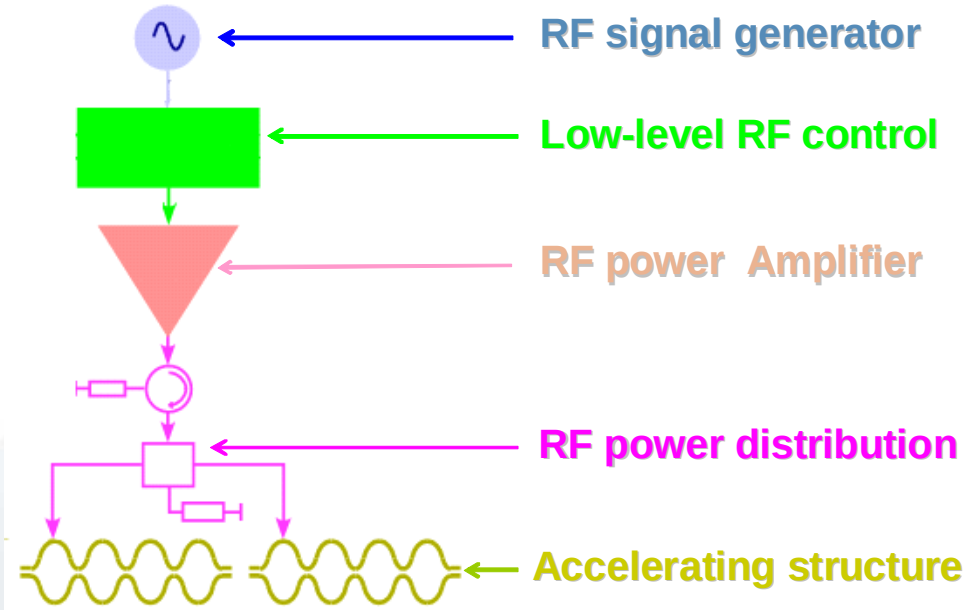
RF systems

Francis Perez

Part II:

High Power Amplifiers

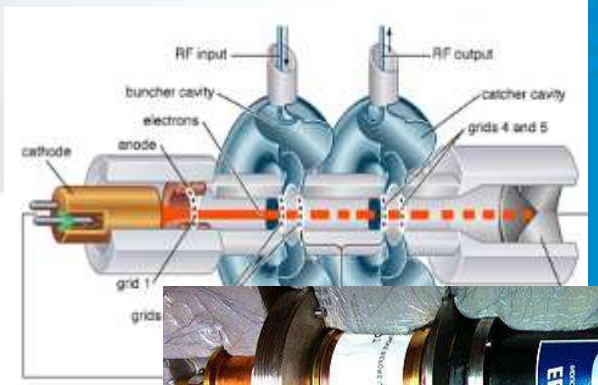


Definition:

An **RF power amplifier** is used to convert a low-power RF signal into **a high power**.

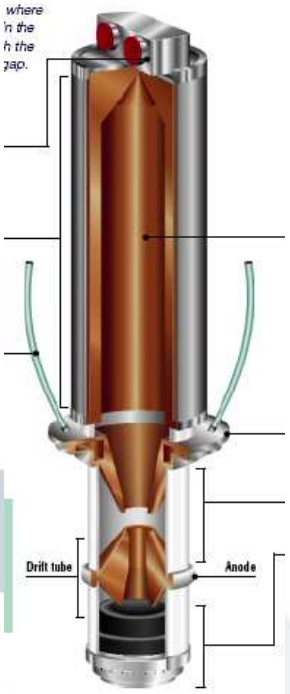
- There are several types of amplifiers with different characteristics.

  - Frequency
  - Power
  - Maintenance cost.
  - Efficiency.
  - Size and weight.



- **Tetrodes – Grided tubes**
- **Klystrons**
- **Inductive Output Tubes**
- **Solid state amplifiers**

vacuum tubes

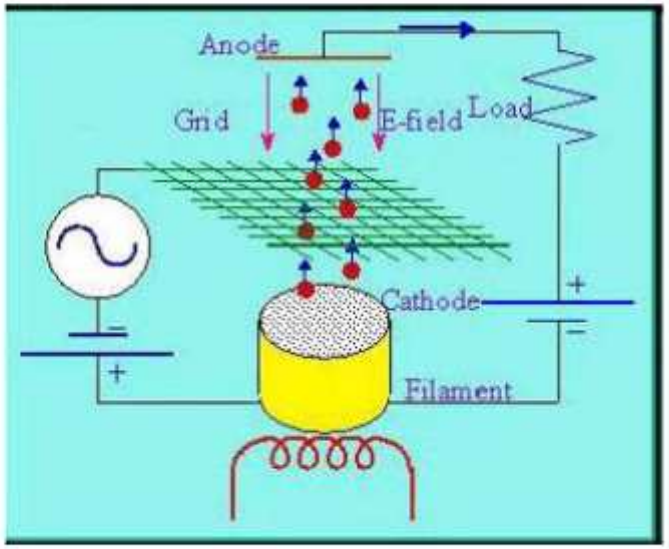


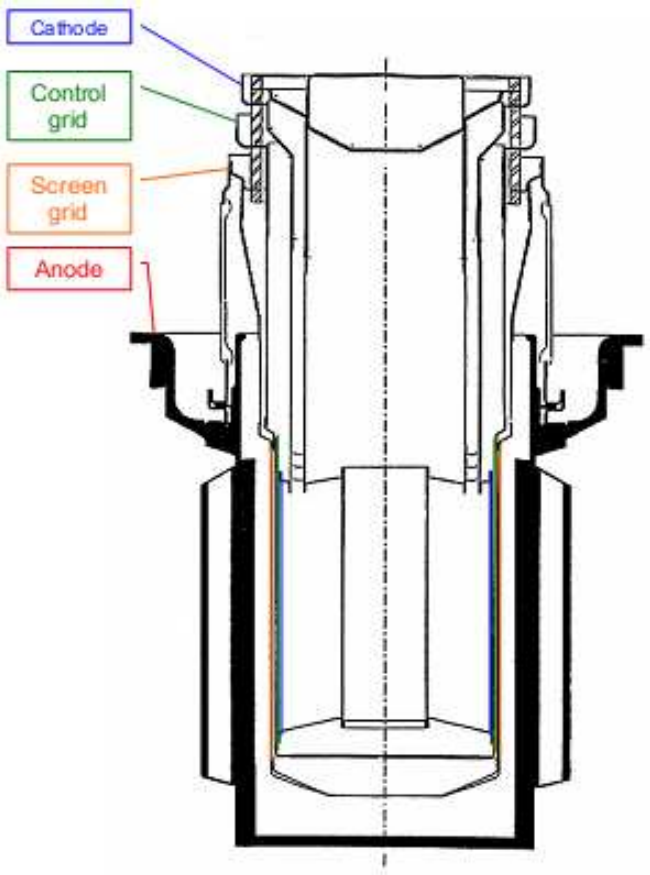
Grided Tubes - Tetrode

- **Gridded Tubes (electron tubes)**
- Frequency range: 0...0.5 GHz (tetrodes), 0...3 GHz (triodes)
- Power range:
  - for CW (continuous wave) up to 30 MHz: 1 MW
  - at 300 MHz: 200 kW
  - pulsed at 200 MHz: 4 MW
- Medium reliability, lifetime cathode limited to 5000...40000 hours
- Relatively robust
- Inherently medium to high voltage, low current devices
- Density modulated
- High gain at low frequencies, medium gain at high frequencies

Grided Tubes - Tetrode

- Filament burns off electrons
- acceleration in DC field
- density modulation by grid
- => voltage controlled current source





F. Caspers, M. Betz; JUAS 2012 RF Engineering

Grided Tubes - Tetrode

- **Grid tubes:**
  - Evolution of **Triodes**.
  - Electrons produced at the cathode;
  - **Intensity** at the Anode is **modulated by the Control grid**.
  - **Screen grid** → RF isolation.

Used at MaxLab
100 MHz
30 kW

Grided Tubes - Tetrode

Frequency (MHz)	Max. power (kW)	Efficiency (%)	Main Features	Main drawbacks
Up to 200	200/ tube	$\eta \leq 70$	✓ Simplicity. ✓ Low cost.	✘ High voltage. ✘ Transit-time limited.

