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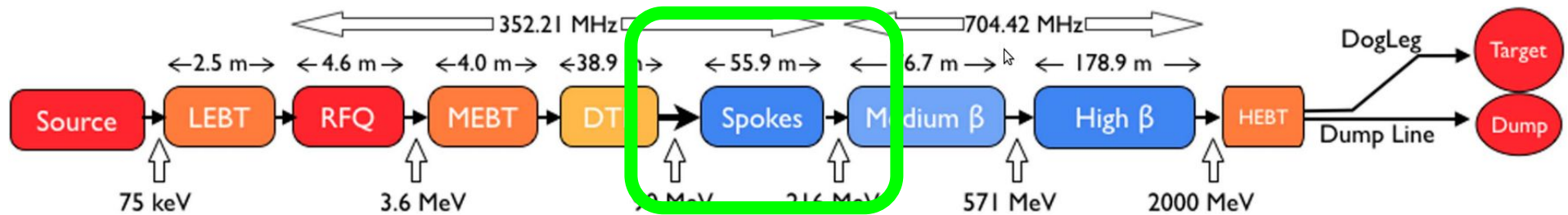
24th virtual European Synchrotron Light Source RF  
(ESLS-RF) Workshop at KIT

# ESS ERIC Radio Frequency Power Stations early test results

Alessandro Cuttin  
on behalf of Elettra RF group

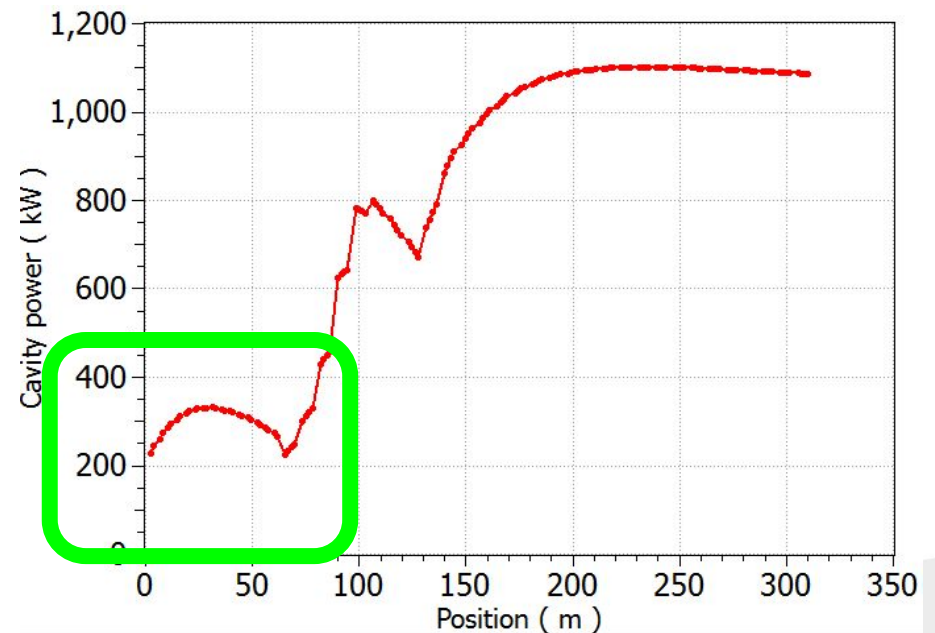


# ESS Radio Frequency Systems



- ✓ Radio Frequency Power Stations (RFPSs) requirements ranges between 260 kW and 350 kW
- ✓ 1 spoke cavity ↔ 1 RFPS
- ✓ each RFPS can be individually controlled in terms of power level, amplitude and phase setting.
- ✓ RFPS design benefits from the experience at FREIA and merges the best of the two existing prototypes.

