# Status of the ELETTRA RF System Upgrade Project

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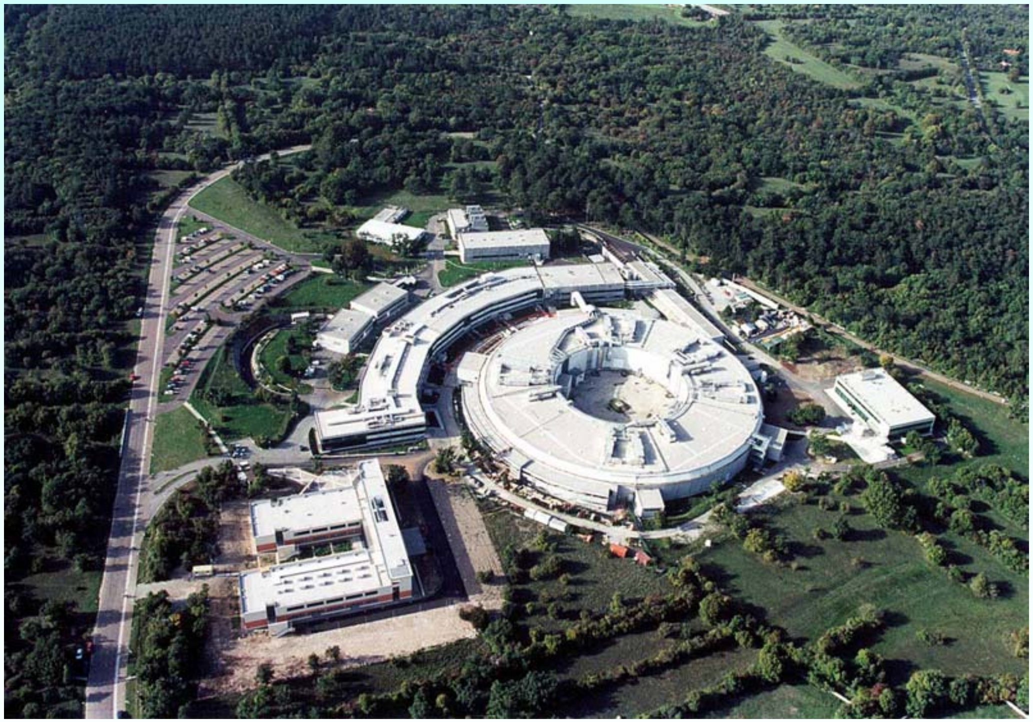


*Summary*

- *Recall on the project*
- *The changes on the power amplifier strategy*
- *The power amplifier*
- *Other activities*
- *Status and outlook*

**6th ESLS RF Meeting**
**Villigen, November 28-29, 2001**

# Recall on the RF upgrade project



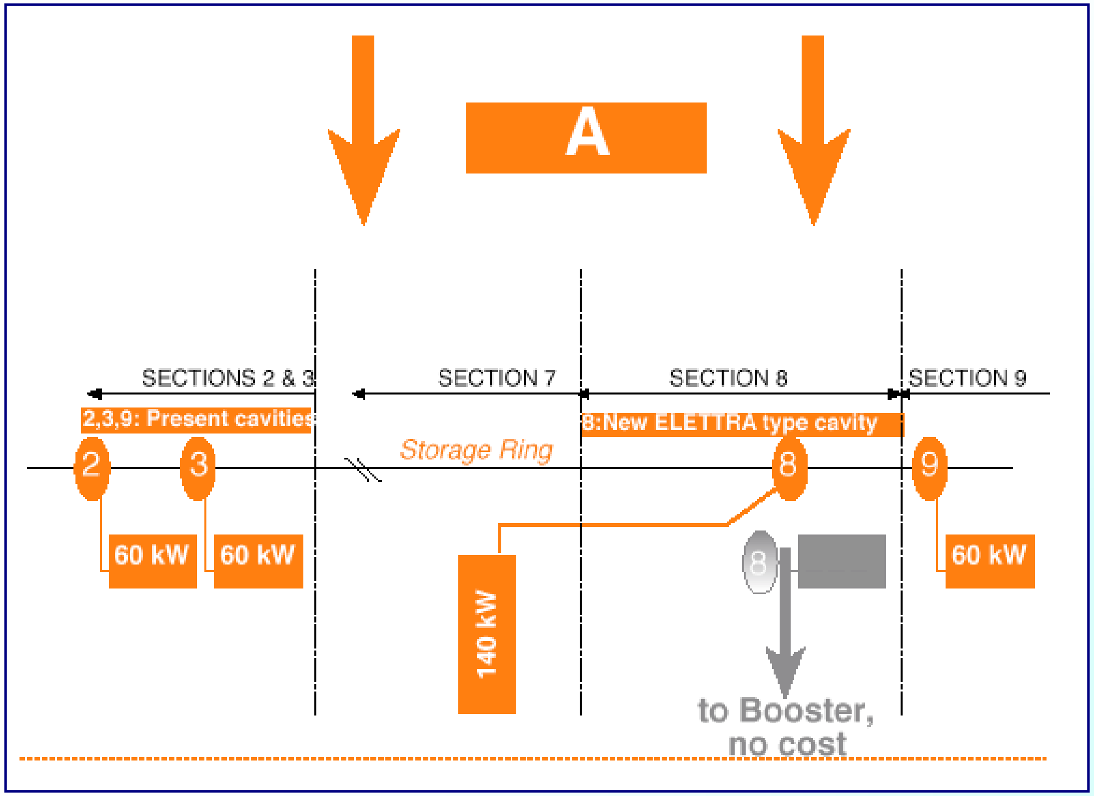
- A project for the upgrade of the existing RF system was launched during year 2001, in order to assure:
  - An increase of the available power for the beam, also in view of future installation of insertion devices and increase of the stored beam current and energy.
  - A higher beam lifetime.
  - A wider operating margin for the operation of the RF system.

