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Klystron development in X band

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R&D Thales Electron Devices

Date du document

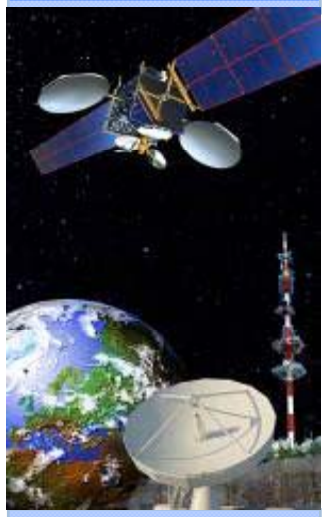
Thales Components & Subsystems

Applications

Medical radiology
Radiography, radiology
Angiography, urology
Dental 3D imaging
Vet exams

Digital flat detectors
X-Ray Imaging Units
X-Ray Image Intensifiers
CCD cameras
Associated sub-systems

Space
Telecom
Broadcast
Earth observation
Navigation….



Traveling Wave Tubes
Amplifiers
Power Grid Tubes
Associated sub-systems

Defense
Radars
Countermeasures
Missiles

Traveling Wave Tubes
Transmitters
Klystrons
CFAs
Associated sub-systems

Science
Fusion
Light Sources
Large accelerators

Klystrons
Gyrotrons
Diacrodes
Associated sub-systems

Industrial
NDT-Security
Laser
Industrial heating
Sterilization

Power grid tubes
X-Ray Tubes
X-Ray detectors
Associated sub-systems

Subsystems and products

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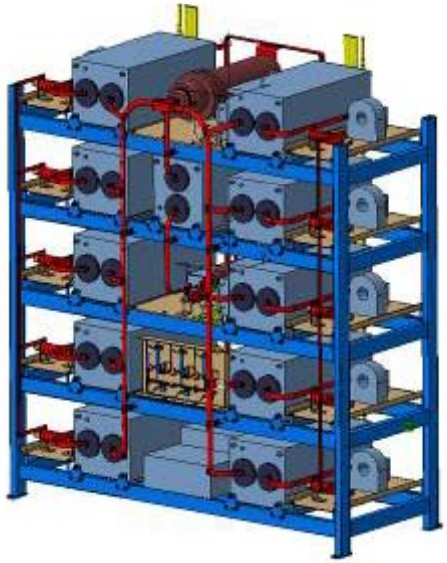
From Components to Subsystems - Science

Klystrons, gyrotrons, IOTs & tetrodes

RF amplifier



Energy storage
Mega Joule Laser

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Outline

- Klystron technology for X band
- A single beam 9.3 GHz / 4 MW Klystron
- Alternative technologies
  - PPM focusing
  - Multi-Beam Klystron

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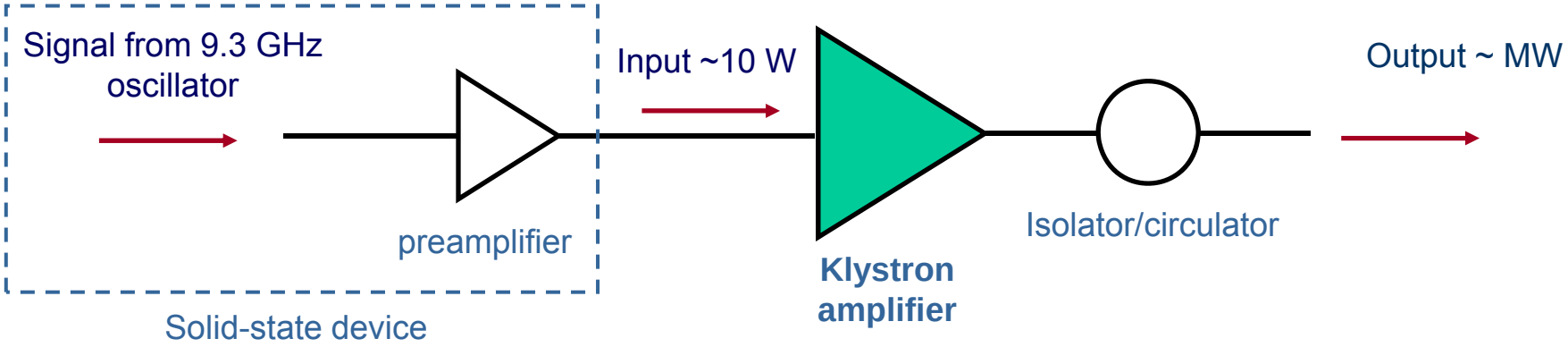
Klystron source for medical and industrial applications