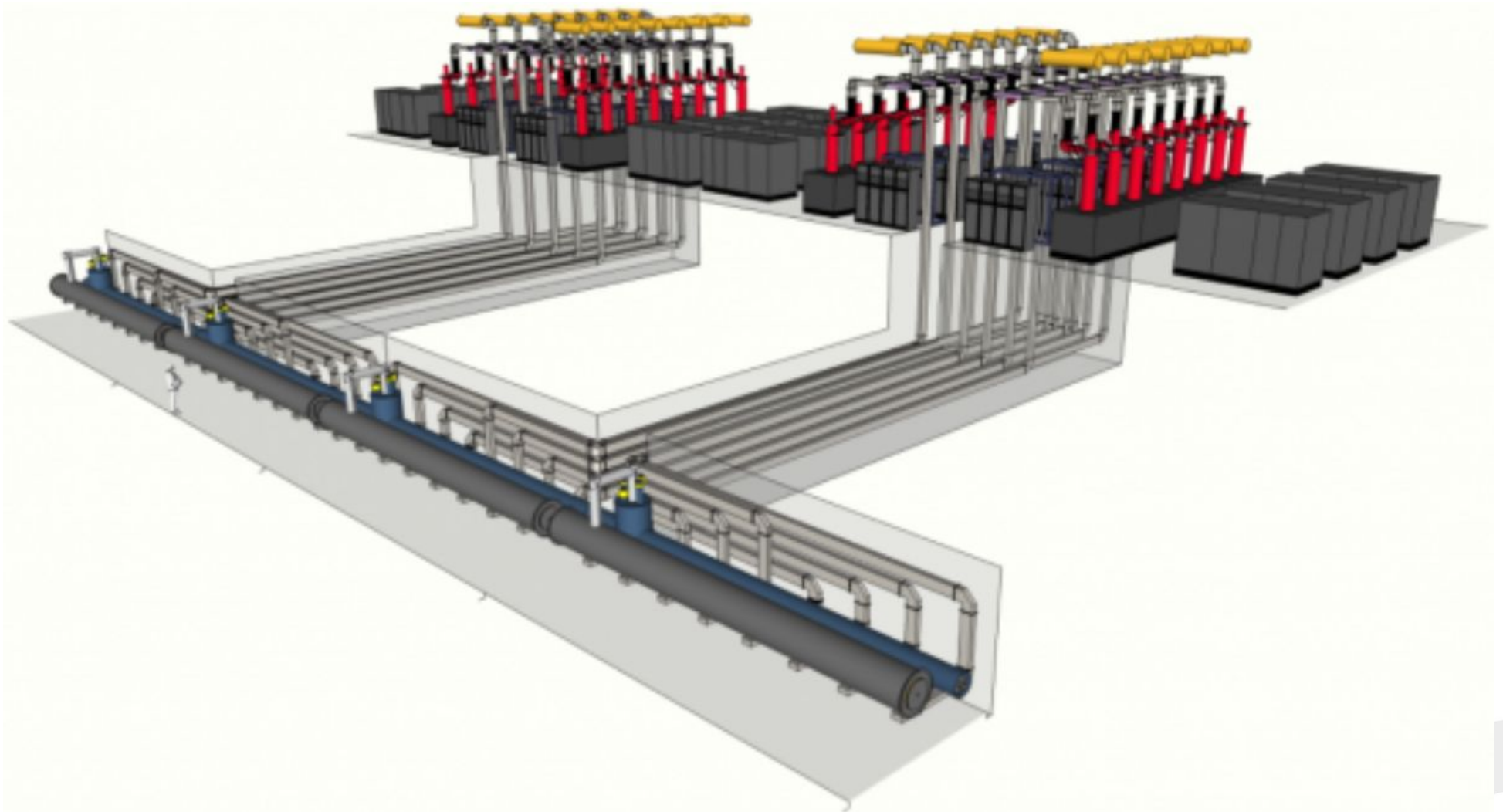
ESS beam power profile





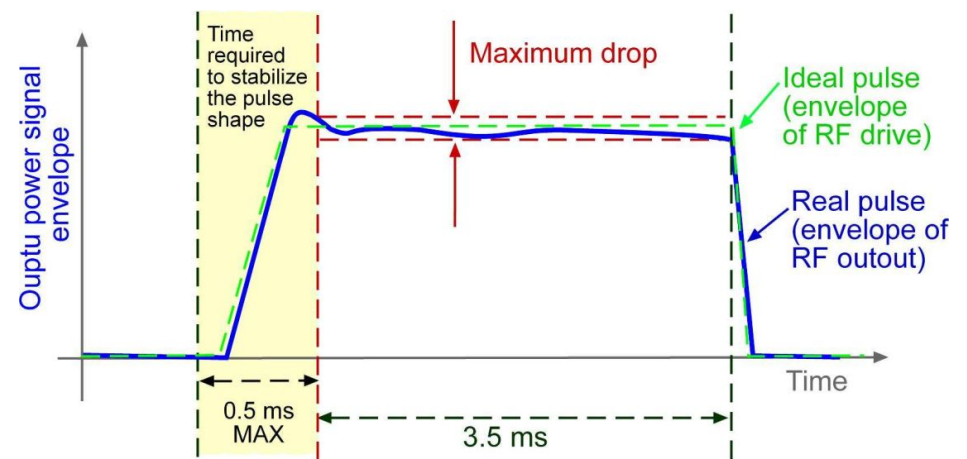
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# ESS Radio Frequency Systems