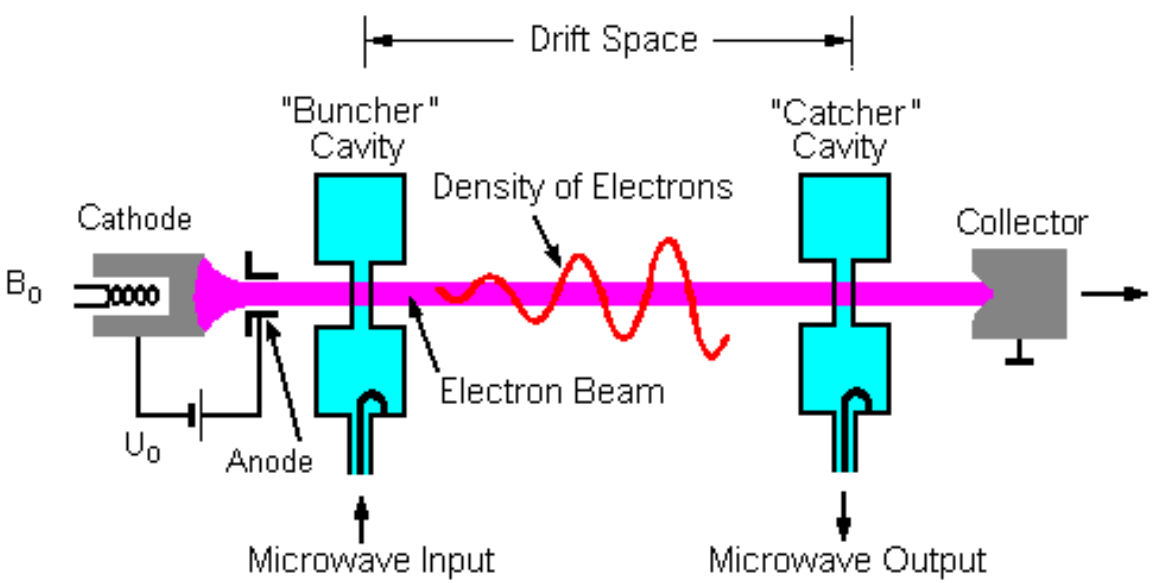
One will use for low frequencies

Klystron

- **Klystrons**
- Frequency range: 0.3...10 GHz
- Power range:
  - CW at 350 MHz: 1 MW
  - pulsed at 3 GHz: 30 MW
- Medium reliability, lifetime cathode limited
- Needs expert care
- Inherently very high voltage device
- Velocity modulated
- Very high gain (≈40 to 60 dB, about 10 dB per passive resonator)
- Tend to be noisy (acoustically and electrically)

Klystron

- **Klystron principle**:
  - High electron DC current produced in the **klystron gun**.
  - Electron beam is velocity **modulated in the first cavity**.
  - **Velocity modulation → Density modulation.**
  - RF power output is **extracted from a output cavity**.



Klystron

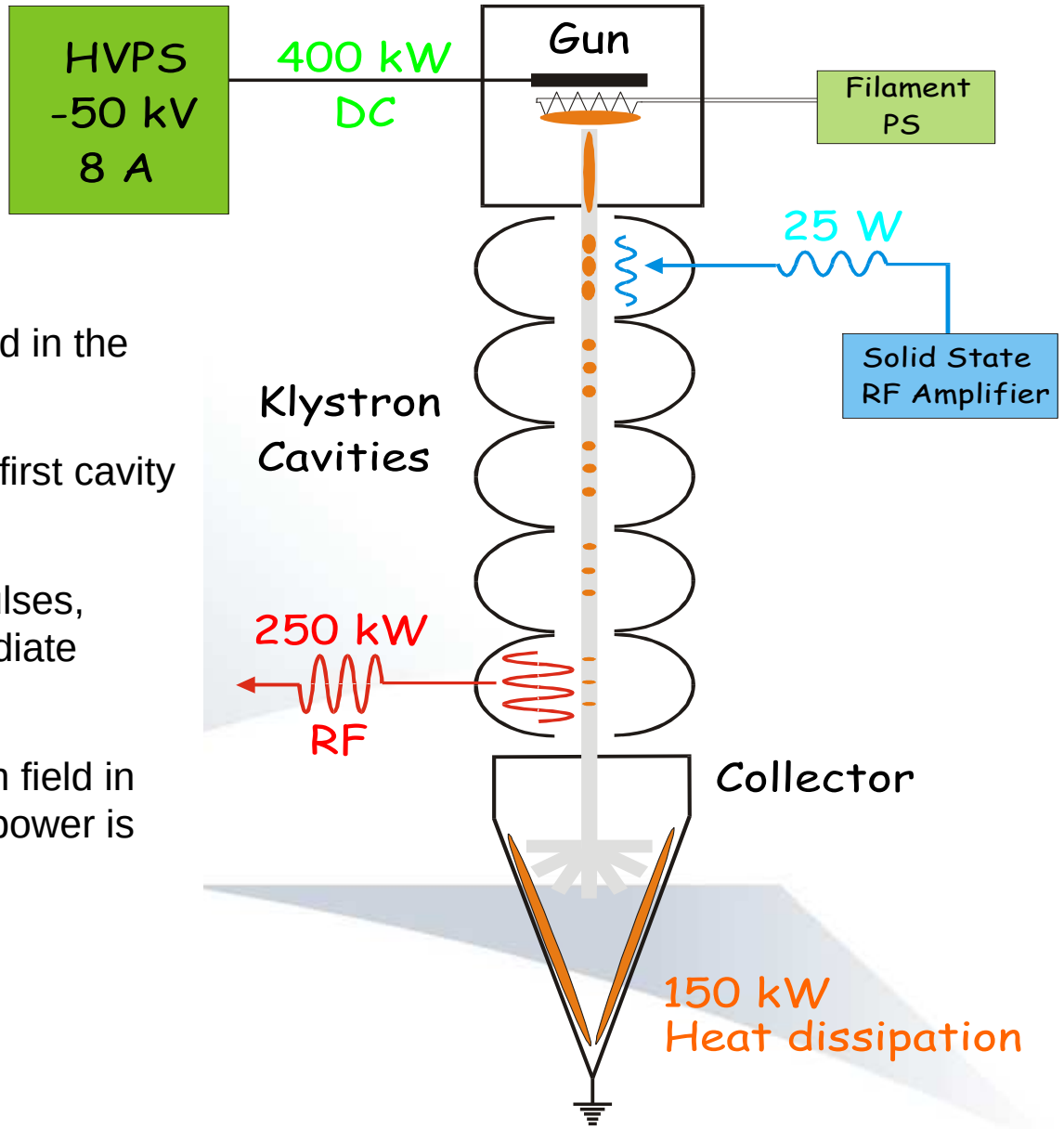
Klystron principle:

- High electron DC current produced in the klystron gun.

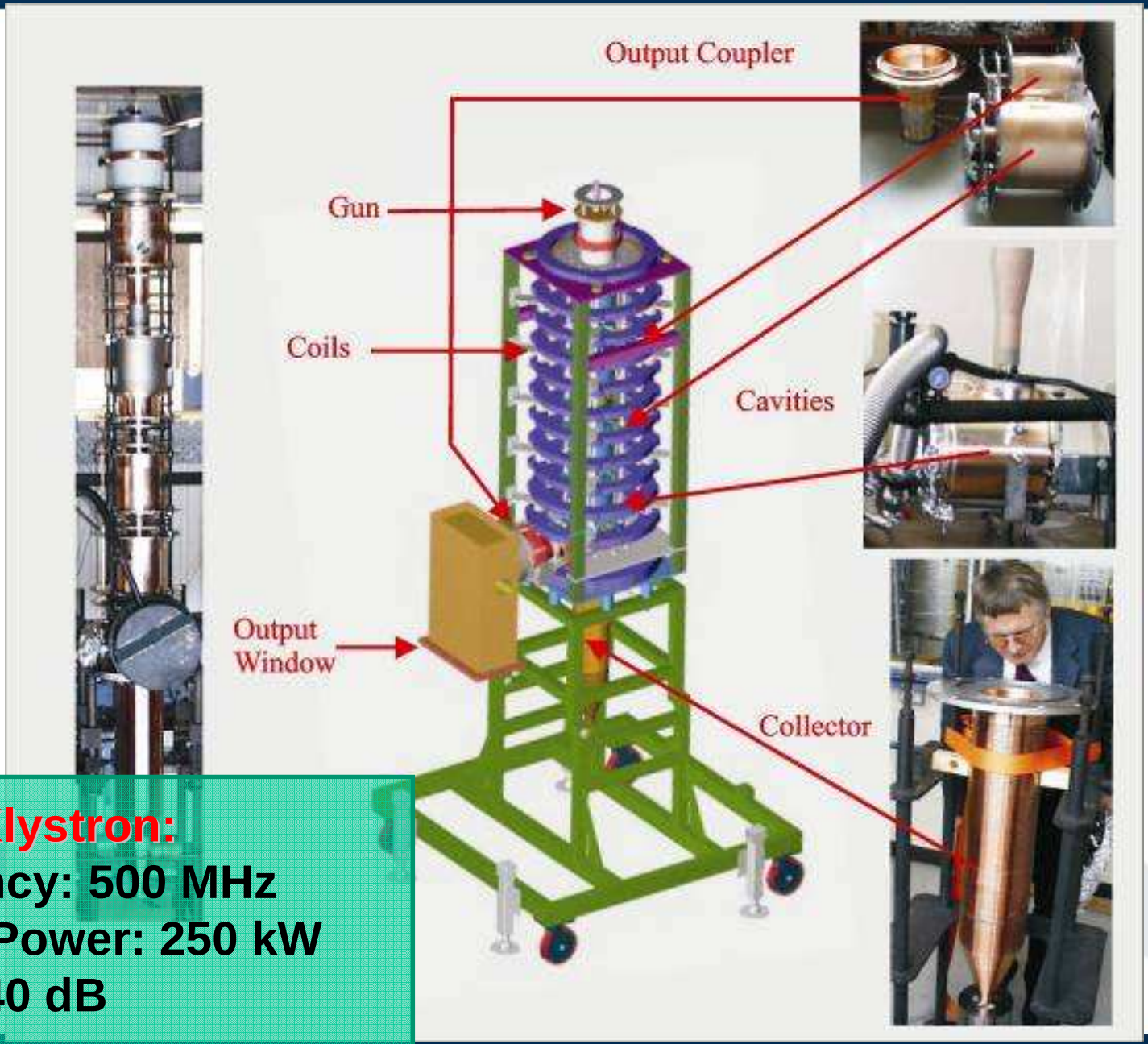
- Current velocity modulated in the first cavity by the driving power.