The klystron, a high-gain amplifier



Klystron is a high-power, high-gain amplifier providing :

- More peak power than magnetrons
- Stability of output power
- Reliability : theoretical long lifetime even at high frequencies
- Output power versatility

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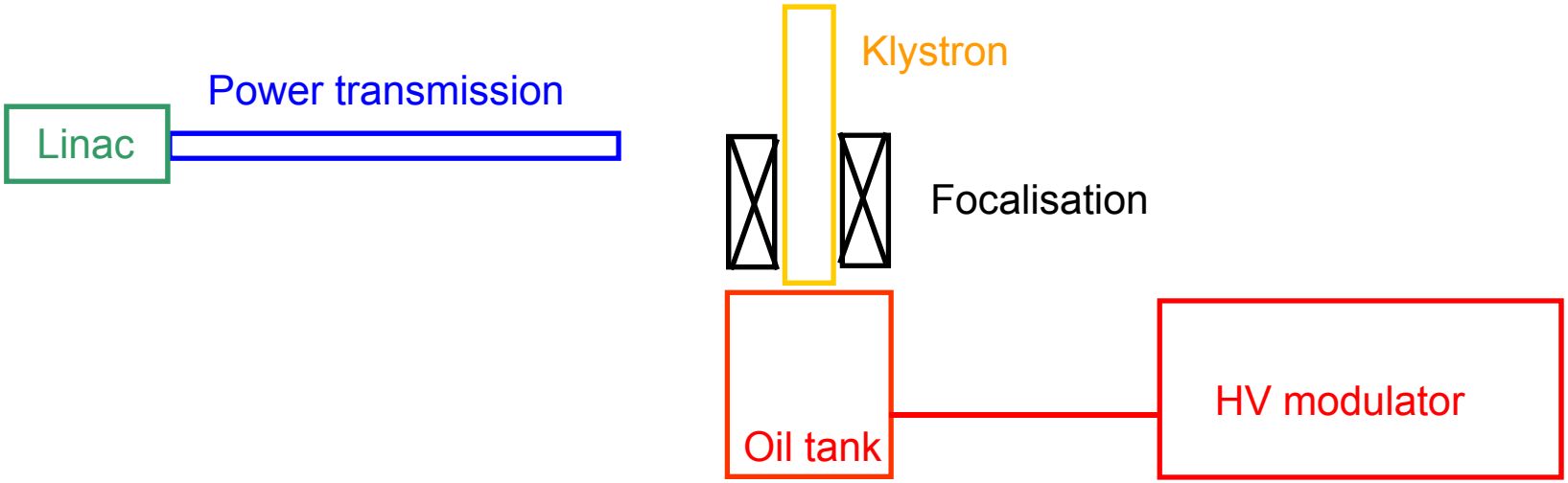
X band for industrial and medical applications



… but in field of industrial and medical applications, some others parameters have strong importance :

- Compactness of the source as a whole : klystron + (oil tank) + HV modulator
- Availability of passive components
- Power consumption
- Cost

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Single beam 4 MW Klystron
Electromagnet focusing

9.3 GHz Klystron

RF source characteristics

Frequency (f)	9.3 GHz
Pulsed output power	4.0 MW
Average output power	4 kW
RF pulse duration	5 µs
Pulse repetition rate	200 Hz
Duty cycle	0.001
-1 dB bandwidth	>30 MHz
Perveance (K)	1.0 µA / $V^{1,5}$
Efficiency	49 %
Expected lifetime	> 30 000 hours