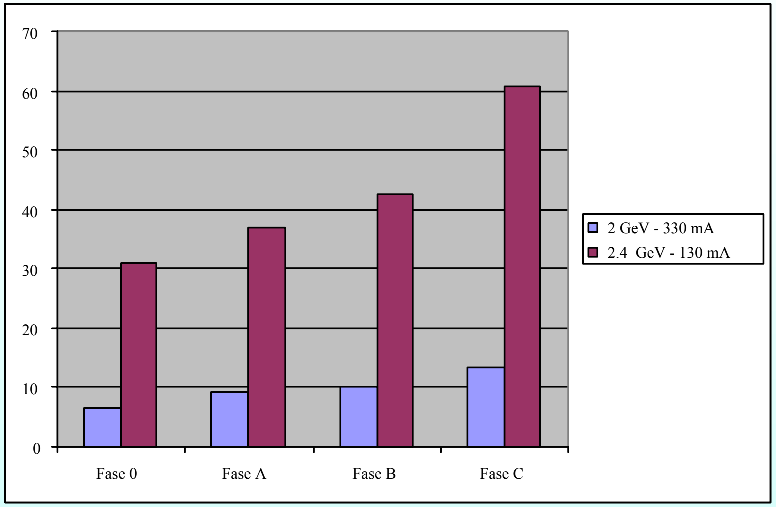
- The upgrade takes into account the following **boundary conditions**:
  - ELETTRA is a users' facility ⇨ impact on machine operation has to be minimised.
    ⇨ reliability is a fundamental issue
  - The number of the cavities has to remain the same ⇨ no new space for RF and no new potential source of mbi.
  - The project has to be consistent with other facility upgrades ⇨ for example the new booster injector.

- **The first phase (phase A) of the project was approved and started last year.**
  - This phase is necessary too keep the performances of the machine, allowing also a slight improvement.
  - The completion of this phase will provide the booster plant.

# Recall on the RF upgrade project






Evolution of Touschek lifetime at the usual operating current and energies

# Powering strategy

- For phase A we need **140 kW**, eventually if we go to sc cavities we will need 180 kW.
- Since the beginning we discarded the possibility of combining three klystrons of the same type as the ones used in the storage ring.
- First we considered the use of a **single 180 kW 500 MHz** klystron.
  - Traditional choice for an accelerator.
  - Reliability and lifetime well known.
  - 180 kW 500 MHz klystron already existing.
- Then
  - We were informed that E2V Technologies (at that time Marconi) decided to withdraw from the scientific klystron market.
  - This follows the decision of Philips to close completely the klystron production in 1996.
  - Still Thales and CPI could provide such klystrons but will it be still the same in the future?
  - For DIAMOND the use of TV IOTs combined to provide the required power was proposed.

⇨ **Investigate in detail the option of combining IOTs**

# Powering strategy



- The use of IOTs is a novel solution for a light source.
- An IOT with output power higher than 80 kW is not available, so IOTs have to be combined.
- IOTs are now the preferred choice for new transmitter in the high power TV market.
- CW applications are very few, although the combination of IOTs has been proposed for new machines.
- An advisory meeting was held in Trieste in February 2002 (M. Dykes,C. David, M. Ebert, H. Frischholz, CPI-EIMAC, E2V Technologies, Thales).

⇨ **As a result of all these studies the option of combining IOTs was adopted.**

# Comments on the option



- **Efficiency**: higher for an IOT (class AB operation) and still quite high in the output power range of interest for pure drive modulation.
- **Gain**: lower for an IOT than for a klystron (typ. 23 instead than 41 dB).
- **High voltage**: IOT cathode voltage is lower than for a scientific klystron.
- **Physical dimensions**: an IOT is smaller and lighter than a similar power klystron. But we need more transmitters plus the combining system.
- **Electrical and cooling requirements**: lower for an IOT due to the higher efficiency.
- **Return of experience**: there is little experience on IOT in cw operation. However in TV operation, their lifetime is approaching or similar to klystron's.
- **Redundancy and flexibility**:
  - possibility of a modular approach.
  - operation at reduced power and repair in parallel with machine operation.
- **Maintenance and replacement**: replacement of an IOT is faster than for a klystron.
- **Commercial aspects:**
  - Manufacturing costs of an IOT based system are only slightly lower than a klystron based one. In addition running costs are lower.
  - IOT market is mature and growing. TV IOTs are virtually on stock.

# CW operation



- TV operation the power is modulated according to the TV signal. TV linearity is more demanding
- Peak power is higher in TV operation, but average power is lower.
- Efficiency is higher for a cw operation than for a TV operation.
- Collector dissipation is lower in cw operation, due to the increased efficiency. Also electron peak power loading on the collector should be lower (more evenly spread on the collector surface).
- Output cavity cooling should be increased for cw operation.