- The e-beam is then grouped in pulses, which are enhanced in three intermediate cavities (shorter pulses)

- This pulsed stream induces a high field in the last cavity, out of which the high power is decoupled.



Klystron



ANKA Klystron:
Frequency: 500 MHz
Output Power: 250 kW
Gain > 40 dB

Klystron modulators

ALBA Linac:
Frequency: 3.0 GHz
Output Power: 30 MW
Gain > 40 dB

3 GHz – multicell structure

Klystron

Frequency (GHz)	Max. power (MW)	Efficiency (%)	Main Features	Main drawbacks
0.3 - 30	~ 2 (HP tubes) ~100 (Pulsed tubes)	$40 \leq \eta \leq 60$	✓ High power. ✓ High gain. ✓ Controlled output.	✘ High voltage. ✘ Efficiency.

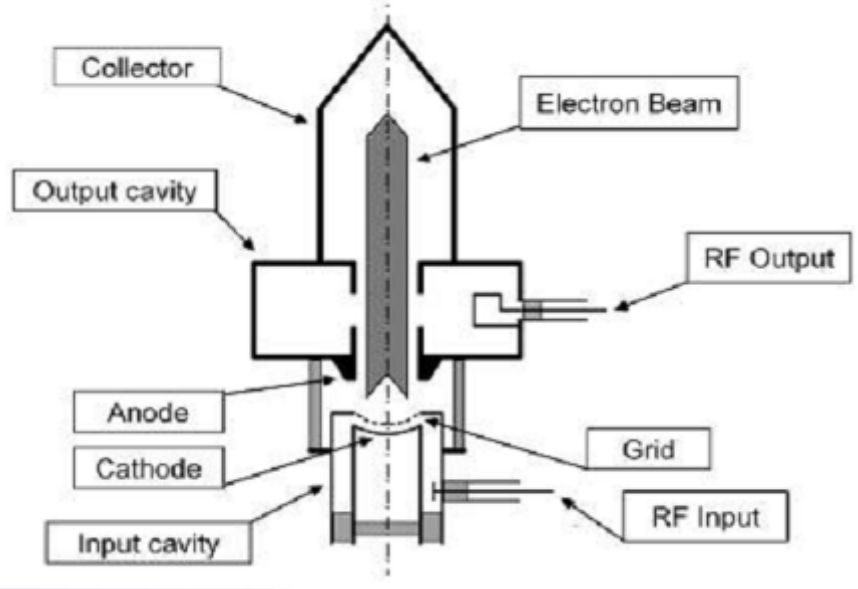
One will use for high power

IOT (Inductive Output Tube)

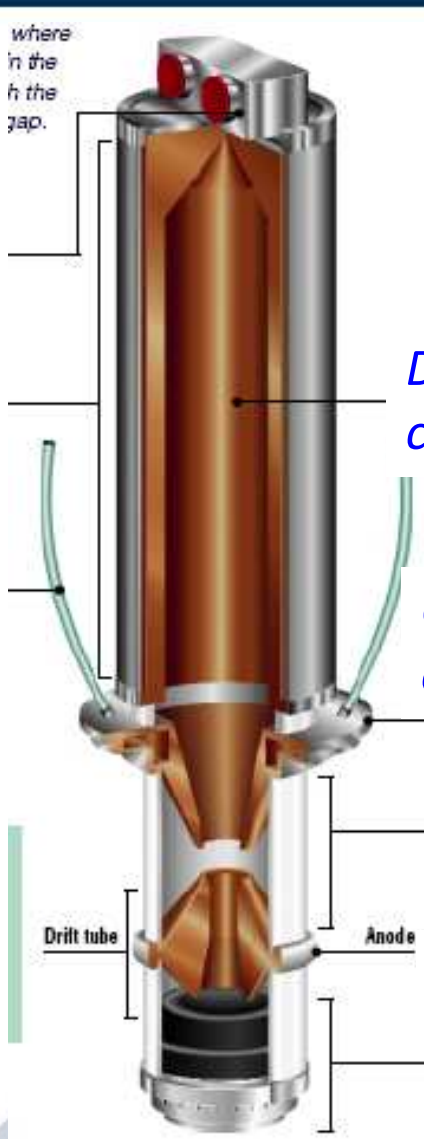
- IOTs combine design aspects of **Triodes and Klystrons**.

  - From **Triodes**:
    - Cathode.
    - Grid.
    - Density modulated.

  - From **Klystrons**:
    - Linear beam
    - Magnetic focussing field.
    - Output cavity
    - Collector