Operating conditions

Cathode voltage (V)	152 kV
Cathode current (I)	60 A
X ray shielding	integrated

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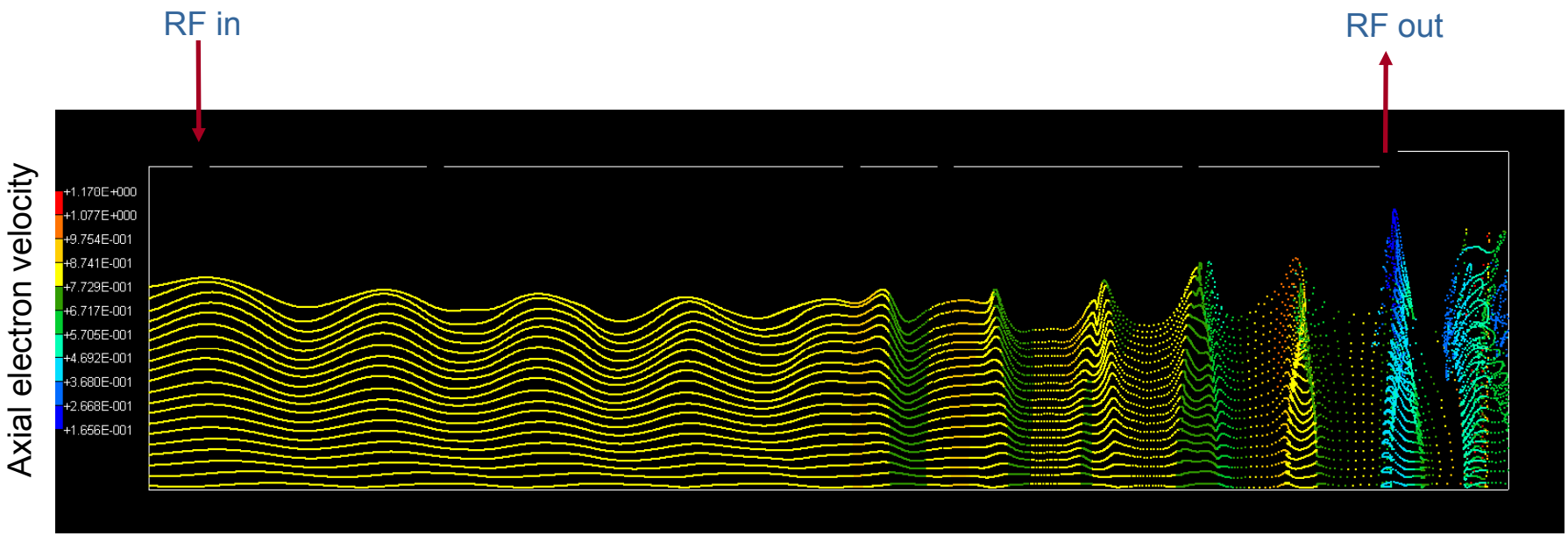
Interaction structure

- 6 cavities including 1 harmonic
- Interaction length (cavity 1 to 6) = 270 mm
- Output cavity carefully shaped to reduce electric field below 60 MV/m (at the expense of coupling factor…)

Simulation of klystron operation : electron beam interaction with cavities' RF field
animation period = 1 / (9.3 GHz)



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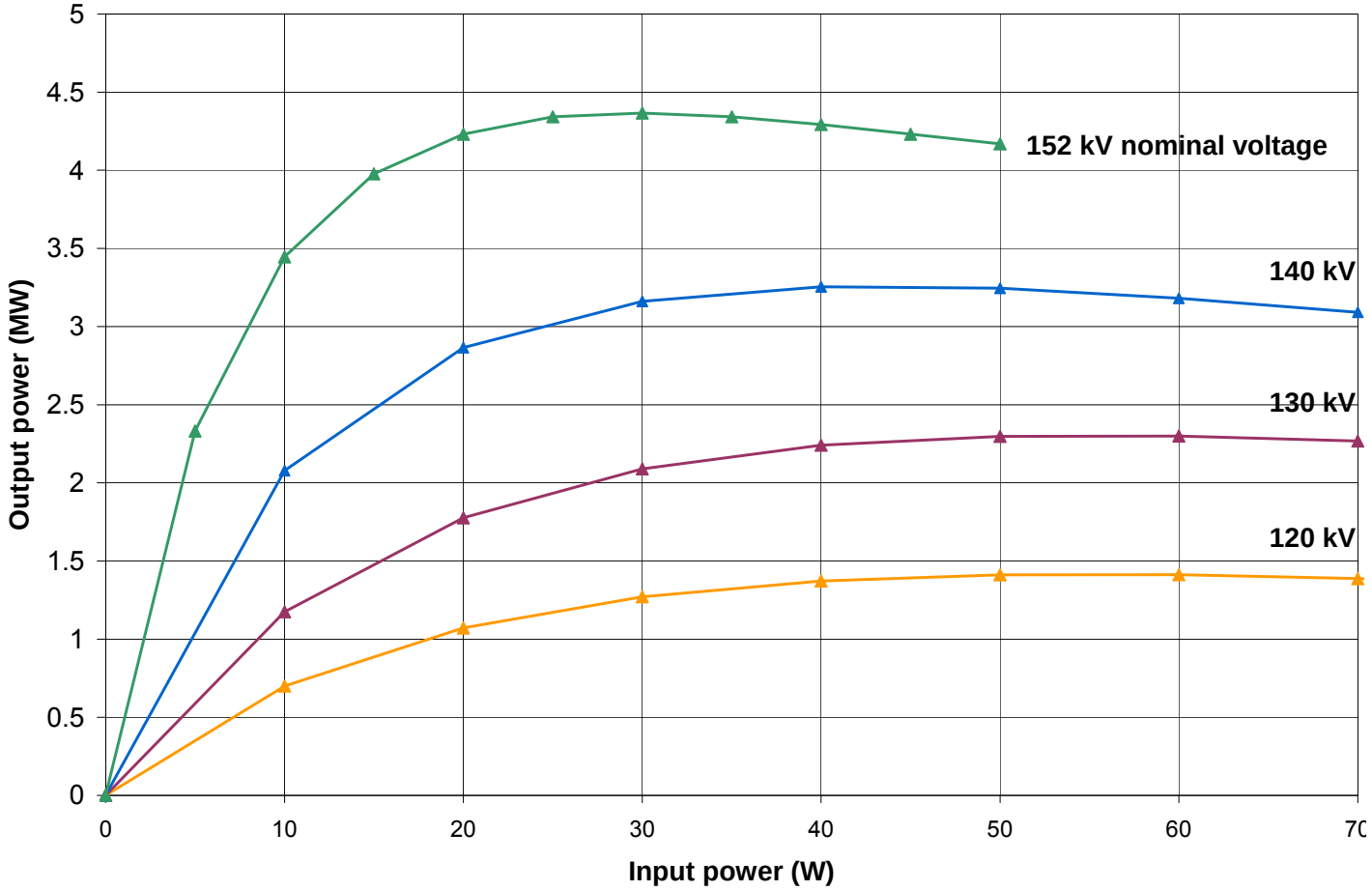
Power transfer curve