*Courtesy of M. Langlois, THALES*

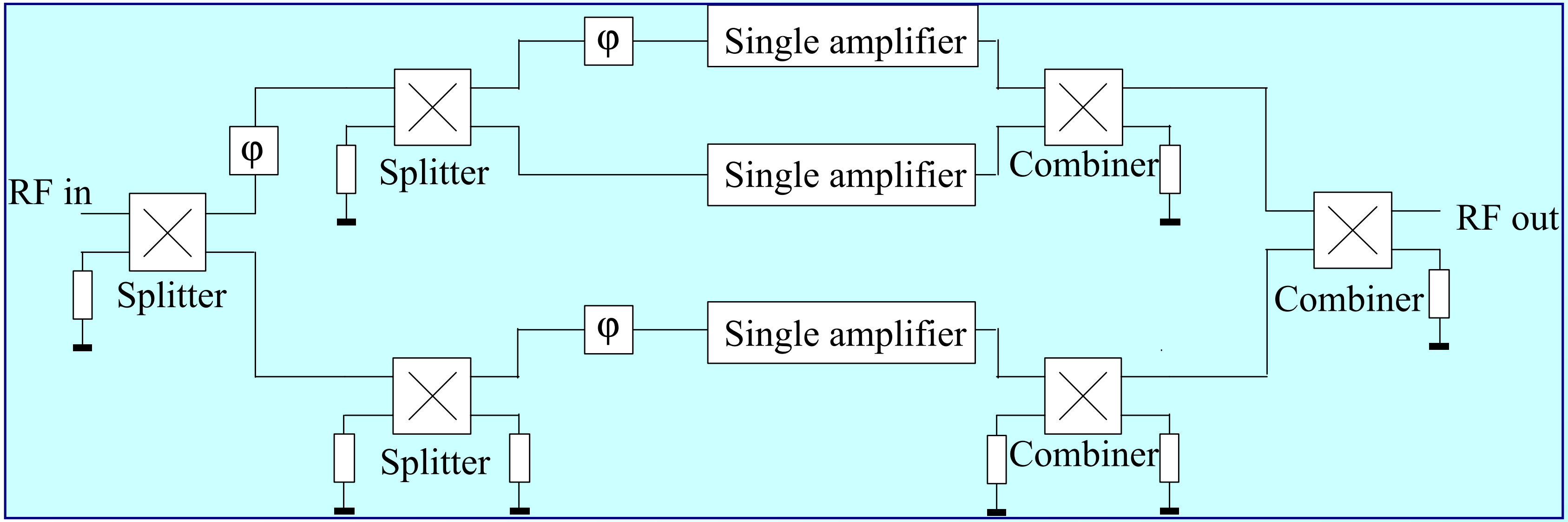
Comparaison de dissipation sur le collecteur
modulations TV et CW

| Tube | modulation | Puissance crête (KW) | Puissance moyenne (KW) | Haute tension (KV) | Courant moyen (A) | Puissance appliquée (KW) | Rendement anodique (%) | Puissance dissipée (KW) |
|---|---|---|---|---|---|---|---|---|
| TH770 | TV analog | 63 | 26 | 34 | 2.1 | 71.4 | 0.36 | 45.4 |
| | DTV | 100 | 25 | 34 | 2.1 | 71.4 | 0.35 | 46.4 |
| | CW | 50 | 50 | 30 | 2.8 | 84 | 0.60 | 34 |
| | | | | | | | | |
| TH790 | TV analog | 84 | 34.7 | 35 | 2.1 | 73.5 | 0.47 | 38.8 |
| | DTV | 140 | 35 | 35 | 2.55 | 89.25 | 0.39 | 54.25 |
| | CW | 60.5 | 60.5 | 31 | 2.9 | 89.9 | 0.67 | 29.4 |
| | CW | 80 | 80 | 35.5 | 3.4 | 120.7 | 0.66 | 40.7 |

NB: TV analog : norme B/G amplification commune image et son . La puissance crête est sur l'image et le son est en FM à -10dB.
DTV: norme ATSC en usage aux U.S.A. pour la télévision numérique.