# Spoke RFPS - requirements

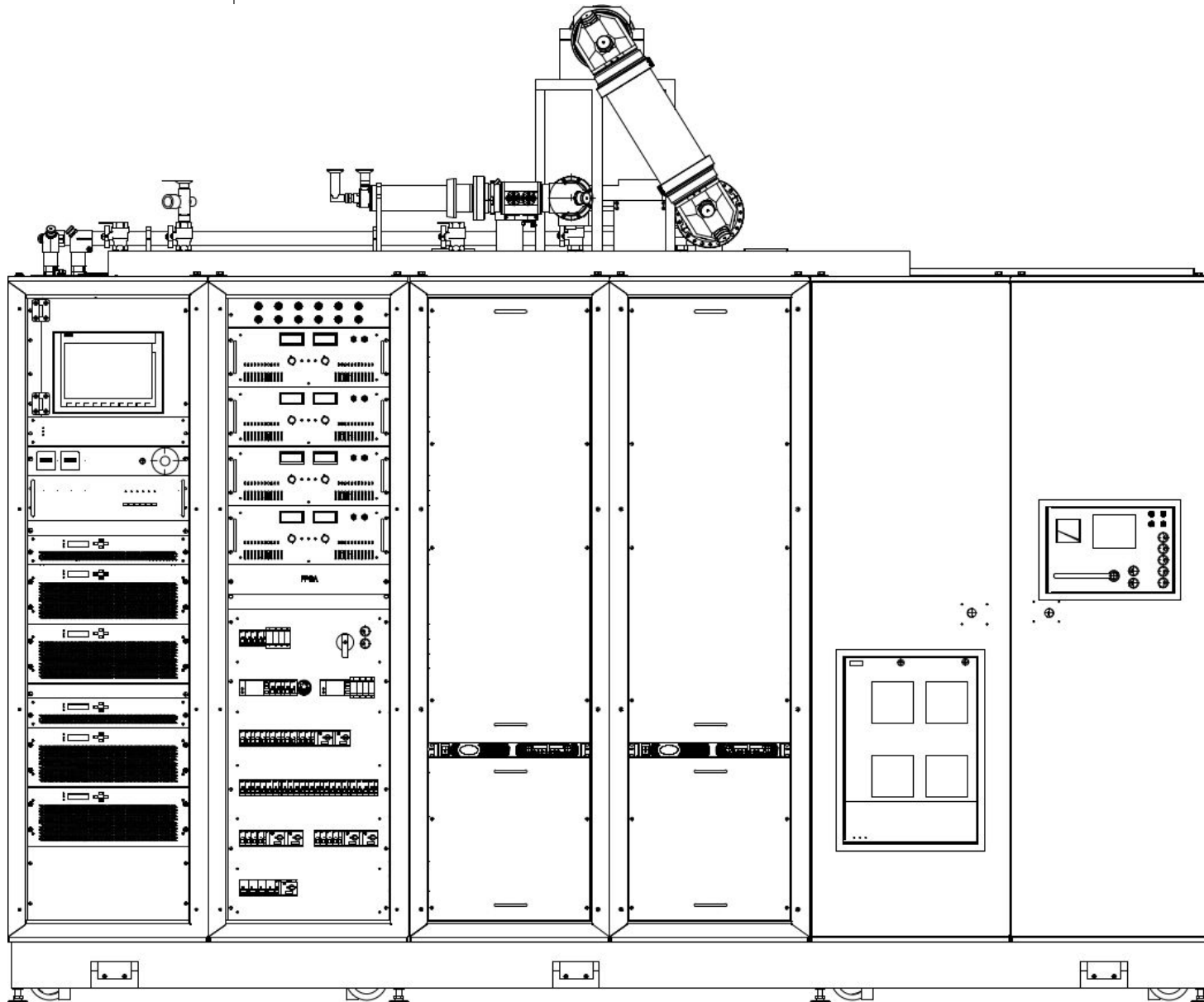
- ✓ RF output power: 400 kW
  - accounts for distribution losses and system margin
- ✓ Pulse duration: 3.5 ms
- ✓ Pulse repetition rate: 14 Hz
- ✓ Frequency: 352.21 MHz
- ✓ System bandwidth: 2 MHz
- ✓ Total gain: > 76 dB
- ✓ Cooling: forced air and water