Calculation result at nominal cathode voltage : (V=152 kV)

- saturation gain = 51.5 dB
- Output power = 4.3 MW
- Efficiency = 49 %

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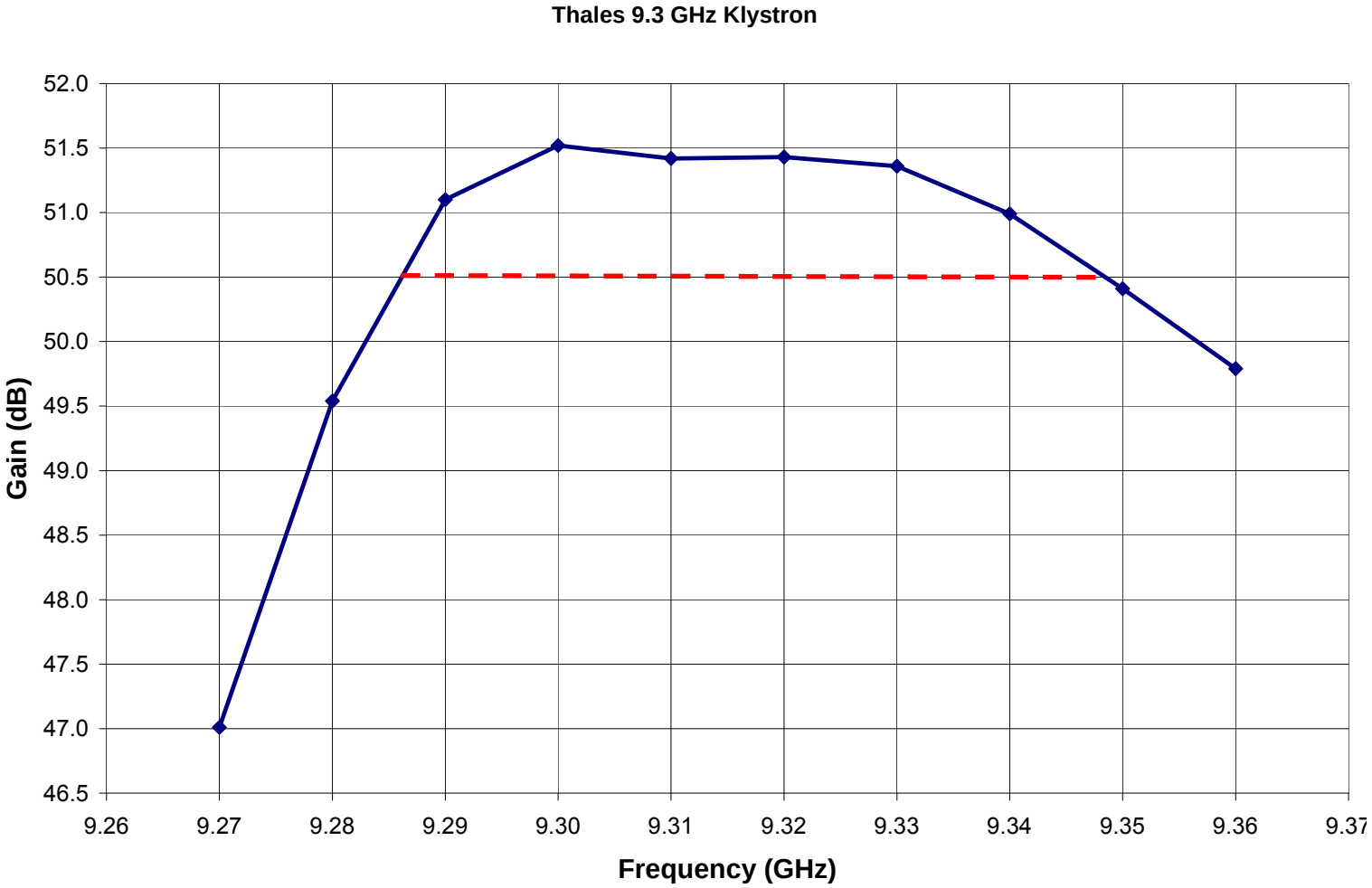
Bandwidth at saturation