IOT



Collector

Defocusing coil

Output cavity

e- gun

H.V supply
36 kV / 3.5 A

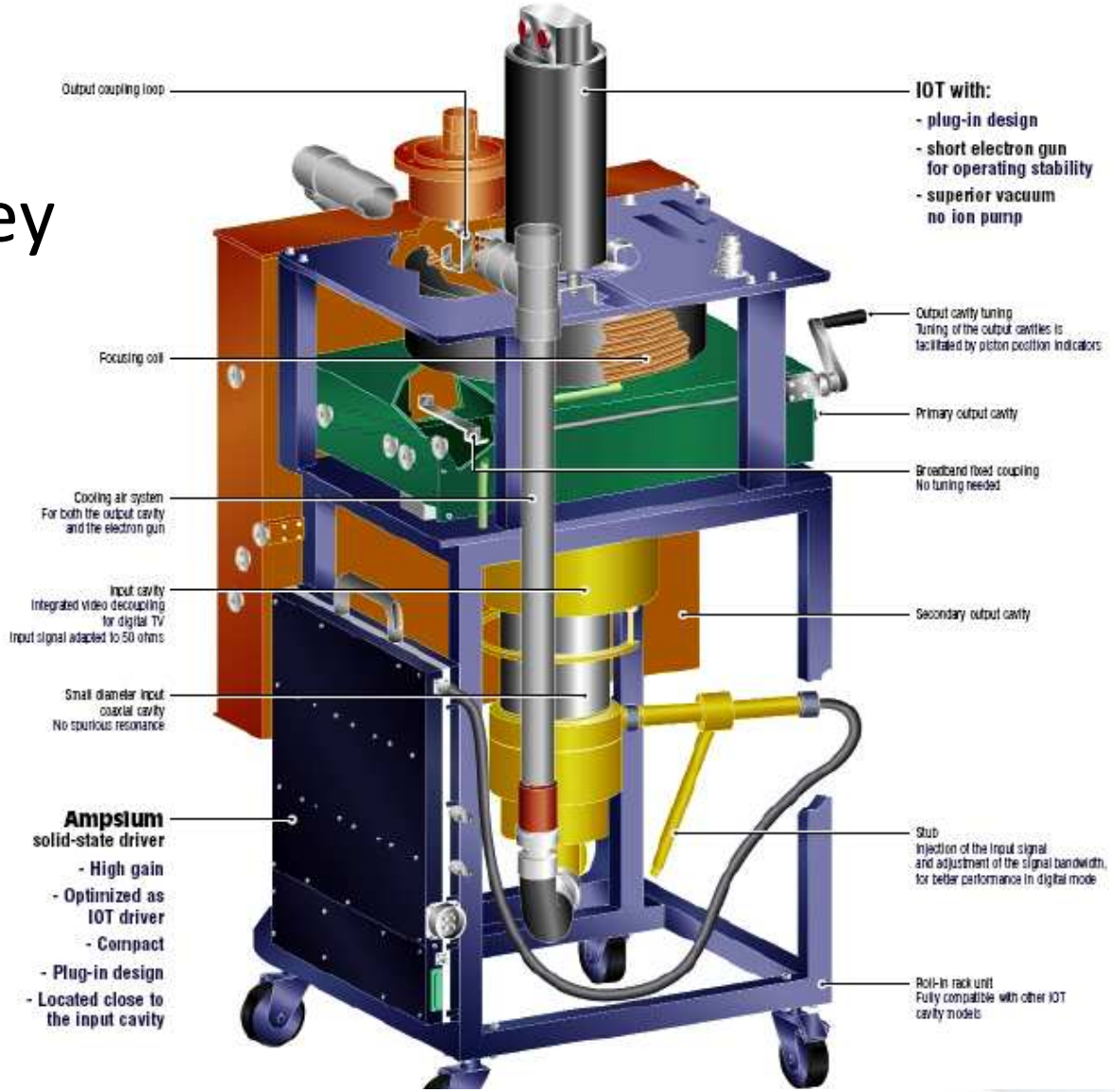
RF OUT
80 kW @ 500 MHz

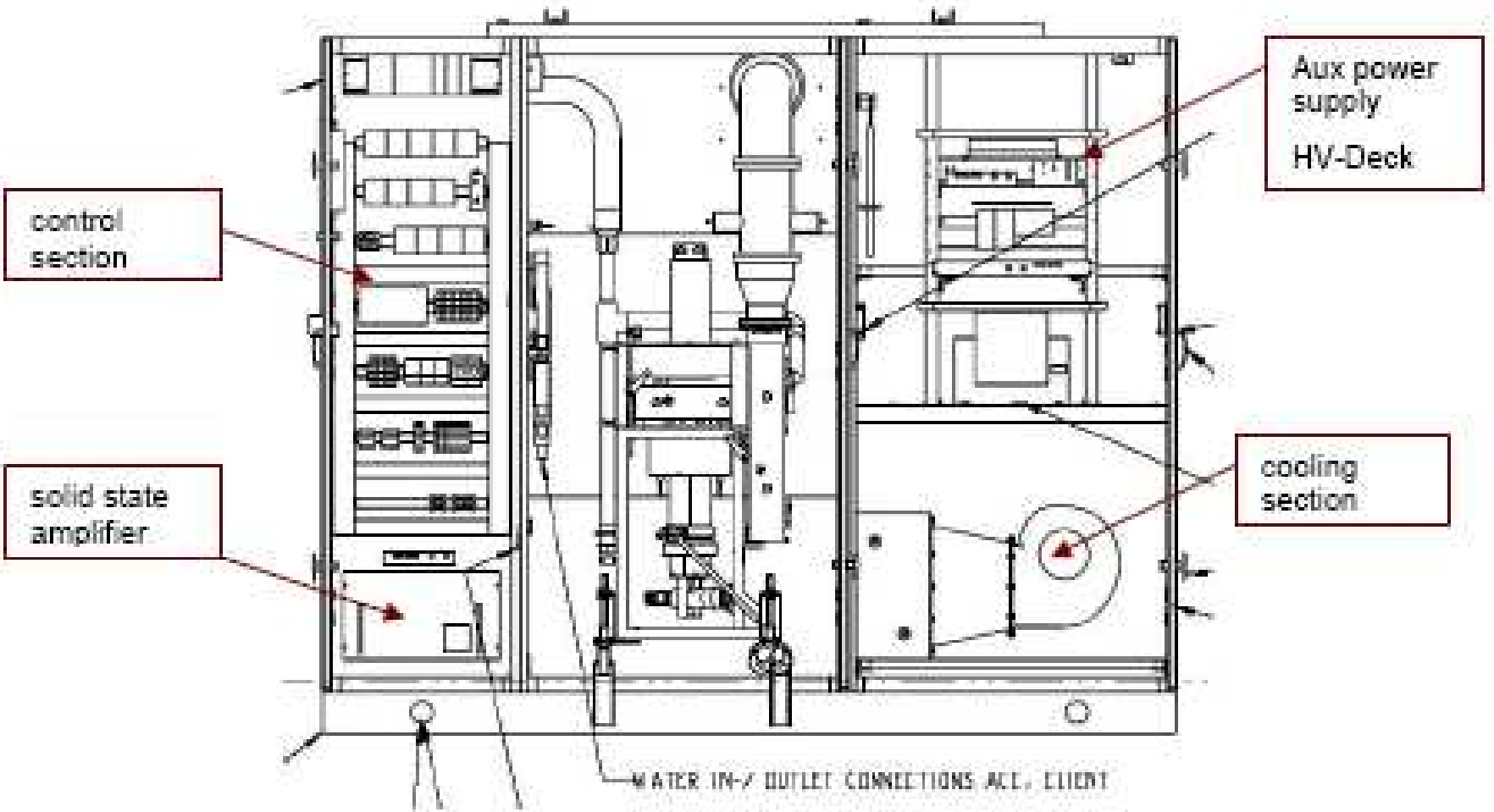
500 MHz pulses

RF IN
400 W @ 500 MHz

IOT

IOT in the troley




control section
solid state amplifier
Aux power supply
HV-Deck
cooling section
WATER IN-/ OUTLET CONNECTIONS ACC. CLIENT

IOT

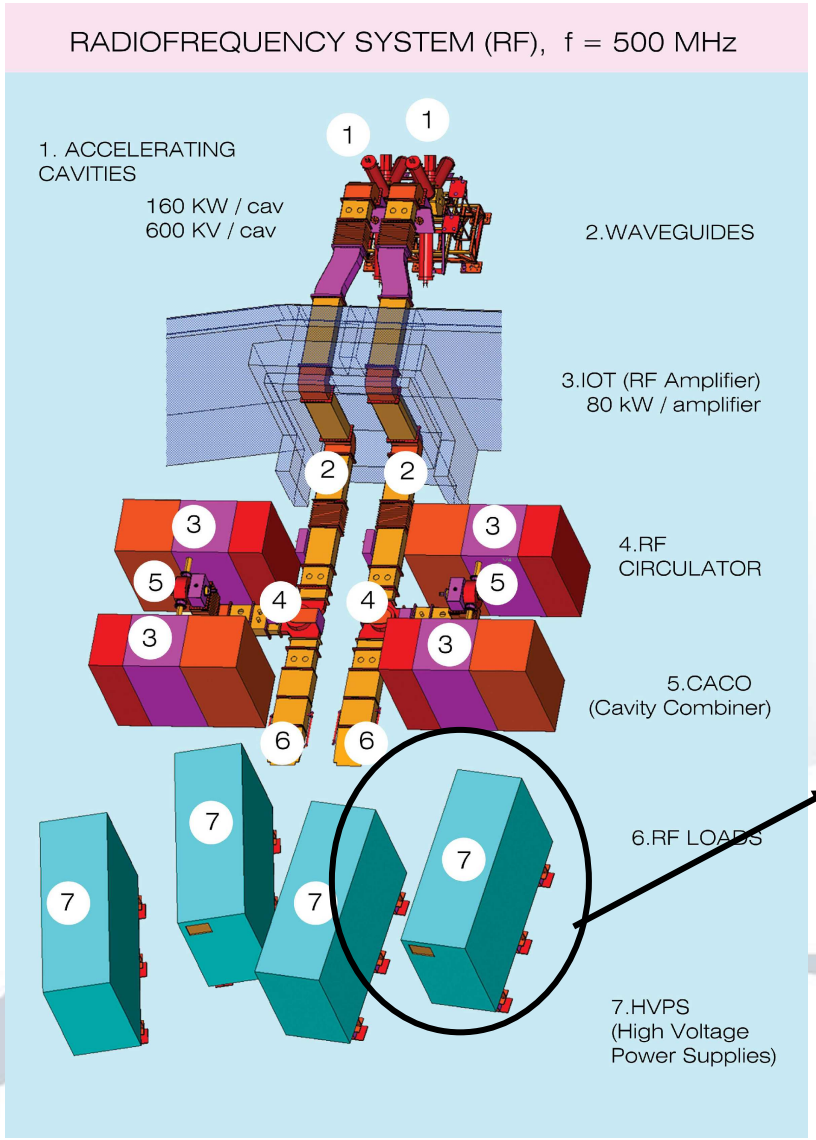
Frequency (MHz)	Max. power (kW)	Efficiency (%)	Main Features	Main drawbacks
100 - 2000	100 /tube	$\eta \leq 80$	✓ Efficiency. ✓ Reliable and cheap.	✘ High voltage. ✘ Power limited at high frequencies,