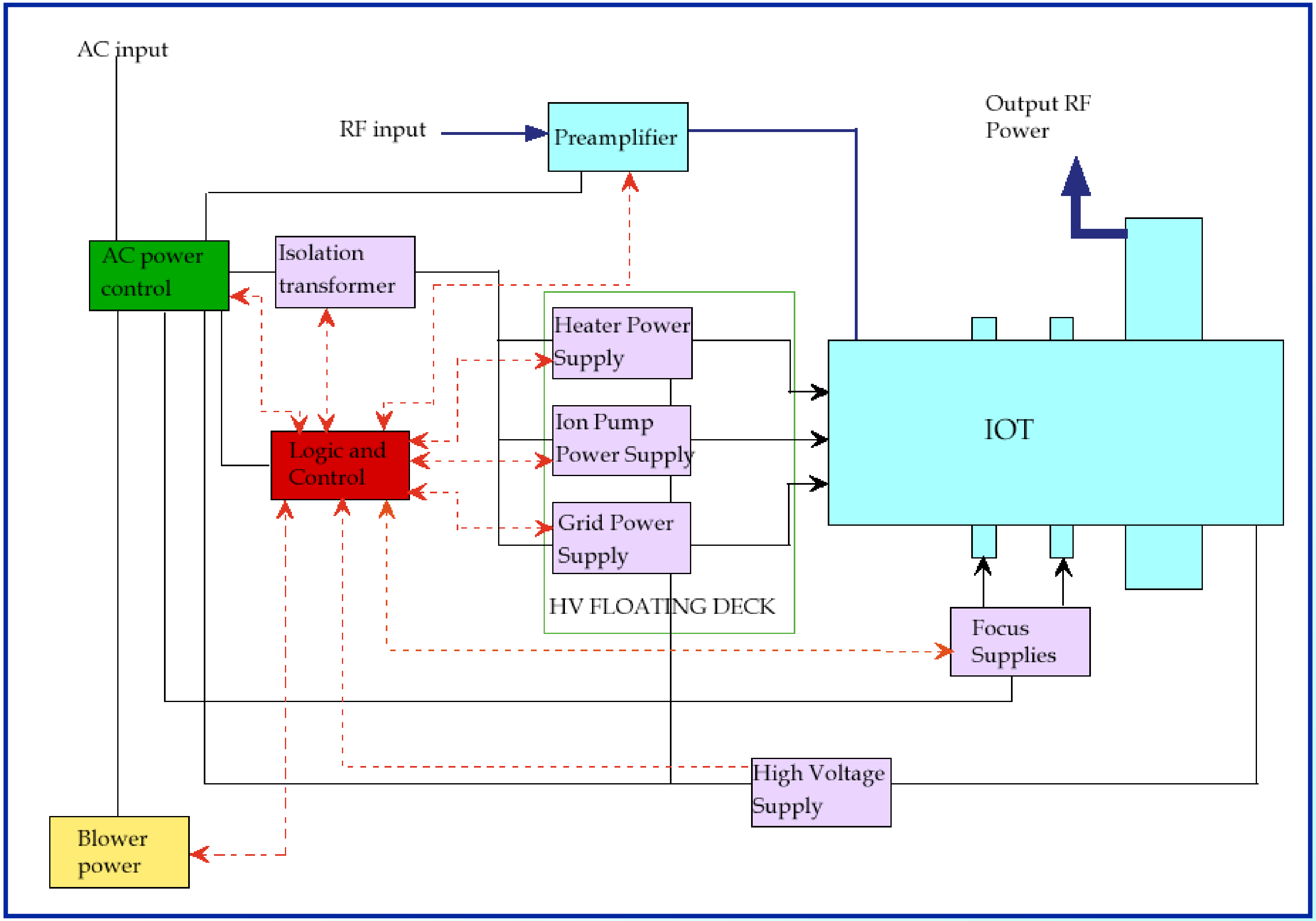
# System architecture

- Since the input power to the cavity will be limited to 120 kW, the options are:
  - A **2 x 80 kW system** (150 kW at system output)
  - A **3 x 50 kW system** (140 kW at system output)
- The system will have an open design to allow the addition of a further unit in the future.
- IOTs in the range from 50 to 80 kW are already available on the market from CPI/EIMAC, E2V Technologies or Thales.
- For the combining system, we take advantage of the experience in the broadcast field: a standard solution will be adopted.



# Single amplifier





## CHK2500W (K2)$^2$ Klystrode® IOT Cavity Amplifier

K2H50 IOT

**Typical Operation at 500 MHz (CW):**

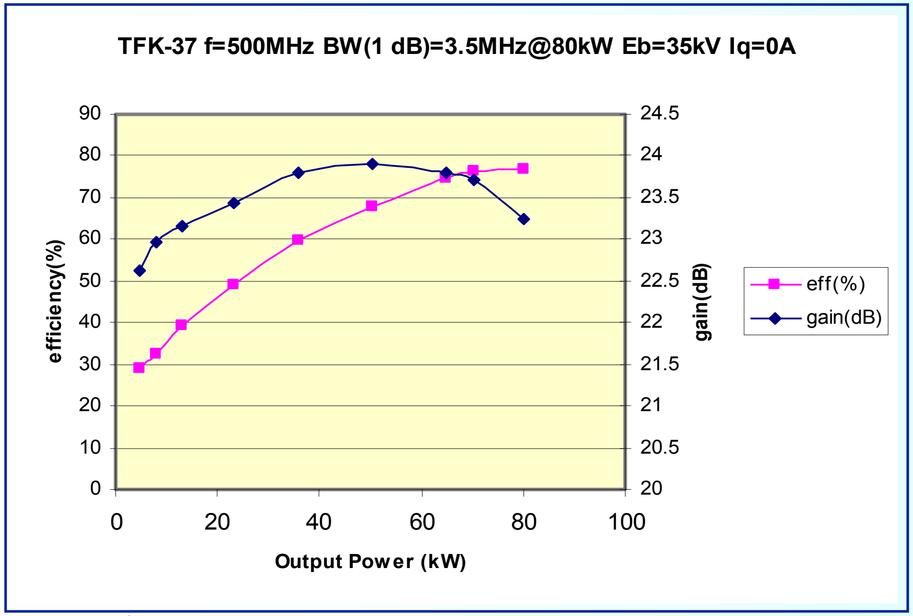
| | | | | | |
|---|---|---|---|---|---|
| Beam Voltage: | 28 | 30 | 32 | 34 | kV |
| Drive Power: | 230 | 210 | 195 | 154 | W |
| Output Power: | 50.3 | 51.3 | 50.1 | 50.6 | kW |
| Current: | 2.75 | 2.70 | 2.62 | 2.08 | A |
| Gain : | 23.4 | 23.9 | 24.1 | 25.2 | dB |
| Efficiency: | 65.3 | 63.3 | 59.8 | 71.6 | % |
| Heater Requirements: | 8.5 | 8.5 | 8.5 | 8.5 | A |
| Quiescent Beam Current: | 0.1 | 0.1 | 0.1 | 0.0 | A |
| Grid Bias Voltage: | Adjust | | | -73 | V |