Wide instantaneous bandwidth compared to magnetron



Calculated bandwidth at –1 dB : 60 MHz (at nominal cathode voltage)

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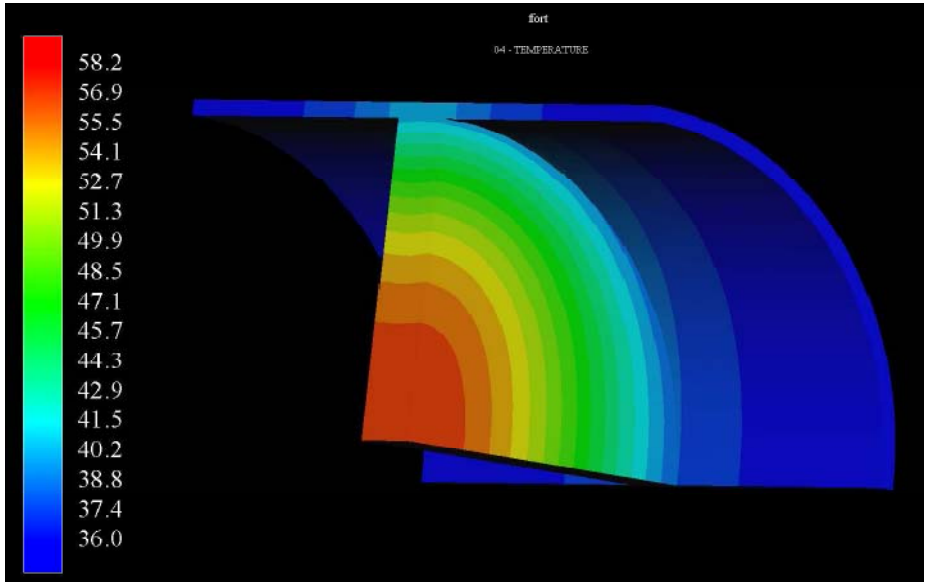
The challenges of X band for standard klystron

- RF electric field in output cavity
  - Directly limits the **pulsed output power**

- Power loss in output window
  - Directly limits the **average output power**



Calculation of window's temperature

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Klystron & electromagnet interfaces

- Output waveguide
  - WR112 flange
  - SF_6 pressurization (3 bars)
- Water cooling
  Total flow ~ 26 L / min
- Electromagnet
  Power consumption ~ 4 kW
- Electron gun power supply
  - 152 kV / 60 A / 9.2 kW modulator
  - Oil tank insulation
  - Heater voltage 15 V , current 13 A
- Input driver
  Input power = 30 W at saturation

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Footprint and weight

- Klystron
  - Height = 0,9 m
  - Weight ~ 60 kg
  - Output flange at 400 mm from axis