Stability - Reproducibility - Reliability - Efficiency



# Spoke RFPS







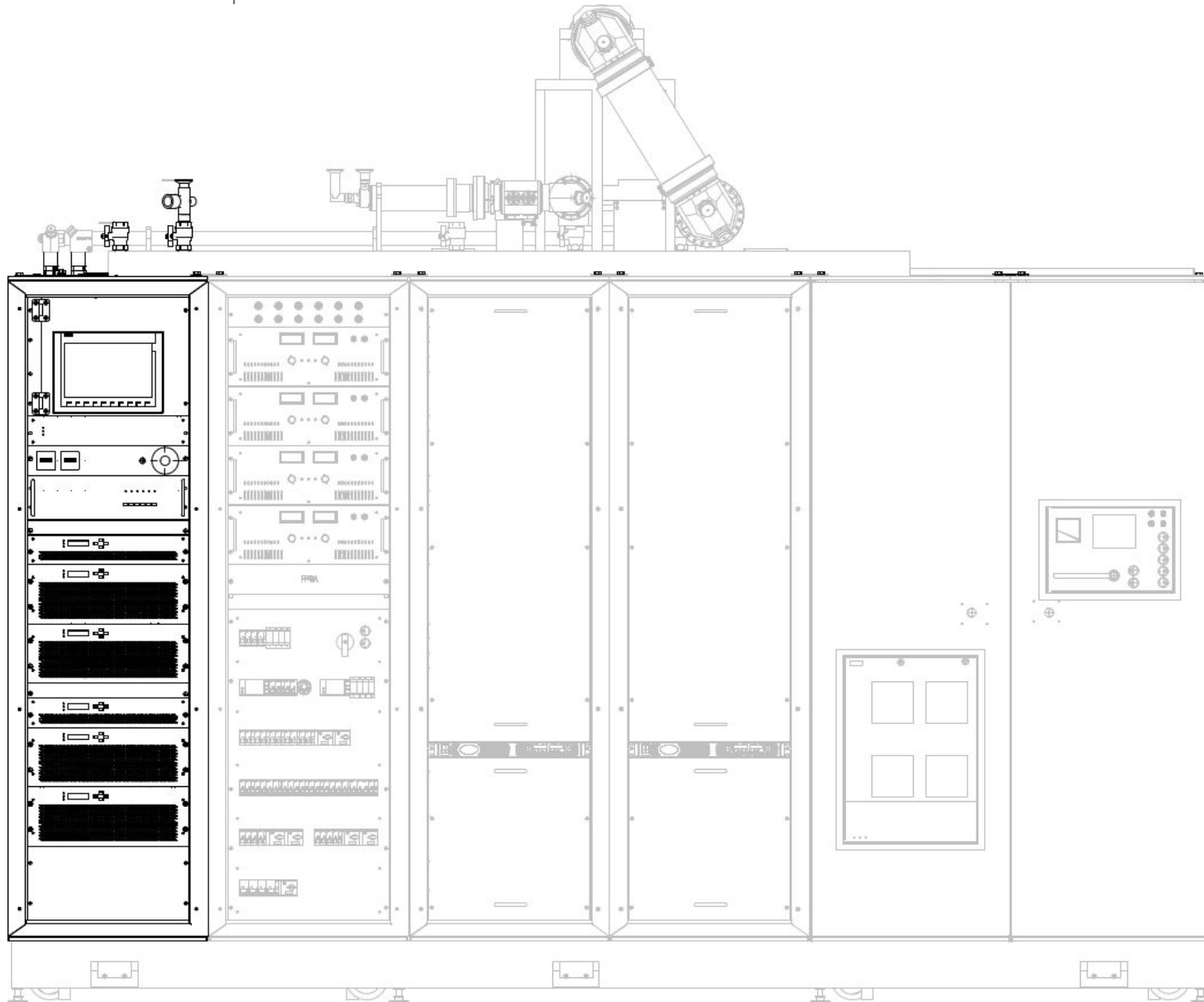
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# Spoke RFPS





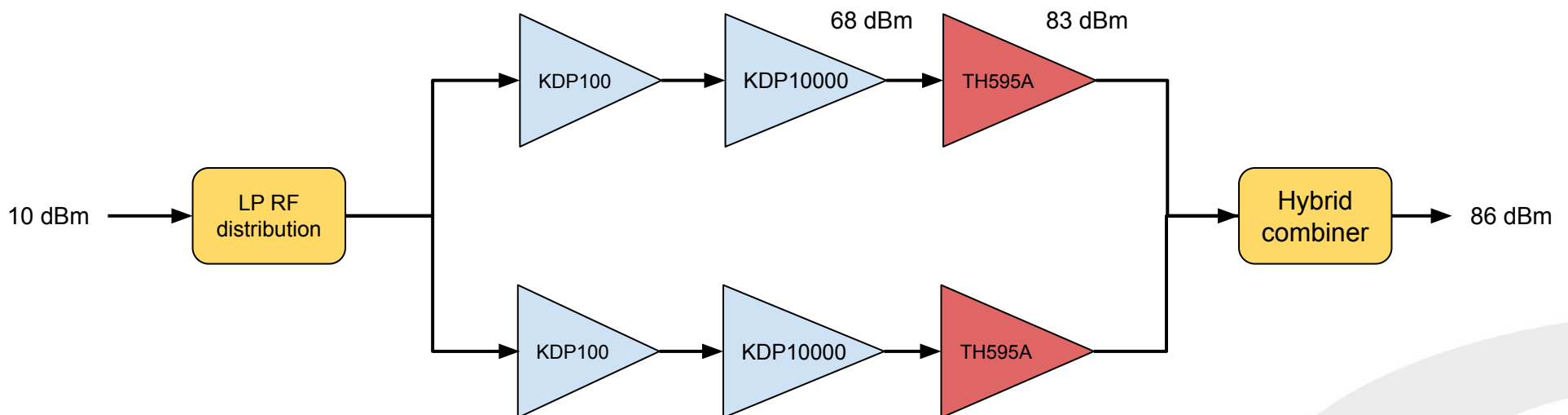
# RF amplification chain





## Two-stage hybrid amplification chain

- ✓ Solid state driver
  - less complex wrt tube driver for same gain
  - more reliable
  - modular and compact
- ✓ Combination of 2 TH595A tetrodes
  - efficiency
  - gain
  - cost