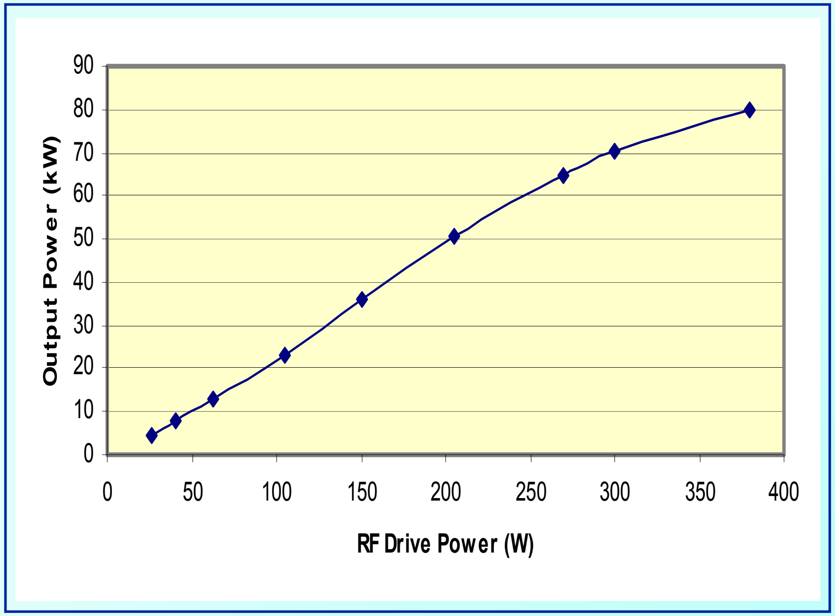
(Data taken at 4.5 MHz Bandwidth)_

Summary of Eimac IOT Specifications at Interested Power Levels

# K2H50 IOT

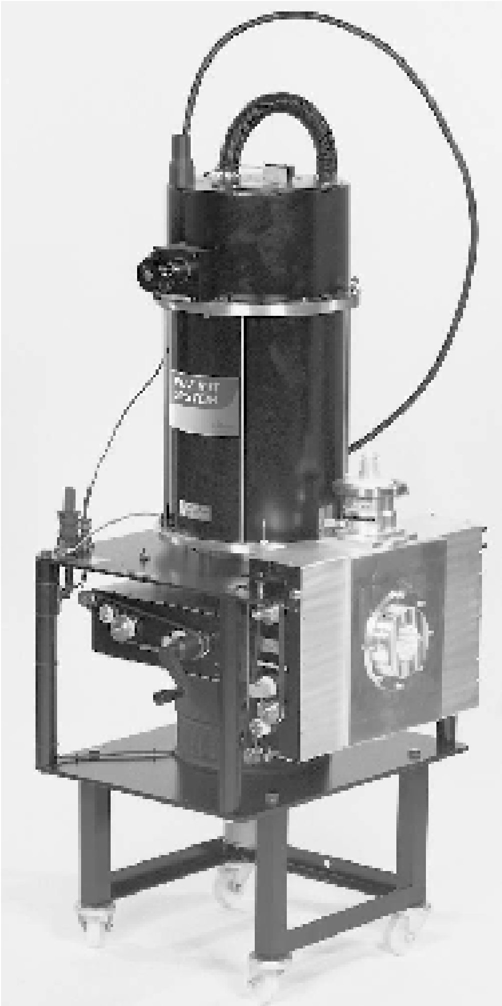
| | 50 (kW) | 60 (kW) | 67(kW) | 80 (kW) |
|---|---|---|---|---|
| beam voltage (kV) | 30 | 30 | 35 | 35 |
| beam current (A) | 2.14 | 2.67 | 2.6 | 2.9 |
| grid current (A) | 0.14 | 0.24 | 0.14 | 0.2 |
| RF drive power (W) | 190 | 267 | 275 | 380 |
| gain (dB) | 24.2 | 23.5 | 23.9 | 23.2 |
| efficiency (%) | 77.9 | 74.9 | 73.6 | 76.7 |



# E2V Technologies





## IOT8505

**Visual Service**

| | | | | |
|---|---|---|---|---|
| Output power (peak sync.) | 55 | 64 | 75 | kW |
| Beam voltage | 32 | 32 | 35 | kV |
| Beam current (peak sync.) | 3.15 | 3.25 | 3.55 | A |
| Beam current (black level) | 1.8 | 2.1 | 2.4 | A |
| Beam current (grey level) | 1.4 | 1.6 | 1.8 | A |
| Grid bias voltage with respect to cathode voltage | | | see note 13 | |
| Drive power (peak sync.) | 280 | 330 | 330 | W |
| Conversion efficiency (peak sync.) | 55 | 57 | 60 | % |
| Body current (RF) | 15 | 20 | 25 | mA |
| Figure of Merit (see note 15) | 120 | 120 | 120 | % |

## IOTD3130

**Visual Service**

| | | | | |
|---|---|---|---|---|
| Output power (peak sync.) | 66 | 77 | 88 | kW |
| Beam voltage | 30 | 32 | 35 | kV |
| Beam current (peak sync.) | 4.0 | 4.4 | 4.6 | A |
| Beam current (black level) | 2.7 | 3.0 | 3.1 | A |
| Beam current (grey level) | 2.0 | 2.1 | 2.1 | A |
| Quiescent beam current | 600 | 600 | 600 | mA |
| Grid bias voltage with respect to cathode voltage | | | see note 14 | |
| Drive power (peak sync.) | 525 | 575 | 650 | W |
| Conversion efficiency (peak sync.) | 55 | 55 | 55 | % |
| Figure of Merit (see note 18) | 105 | 110 | 115 | % |

# CW testing on an IOT 8505 at 500 MHz.

The following tests were carried out on an IOT8505 using a single output cavity.

| Conditions | Test 1 | Test 2 | Test 3 | Test 4 | Test 5 | Test 6 |
|---|---|---|---|---|---|---|
| Beam voltage (kV) | 35 | 35 | 30 | 28 | 26 | 25 |
| Grid voltage (V) | 108 | 108 | 85 | 81 | 78 | 74 |
| Beam current (A) | 2.38 | 1.58 | 1.66 | 1.71 | 1.75 | 1.77 |
| Focus current (A) | 26.8 | 26.8 | 26.8 | 26.8 | 26.8 | 26.8 |
| Body current (mA) | 54 | 12 | 8 | 8 | 7 | 7 |
| Grid current (mA) | - 2.0* | 0 | 0 | 0 | 0 | -2.0* |
| Output power (kW) | 60.0 | 30.0 | 29.8 | 29.9 | 30.6 | 29.9 |
| Input power (W) | 250 | 140 | 115 | 118 | 123 | 140 |
| Efficiency (%) | 72.0 | 54.0 | 59.8 | 62.4 | 67.2 | 67.6 |

* Interceptive

For each test the grid voltage was set for 0mA of idle current.