- Electromagnet
  - Outer diameter = 500 mm
  - Weight ~ 350 kg

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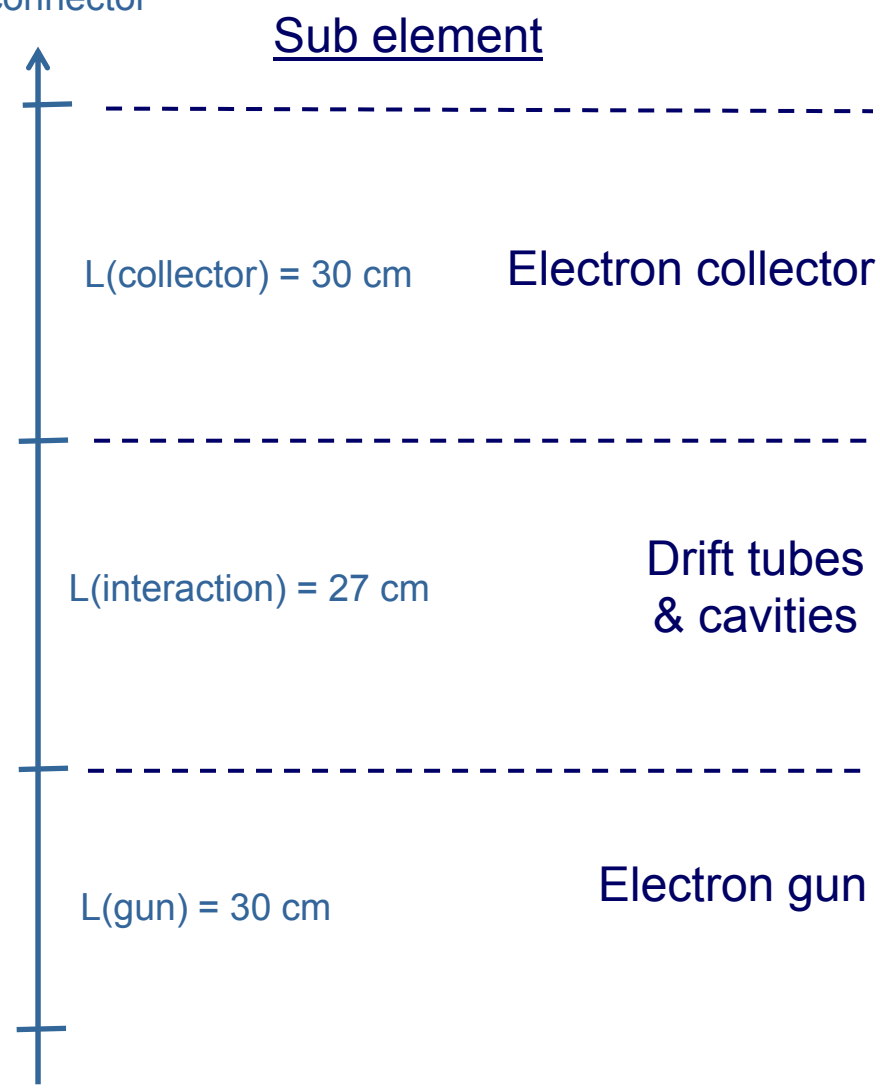
Scaling of klystron length

Klystron length = 87 cm + HV connector



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Scaling : electron gun

Gun ceramic length :

$$L(gun) \propto V$$

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Scaling : interaction structure

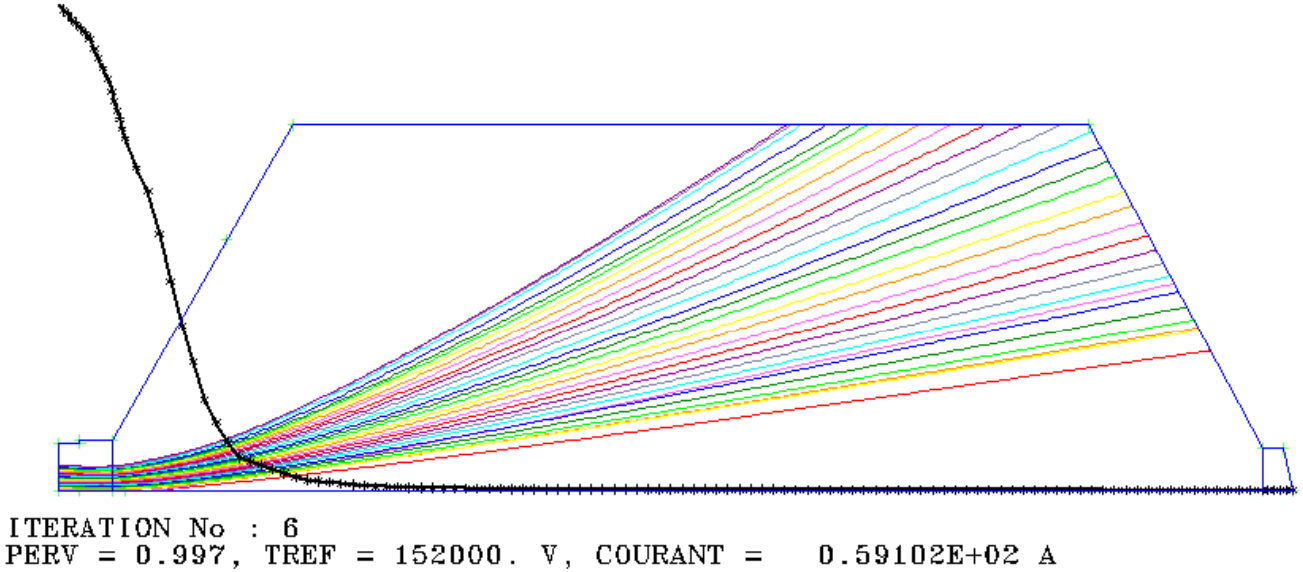
<u>Interaction structure length</u> :