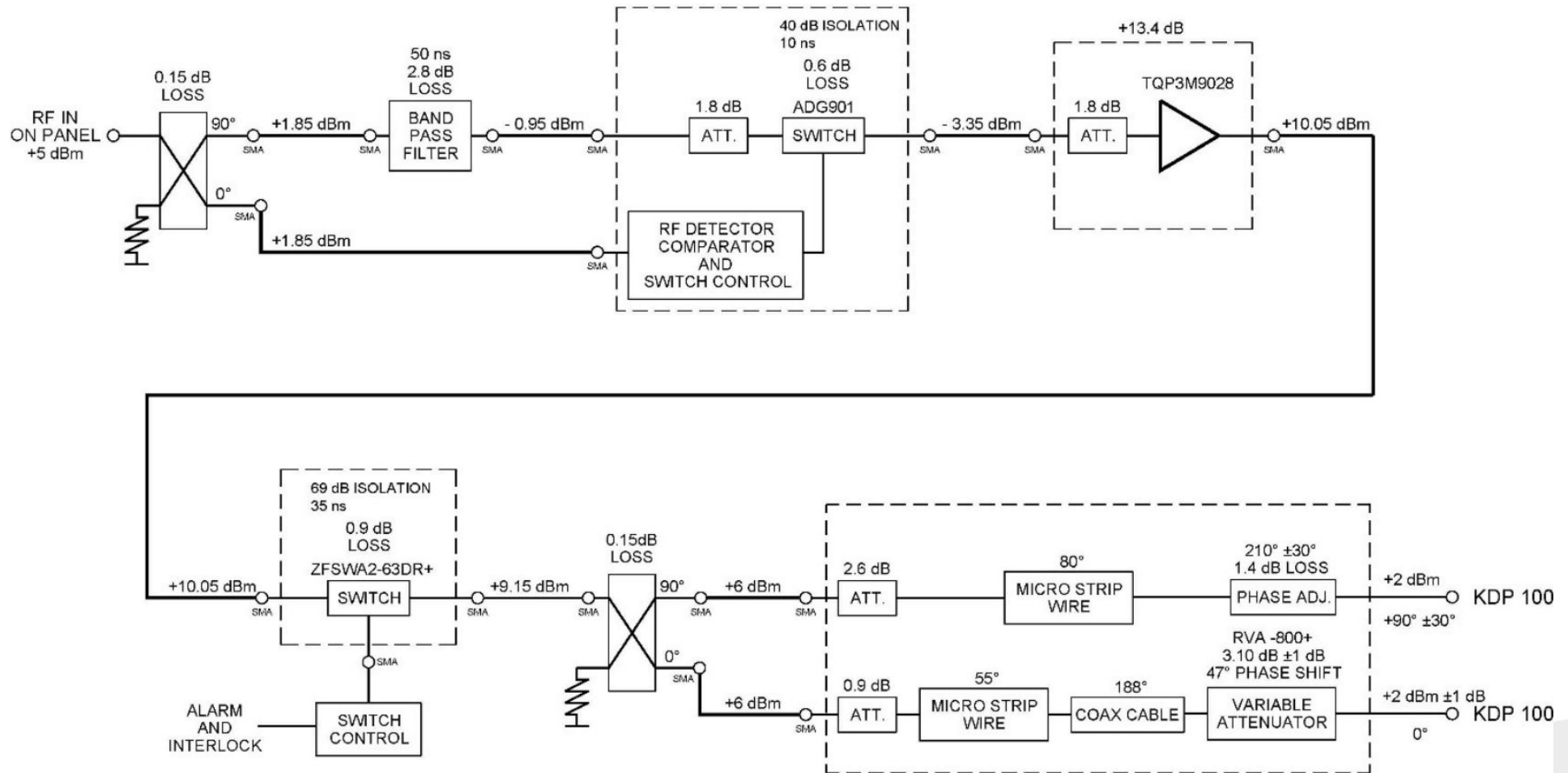
# RF low power distribution

Conceived to obtain:

- ✓ protection of tetrodes
- ✓ safe and reliable operations
- ✓ easy tuning of amplification branches