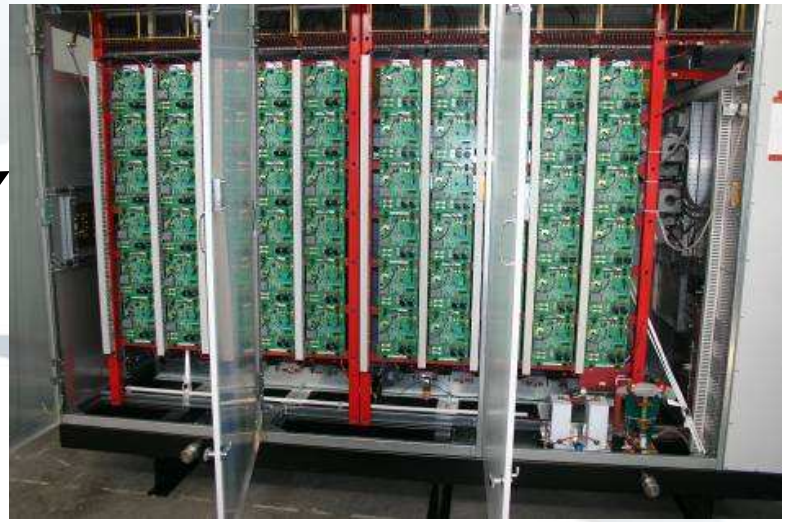
One will use for high eficiency

RF transmitter/modulator

In terms of power, its function if to transform a DC power (high voltage) into an RF power (voltage)

High Voltage Power Supply: HVPS



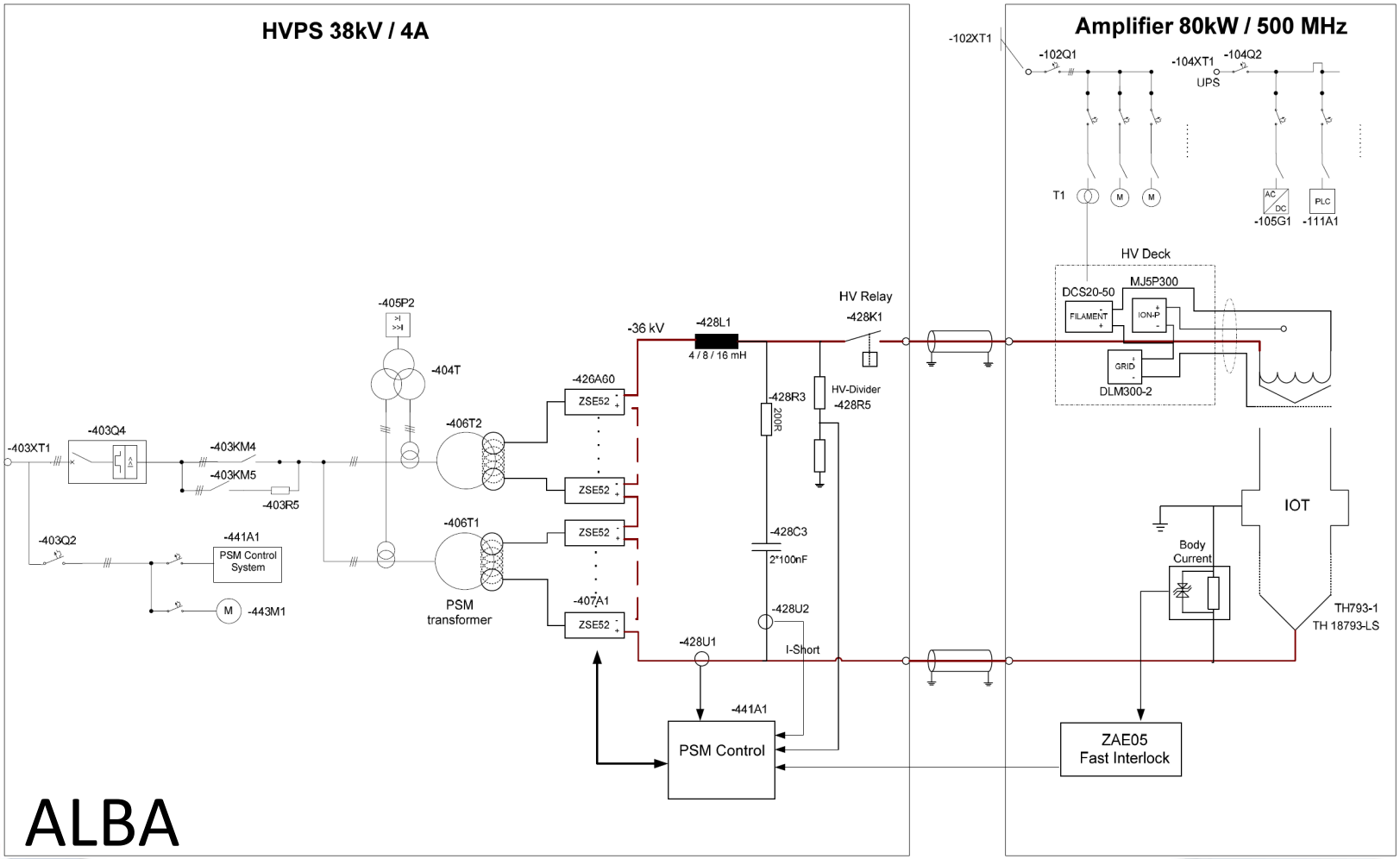


ALBA

High Voltage Power Supply: HVPS

HVPS

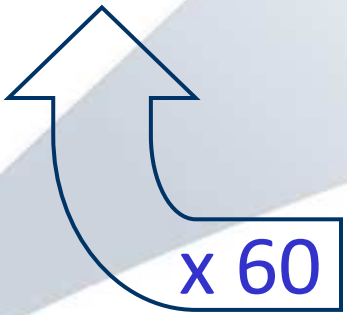
IOT



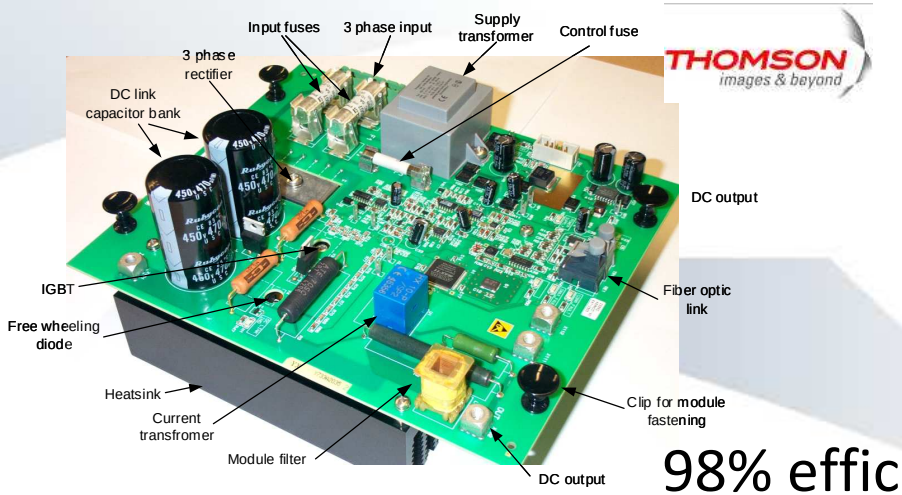
ALBA

High Voltage Power Supply: HVPS

Built up with
60 modules in series
of 700 V each



ALBA



98% efficiency

Klystron modulators

ALBA Linac:
Frequency: 3.0 GHz
Output Power: 30 MW
Gain > 40 dB

500 MHz - 5 cell Petra type

IOT transmitter

ALBA Booster IOT:

Frequency: 500 MHz

Output power: 80 kW

SR RF

IOT transmitters

500 MHz – Dampy cavity

ALBA SR IOTs:
Frequency: 500 MHz
Output power: 160 kW
2 × 80 kW IOT.