$$L(\text{interaction}) \propto \lambda_q$$

λ_q : reduced plasma length

$$\lambda_q \propto V.K^{-0.5}.f^{-1}$$

Scaling : collector



Collector length (empirical) :

$L(\text{interaction}) \propto K^{-0.5}.(V.I)^{0.42}$

K dependence due to natural beam expansion

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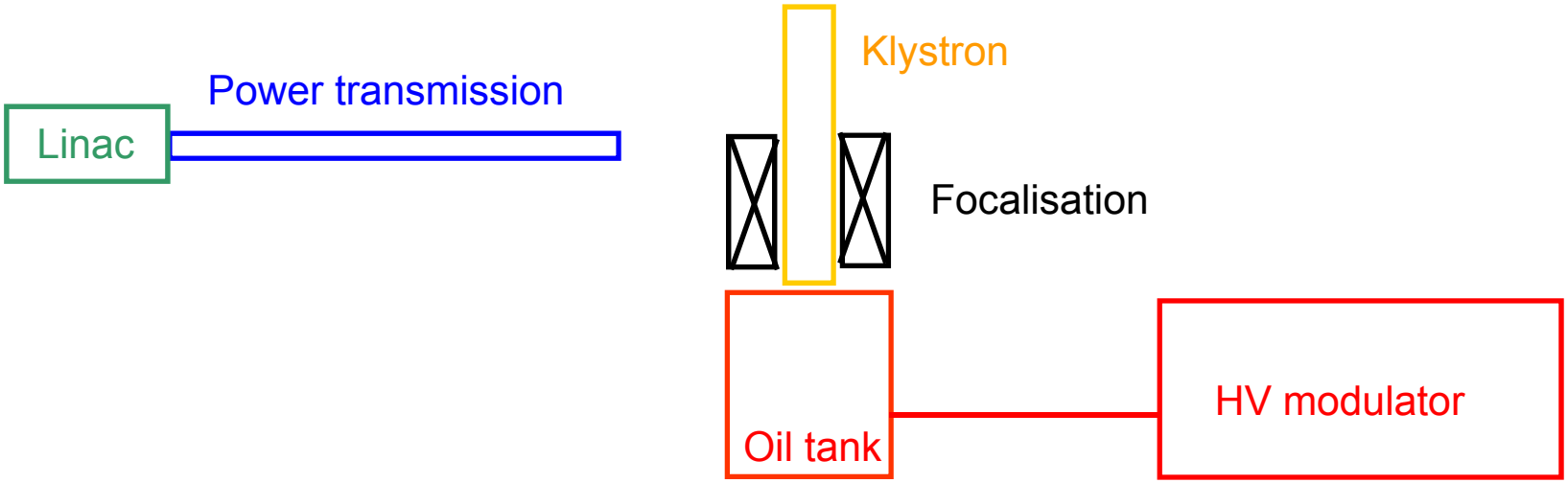
Dimensioning parameters



- System size scales more with power and voltage than with frequency
- Focusing solenoid is a major contributor to weight, size and power consumption

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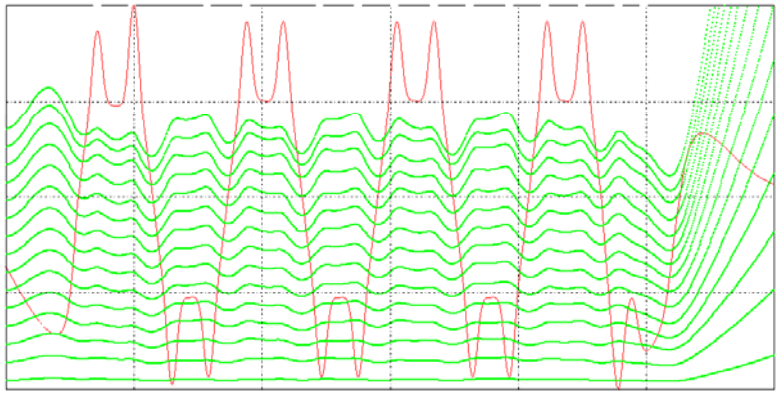
Alternative technologies