# RF low power distribution



## KDP100

- ✓ class A / AB
- ✓ pulsed bias current
- ✓ air cooled

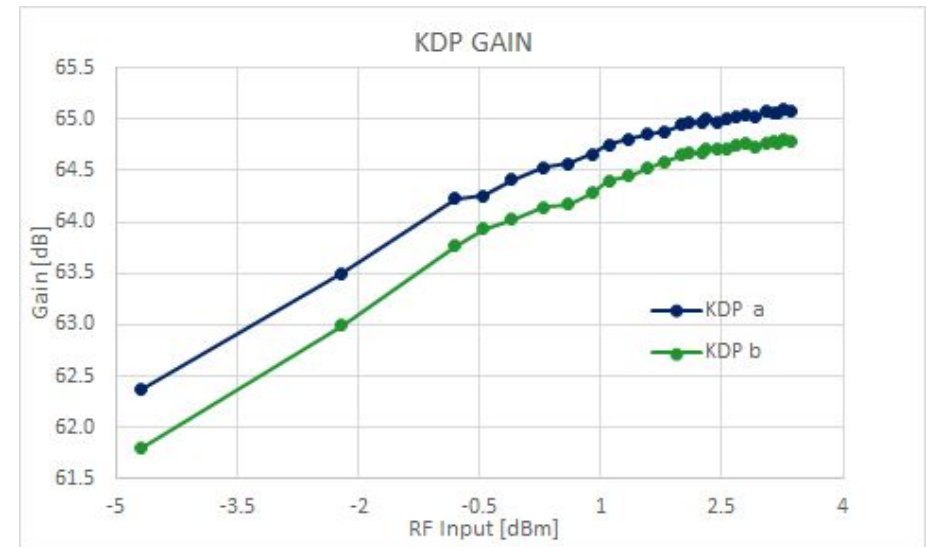
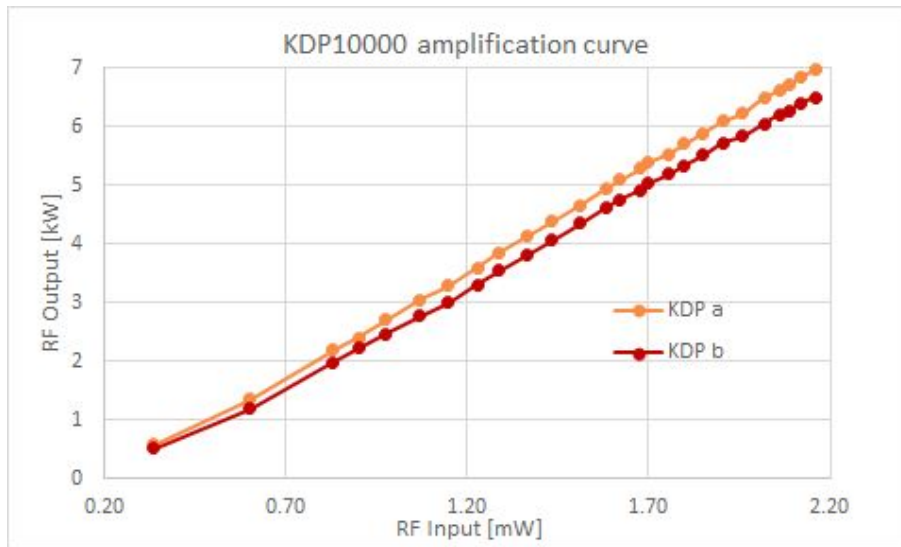
## KDP10000

- ✓ class AB to ensure {intra/pulse-to}-pulse stability
- ✓ pulsed bias current
- ✓ liquid cooled (medium temperature circuit)
- ✓ Adjustable gain  $\pm 1$  dB
- ✓ Redundant





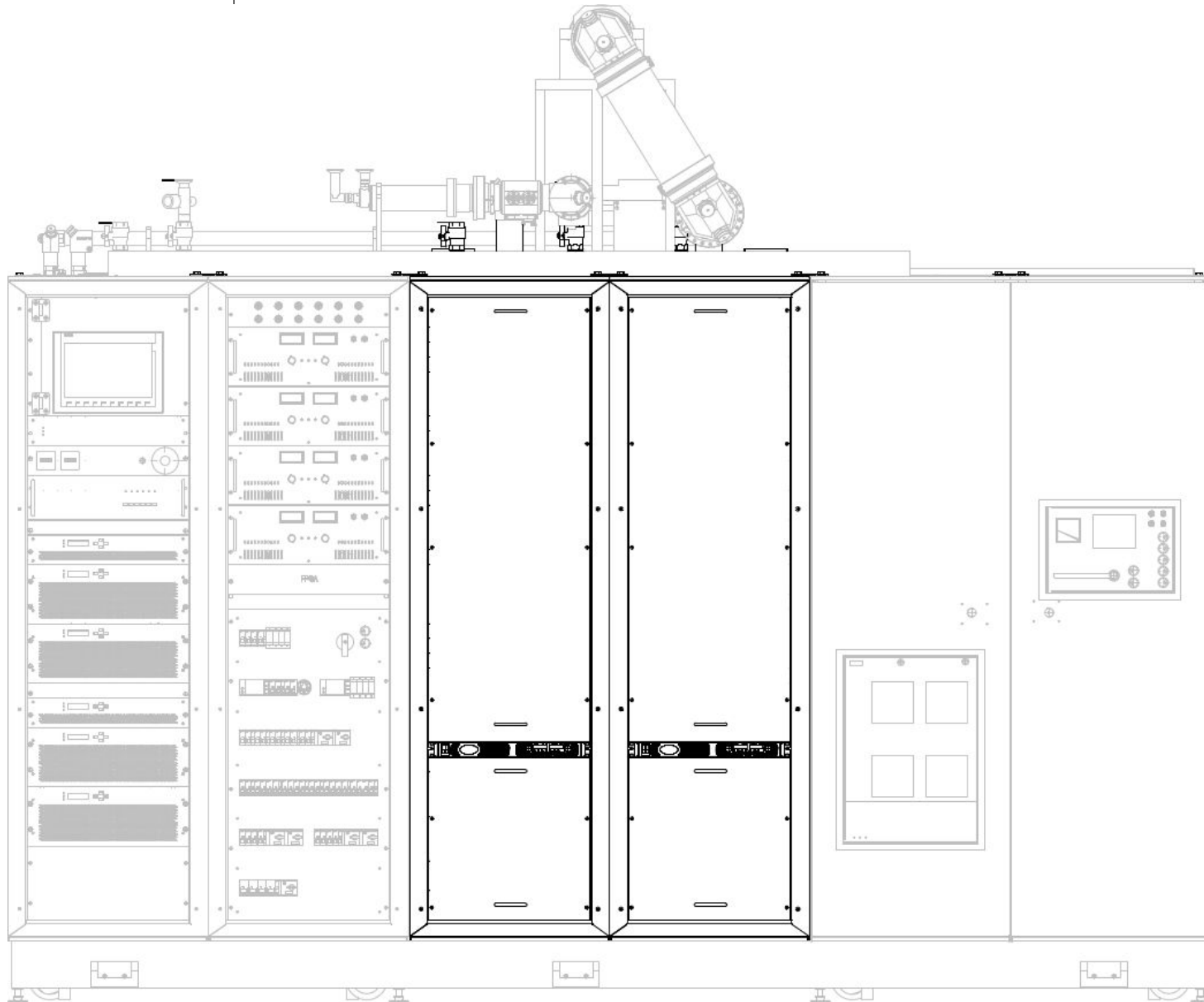
# RF solid state drivers - FAT test results