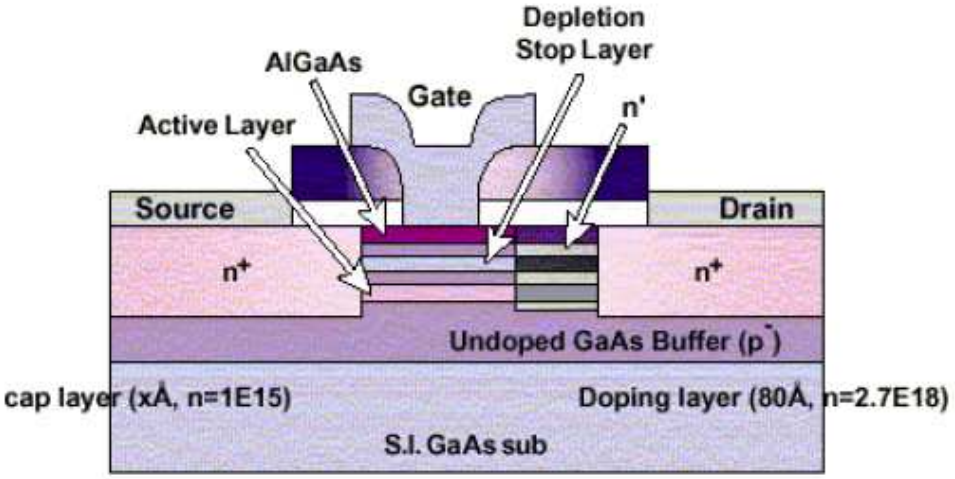
Solid State Amplifiers

- **Semiconductors**
  - Bipolar transistors
  - Field effect transistors
  - many others
- Frequency range: 0...100 GHz
- Power range: from close to thermal noise level to many kW
- High reliability, but lifetime not infinite (thermal fatigue, metal migration, etc.)
- Often unforgiving, failure is normally definitive
- Inherently low-voltage, high current devices compared to tubes
- Low to medium gain

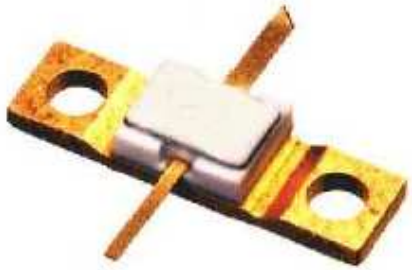
Transistors

Example: a field effect transitor (FET)

Structure of an advanced pulse-doped MESFET



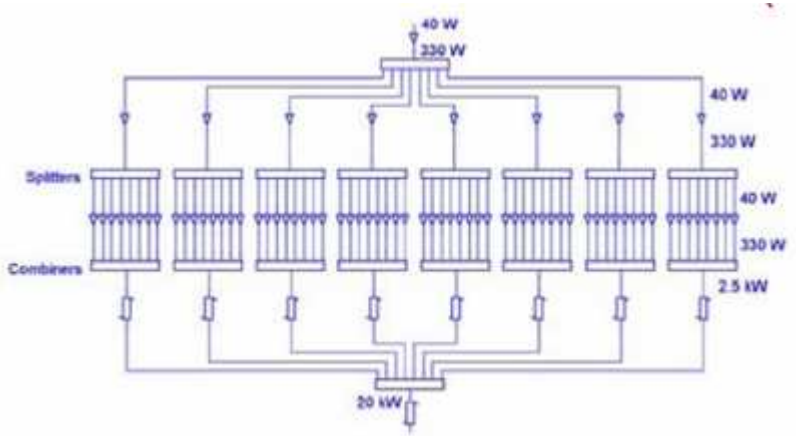
High Power and Low Distortion GaAs FET



Solid State Amplifiers

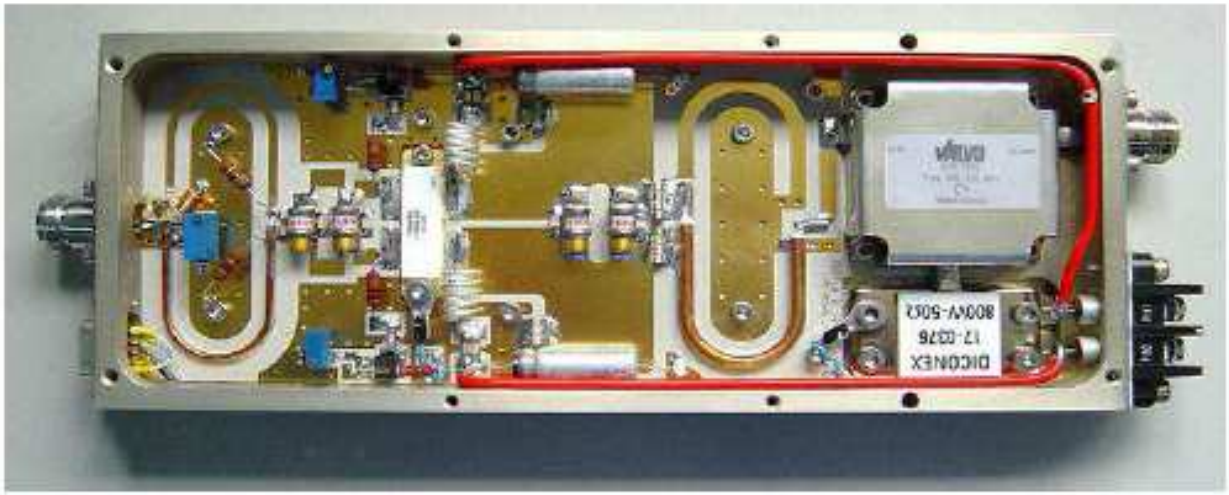
- The power required is obtained by operating **numerous transistors in parallel**.

- Technologies available:
  - **Si bipolar transistors.**
  - **Si LDMOS.**
  - **GaAsFET.**
  - **SITs**