The band-width for all tests was better than 0.6dB at ± 1 MHz.

*Courtesy of R. Heppinstall, E2V Technologies*

TH 790

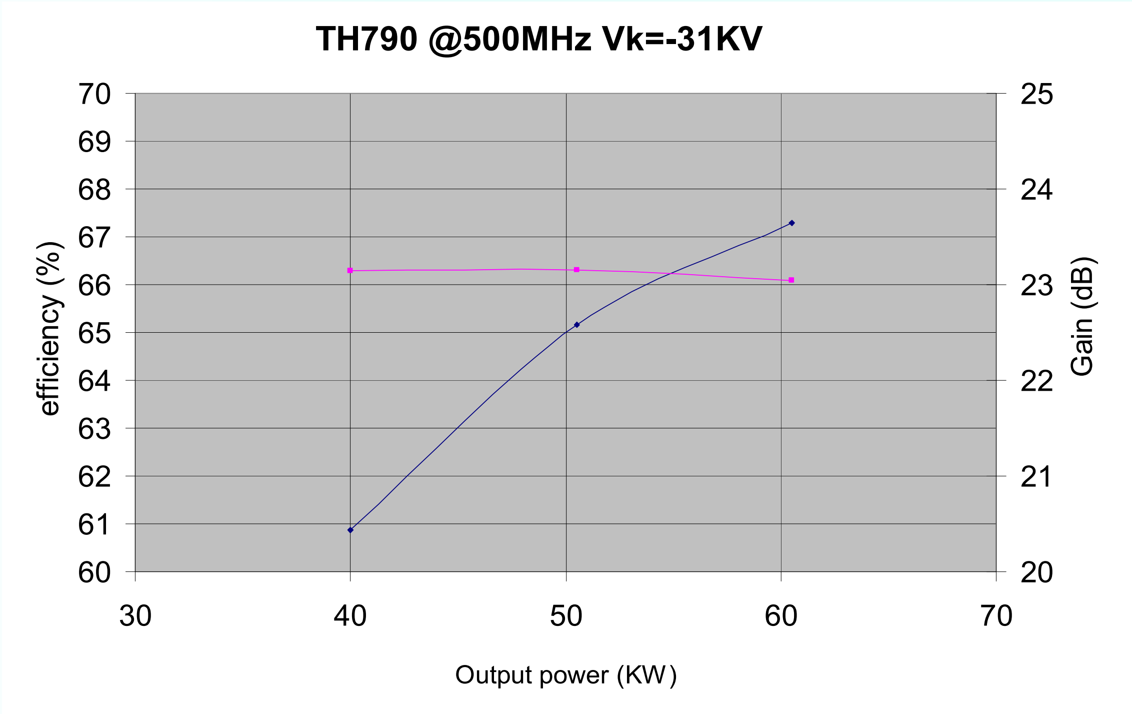
| | |
|---|---|
| . C.W. output power | 80 kW |
| . Beam voltage | 35.5 kV |
| . Beam current | 3.7 A |
| . Body current | 45 mA |
| . Quiescent beam current | 0.5 A |
| . Filament current | 25 A |
| . Focusing current | 22 A |
| . Grid voltage | - 82 V |
| . Efficiency | 61 % |
| . Gain | 23.5 dB |
| . Bandwidth at - 1 dB | 8 MHz |
| . Frequency | 704 MHz |

TH 770

| | |
|---|---|
| . C.W. output power | 50 kW |
| . Beam voltage | 30 kV |
| . Beam current | 2.8 A |
| . Body current | 40 mA |
| . Quiescent beam current | 0.5 A |
| . Filament current | 21 A |
| . Focusing current | 15 A |
| . Grid voltage | - 70 V |
| . Efficiency | 59.5 % |
| . Gain | 23.5 dB |
| . Bandwidth at - 1 dB | 5.5 MHz |
| . Frequency | 600 MHz |

Frequency range: 470 MHz - 820 MHz

| | TV | | CW | | |
|---|---|---|---|---|---|
| | Visual peak of sync. | Average power at black picture | Average power | Efficiency | Beam Voltage |
| TH 760 | 64 kW | 38 kW | 40 kW | 59.5% | 28 kV |
| TH 770 | 80 kW | 47.6 kW | 50 kW | 59.5% | 30 kV |
| TH 790 | 100 kW | 59.5 kW | 80 kW | 66% | 35.5 kV |



# IOTs summary



- The amplifier shall be designed to host IOTs of different manufacturers.

| | |
|---|---|
| Output power | 50 to 80 kW |
| Beam voltage | 30 to 36 kV |
| Beam current | 2.0 to 3.7 A |
| Efficiency | 60 to 77 % |
| Gain | 23± 1 dB |
| Central frequency | 470 to 810 MHz |
| Heater power supply | 10 to 15 V, 10 to 40 A |
| Ion pump | 3 to 4 kV |
| Grid power supply | -100 to –200 V, ± 200 mA |
| Focus power supply | 5 to 10 V, 15 to 30 A |

# Combiners

- Which are the ways to combine the single amplifiers to provide the requires output?
  - Take advantage of the standard techniques used in professional broadcasting, i.e. use:
    - Hybrid combiners
    - Switchless combiners
  - Look for new techniques , as for example combine the IOTs through a TM020 combining cavity, to save in costs and space.