Dealing with :

- weight
- size
- high voltage

PPM focusing technology

Single beam klystron with PPM focusing allows reduction of **size**, **weight** and **power consumption**



Magnetic field (red) and electron trajectories

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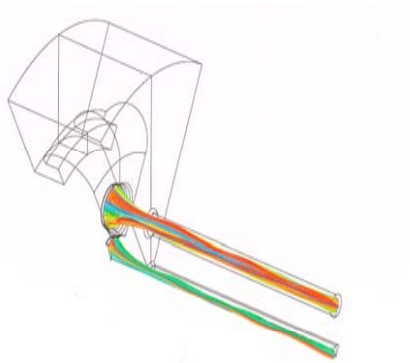
Multi Beam Klystron (MBK) technology

Perveance $K = I / V^{1.5}$

Peak power $P = V.I$



A number of beams interacting together in cavities :

$K(total) = \Sigma K(beam)$

- **Lower voltage** (goal : under 50 kV for operation in air)
- Better efficiency
- Wider bandwidth (less sensibility to cavity frequency)

For medical and industrial systems :

⇒ klystron length and modulator size reduced

⇒ oil tank suppressed

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TH1801 MBK

- 1.3 GHz, 116 kV, 10 MW
- 1.5 ms RF pulse @ 10 Hz
- 7 electron beam-structure

Current status :

- 7 serial tubes under operation at DESY. Stability at every voltage.
- Currently operating under saturation on FLASH machine.
- Full output power for conditionning and optimization of future photo-injector of European XFEL.

7 beam electron gun

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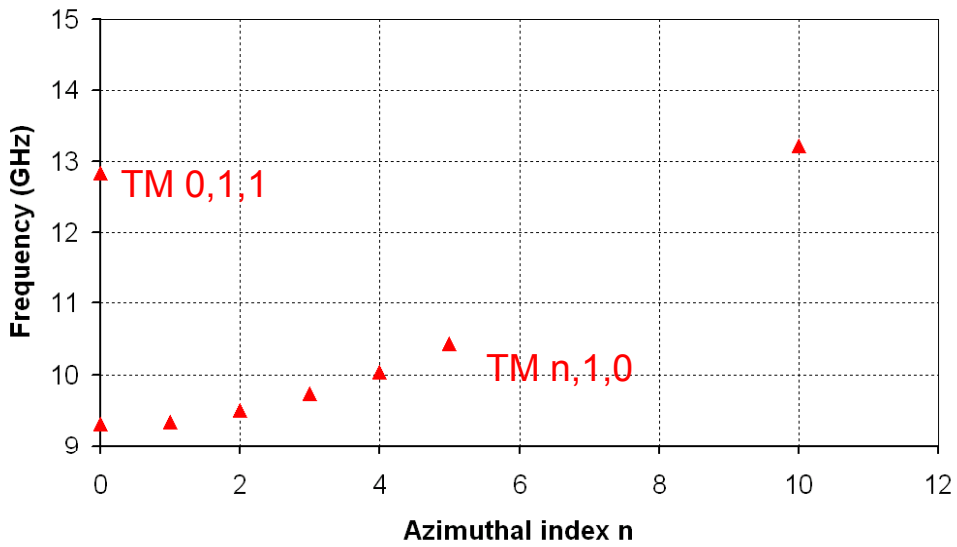
Choice of cavity and operating mode :

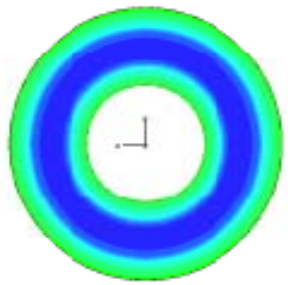
- Compatibility with spatial arrangement of beams
- Good beam-field coupling (high R/Q)
- Sufficient mode separation or damping possibilities to avoid mode competition
- Manufacturing aspect



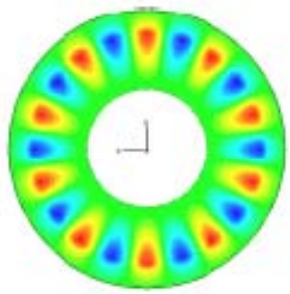
Example : coaxial cavity

Courtesy of C. Lingwood, Lancaster U.

- Fundamental mode :



- High order mode :



TM 0,10,0

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Thales development team

Thales klystron & gyrotron development team :

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Christophe Lievin
Rodolphe Marchesin
Jean-Christophe Bellemere
Sébastien Berger

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