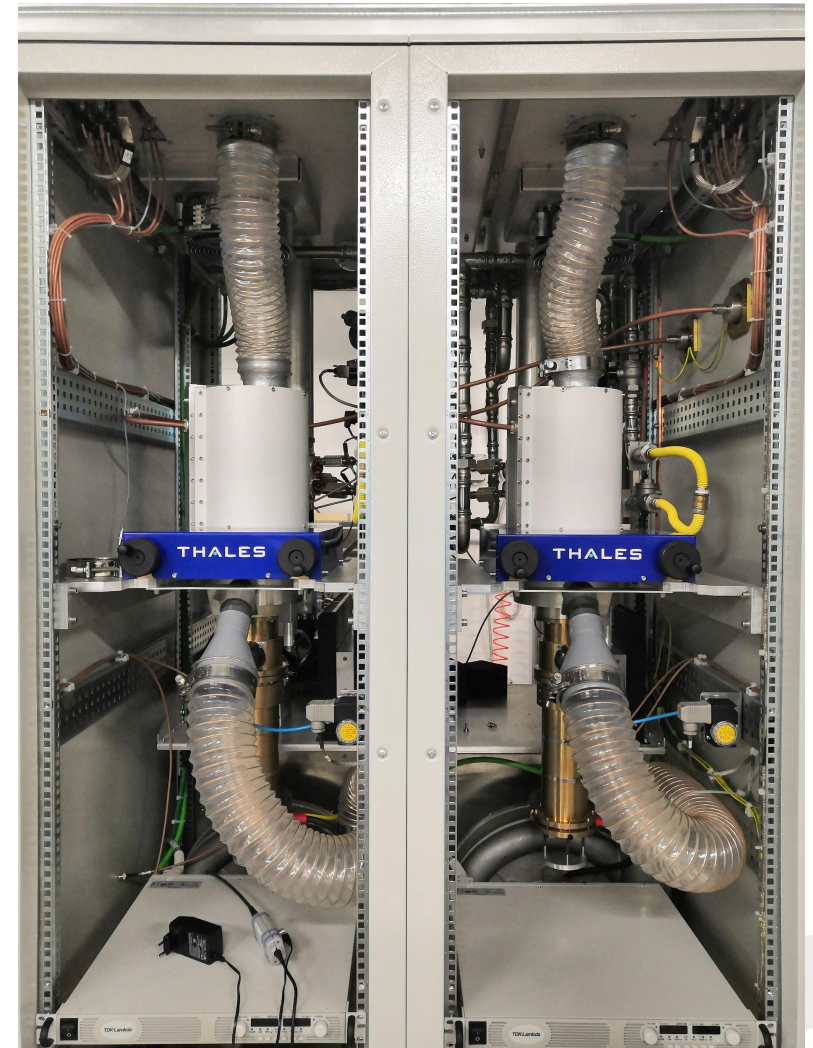


# Tetrodes and cavities



## Tetrode TH595A

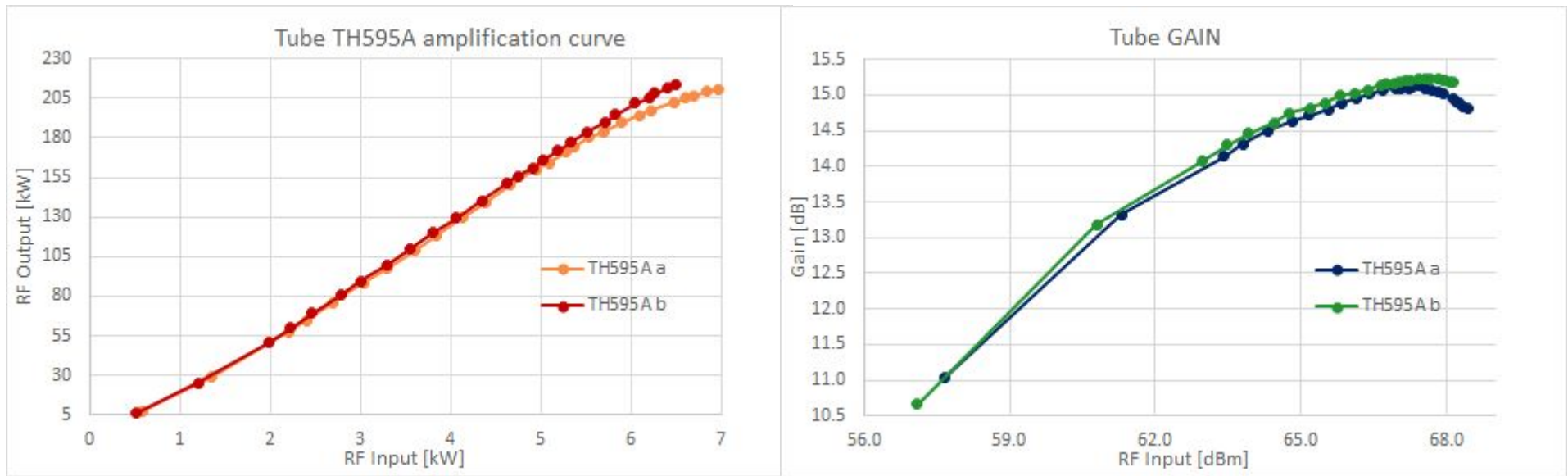
- ✓ improved version of TH595
  - better power dissipation
  - improved grid design
- ✓ anode is water cooled
  - 40 kW anode dissipation
  - more compact system
  - connected to high temperature water cooling
- ✓ up to 210 kW in pulsed mode