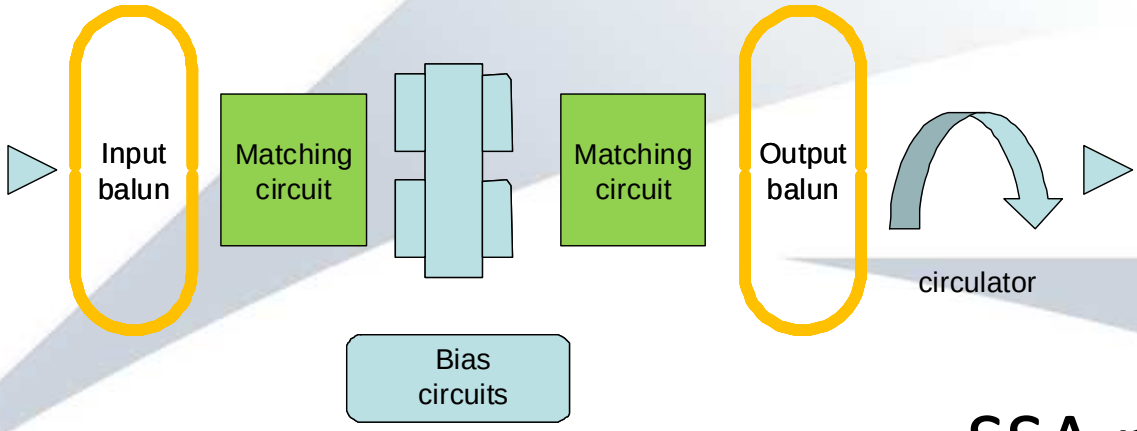


Solid State Amplifiers

6th generation LDMOS → BLF578 : 650 W modules

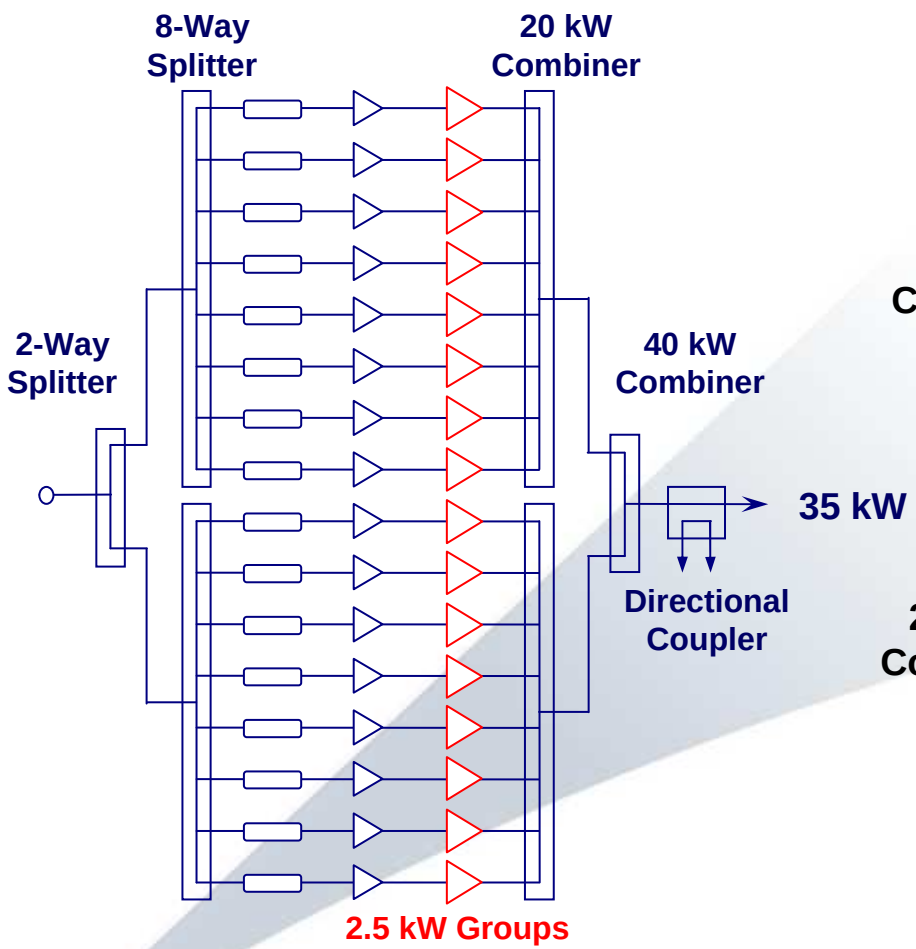


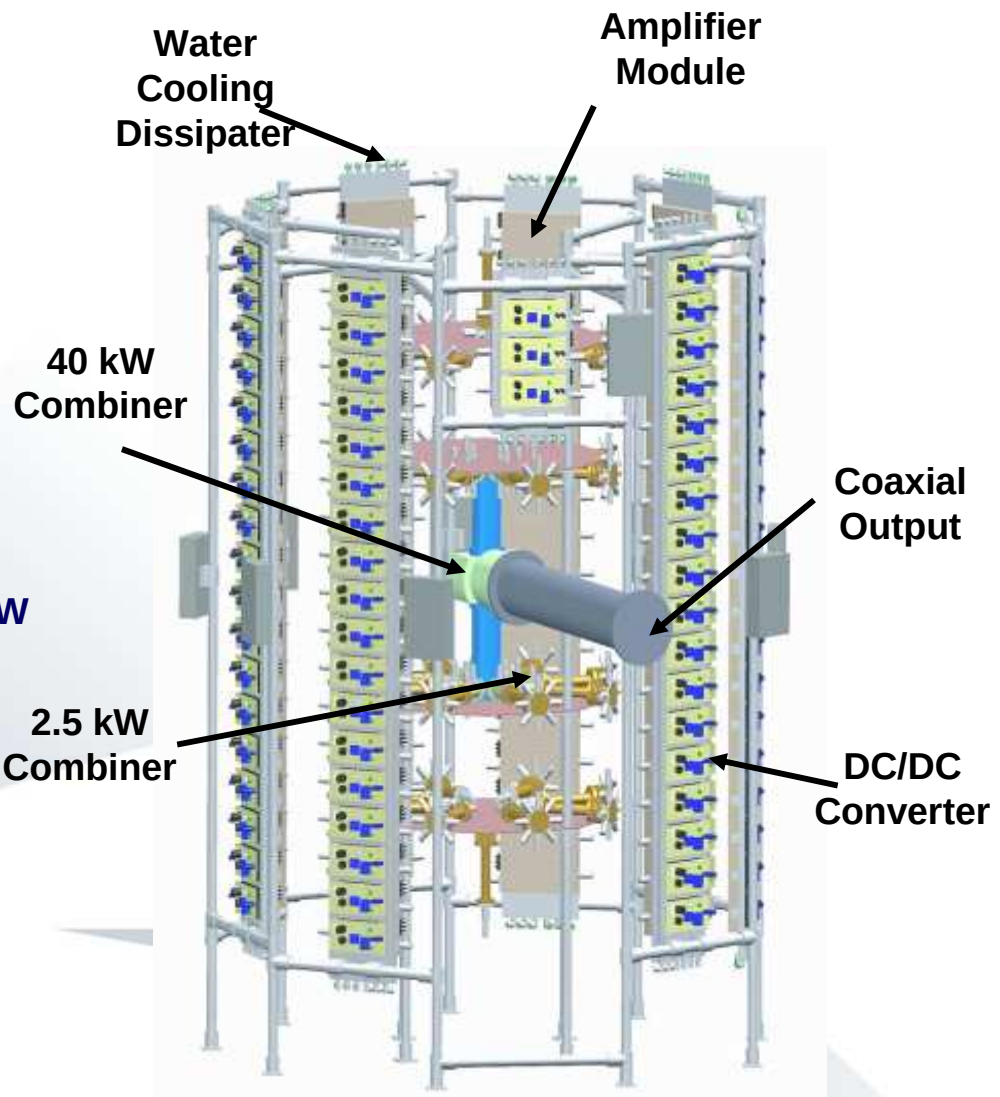
650W CW - 500 MHz amplifier module



SSA module SOLEIL

Solid State Amplifiers

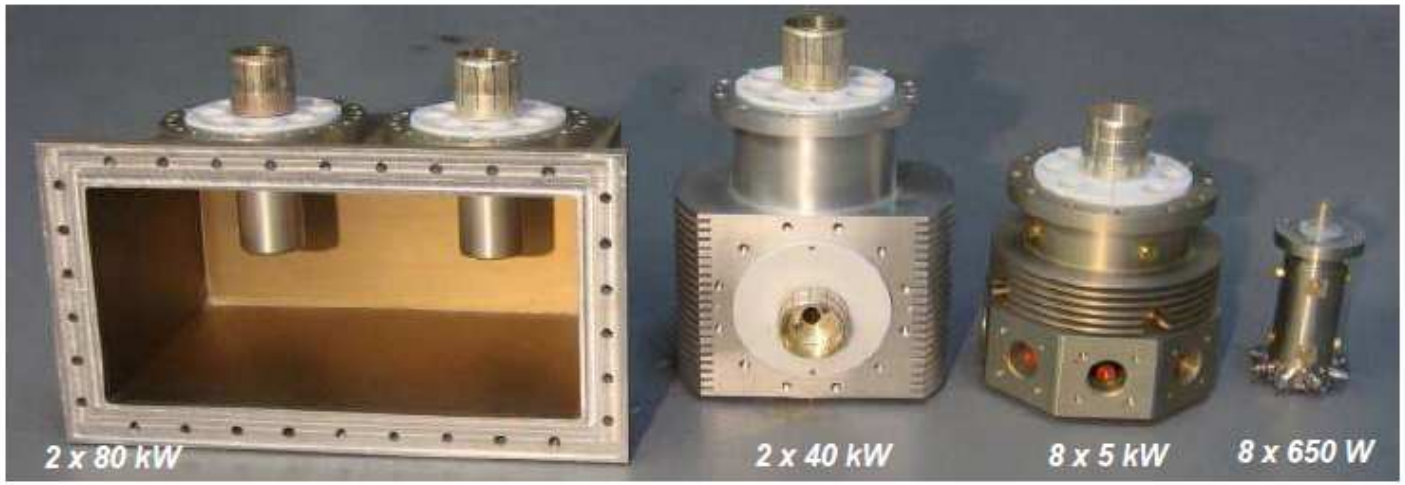


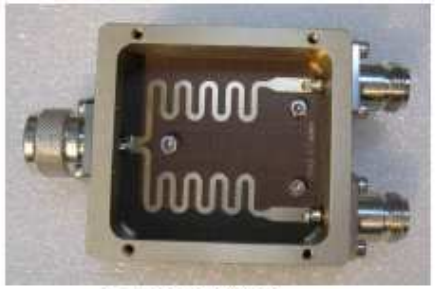


SOLEIL

Solid State Amplifiers

Power combination components





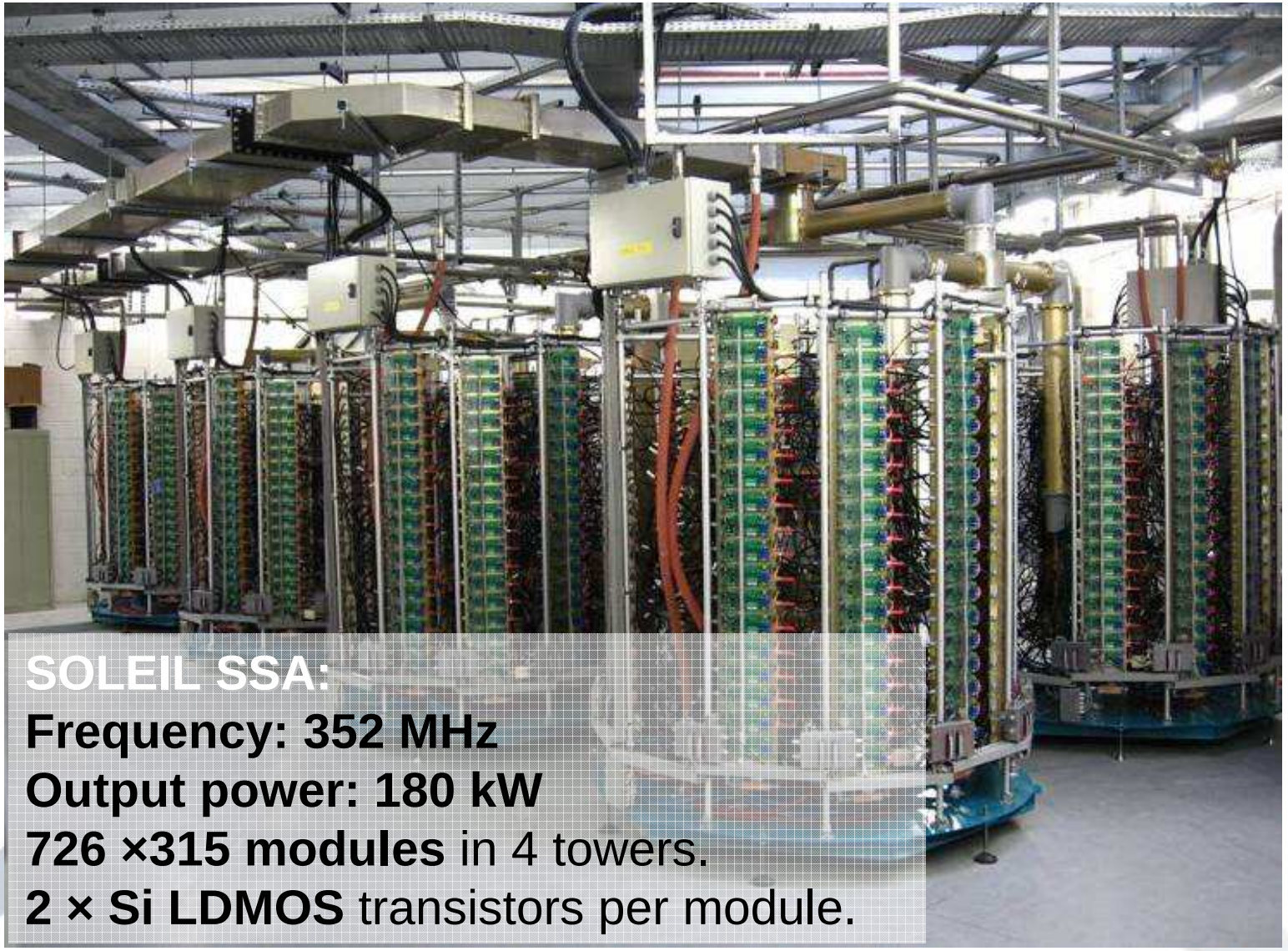
2-way splitter

8-way splitter

P_i - P_r monitoring coupler

SOLEIL

Solid State Amplifiers



SOLEIL SSA:

Frequency: 352 MHz

Output power: 180 kW

726 ×315 modules in 4 towers.