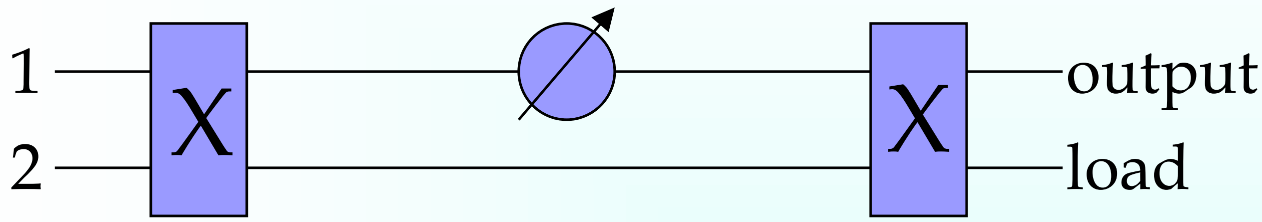
- Due to the time scale of the project we have decided to follow the standard way.

- **Hybrid combiners**
  - Advantages
    - simplicity and low costs.
  - Disadvantages
    - 6 dB power loss when one amplifier is out of service and difficulty of testing a single amplifier. Some type of switching or patching network should be added to allow bypassing the hybrid for testing and emergency purposes. During the switching each transmitter should be set in stand-by.

- **Switchless combiner**
  - Advantages
    - 3 dB power loss when one amplifier is out of service.
    - Four modes of operation.
    - It allows hot adjustment of the system.
    - **Maintenance of one amplifier can be done while the other is in service.**
  - Disadvantages
    - Increased cost and complexity.

# Switchless combiner

- The preferred choice is a switchless combiner.
- This device is made up from two hybrids and a variable phase shifter.




- Depending on the phase shifter position there are four modes of operation.
  - Mode 1: amplifier 1 and 2 to output
  - Mode 2: amplifier 1 to output, amplifier 2 to load
  - Mode 3: amplifier 1 to load, amplifier 2 to output
  - Mode 4: amplifier 1 and 2 to load
- Hot adjustment is possible, i.e. if one input fails, the other can stay on during the change from one mode to the other.
- Maintenance of one tube can be done while the other is on, unaffected.
- These types of combiners have been used for years and the control systems are thoroughly deigned and understood, helping to avoid the complexity issue.
- They are standard components that can be supplied by different manufacturers.

# Complete amplifier

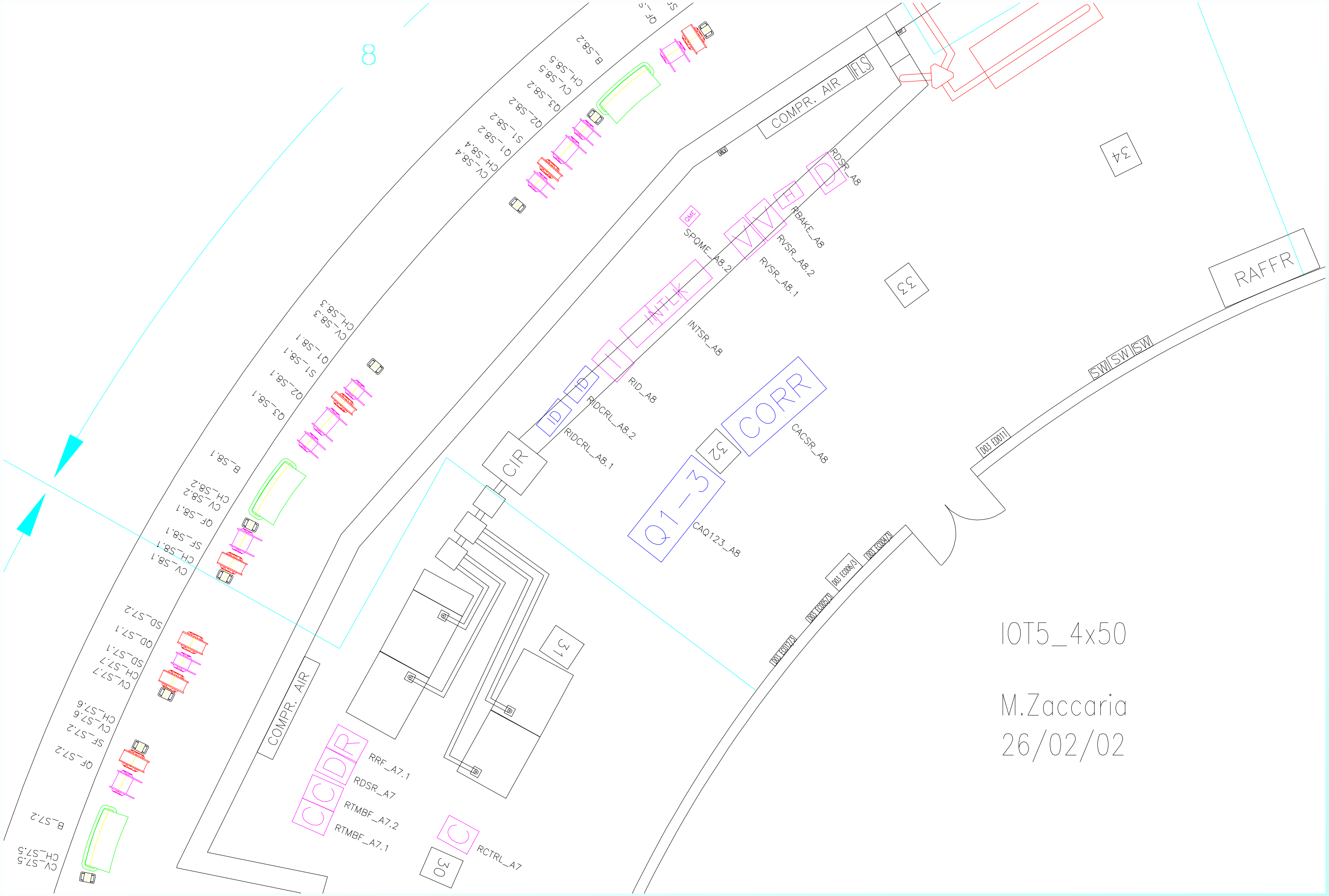


- The complete amplifier will be purchased as a **turn-key system** from industry.
- The call for tender of the amplifier is in progress.

