate adjusted for minimizing the industrial investments .
  - Budgetary estimate limited to the manufacturing costs , i.e. :
    - no development costs
    - no installation and commissionning
  - Current economic conditions .
- In any case , a budgetary estimate is not a commitment without a formal request and a detailed specification and should require additional investigation for having an accuracy better than 20 % .

RF Power for VLLC - Budgetary Estimate (2)

- TED carried out such a costing study 3 years ago for the ITER fusion program : the considered data were :
  - 64 to 72 klystrons 5 GHz , 1 MW CW
  - 16 to 18 HVPS 80 kV/100 A
  - 64 to 72 RF amplifiers .
- The result of this study was : **1.15 € / RF watt** .
- It should be <u>roughly the same for VLLC</u> .

RF Power Sources for VLLC - Conclusions

- An early design of the overall RF power system is mandatory for giving the best Life Cycle Cost to the facility .
- Design criteria are presently well identified
- There are three potential candidates : klystron has today a real advantage
- Experience with high RF power in CW (or long pulses) operation is growing thanks to some accelerator (CERN , KEK , DESY , TJNAL) or fusion (JET ,JT-60 , TORE SUPRA) facilities
- CERN got a valuable stock of reliability data with LEP operation : its exploitation should influence the design of future facilities
- Strong interaction between operators and manufacturers should solve many issues
- Because cathode voltage is an important reliability factor , MBK is challenging klystron for future facilities .