2 × Si LDMOS transistors per module.

Voltage to voltage converters

SSA need voltage to voltage converters

220 V ac to 50 V dc needed by the transistor

High efficiency (96%) 220 V_ac / 50 V_dc power converters

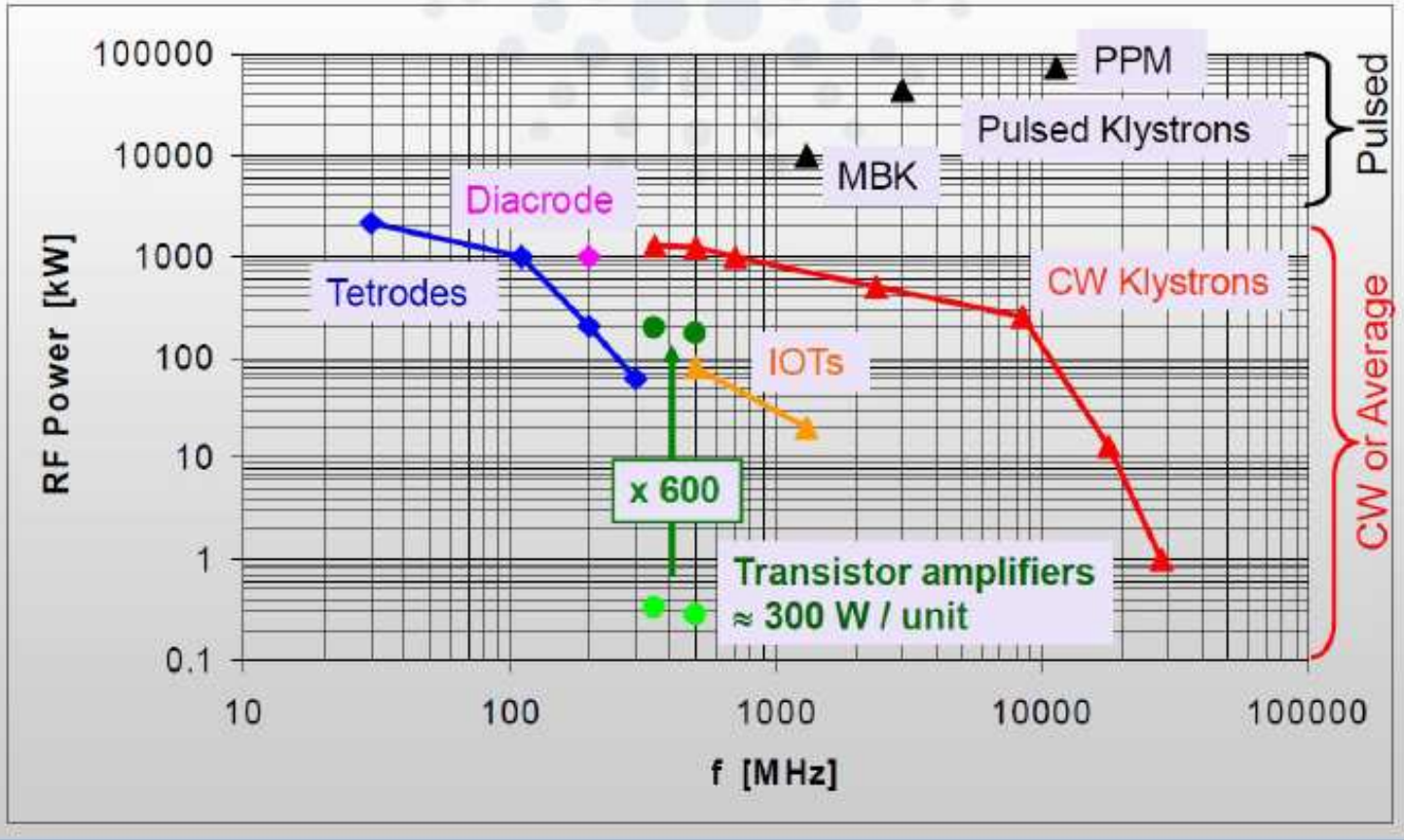
SOLEIL

Solid State Amplifiers

Frequency (GHz)	Max. power (kW)	Efficiency (%)	Main Features	Main drawbacks
0 - 10	0.5/ Module	$\eta \leq 40$	✓ Modularity. ✓ Low maintenance. ✓ Graceful degradation	✘ Efficiency. ✘ Combiner losses. ✘ Transistor isolation.

One will use at medium frequencies, for high reliability

RF power sources for accelerating cavities



Thank you

Questions?