- Scope of the call for tender is the supply of one complete power amplifier (transmitters, combining system and controls).
- Two options have been required:
    - A 150 kW amplifier realised combining two 80 kW IOTs
    - A 140 kW amplifier realised combining three 50 kW IOTs
- For the combining system a simple, standard and reliable solution based on switchless combiners is favoured.
- The amplifier has to be designed in order to allow the installation of IOTs of different manufacturers.
- The system has to be designed open to the addition of a further unit in the future.

# Layout

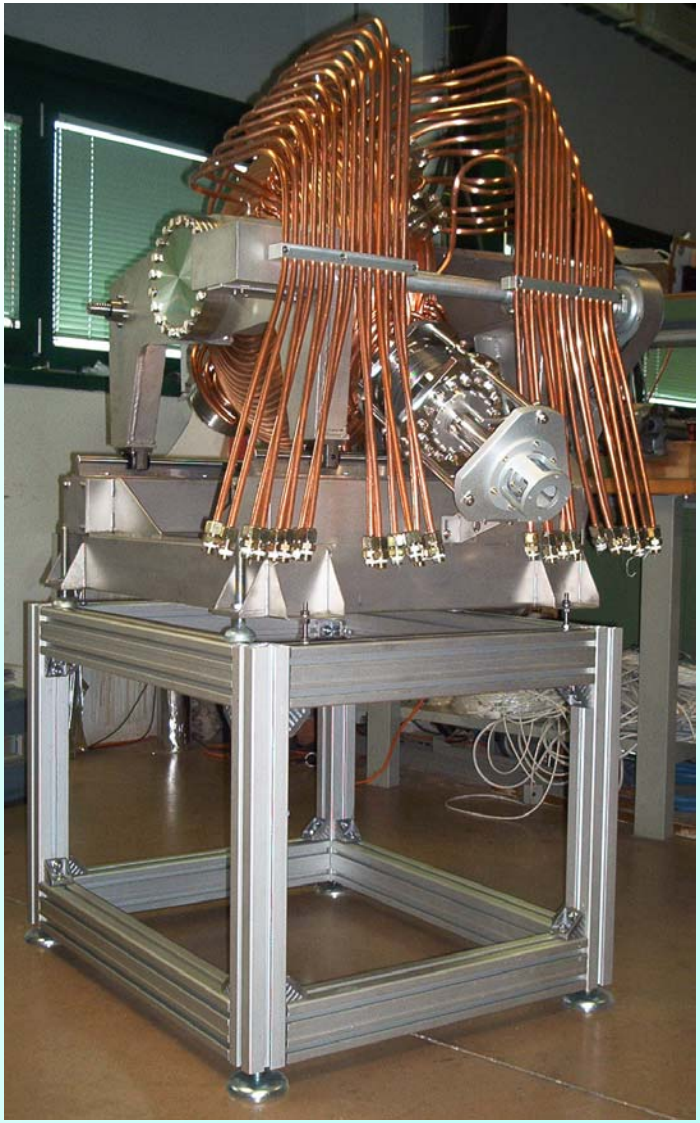



8
COMPR. AIR
FLS
RDSR_A8
RBAKE_A8
RVSR_A8.2
RVSR_A8.1
SPQME_A8.2
INTLK
INTSR_A8
RID_A8
RIDCRL_A8.2
RIDCRL_A8.1
CIR
CORR
CACSR_A8
Q1-3
CAQ123_A8
32
33
34
31
30
RAFFR
SW
SW
SW
COMPR. AIR
RRF_A7.1
RDSR_A7
RTMBF_A7.2
RTMBF_A7.1
RCTRL_A7
IOT5_4x50
M.Zaccaria
26/02/02

# Other components



- Cavity
  - The new cavity, similar to the ones we provided to SLS, is now under RF power conditioning in our laboratory.
  - The replacement of the cavity in section 8 with the new upgraded one is planned during next April machine shutdown.
- Low Level
  - Upgrade of the low level system is under way.
- Civil engineering
  - The study of the waveguide run has started. It has been concentrated on the run from the cavity to the service area, taking into consideration the radiation safety aspects.
  - Upgrade of the cavity cooling rack and of the services will be done during next year shutdowns.



# Status and outlook



## Power amplifier

- The installation of the amplifier could be done starting from the last four months of next year
- A four weeks shutdown has already been foreseen in November 2003. The installation could be split in two periods and for this reason a second long shutdown can be planned at beginning 2004.
- Dismantling of the presently operating amplifier is foreseen at end April 2004.
- A period of operation on a dummy load could be foreseen after the installation and before the connection to the cavity in order to assure the performances of the equipment.

## Other activities

- Circulator and waveguides will be acquired in parallel with the construction of the power amplifier.
- The replacement of the cavity in section 8 with the new upgraded one is planned during next April machine shutdown.
- Upgrade of the low level system will be done in parallel with the acquisition of the power components.

# Acknowledgments




- Many thanks to
  - M. Dykes for all the discussions and information.
  - C. David, M. Dykes, M. Ebert and H. Frischholz for their participation and valuable suggestions during the meeting in Trieste on February 28, 2002.
  - The engineering staffs of CPI-EIMAC, E2V Technologies and Thales Electron Devices for all the information and comments provided.