# FAT tests - main results - RF gain

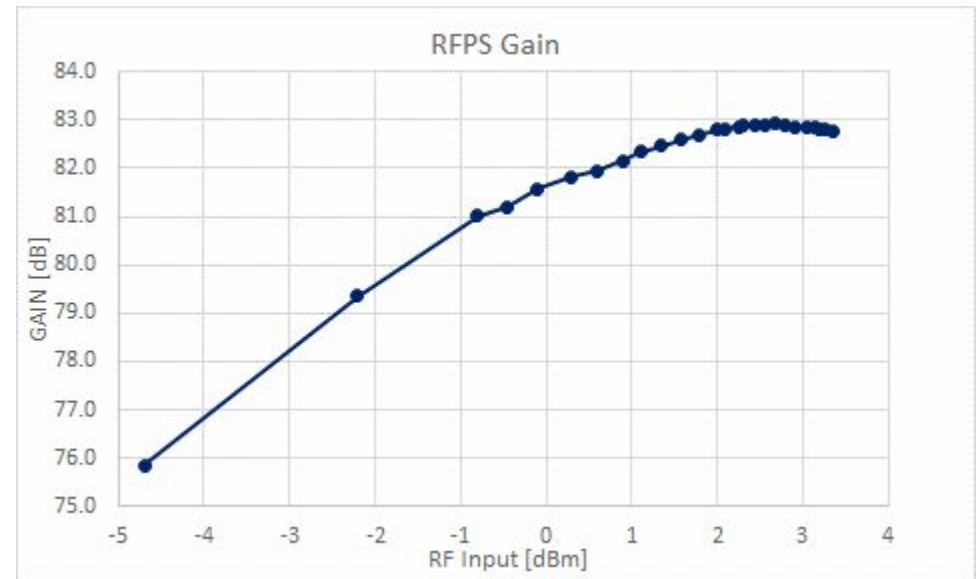
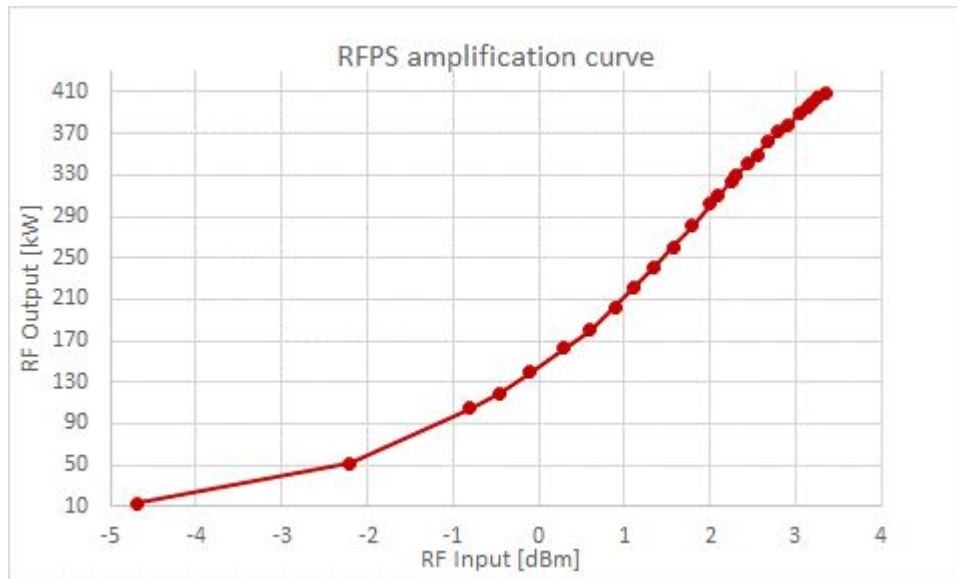
## TH595A





# FAT tests - main results - RF gain

## RFPS (input - output)

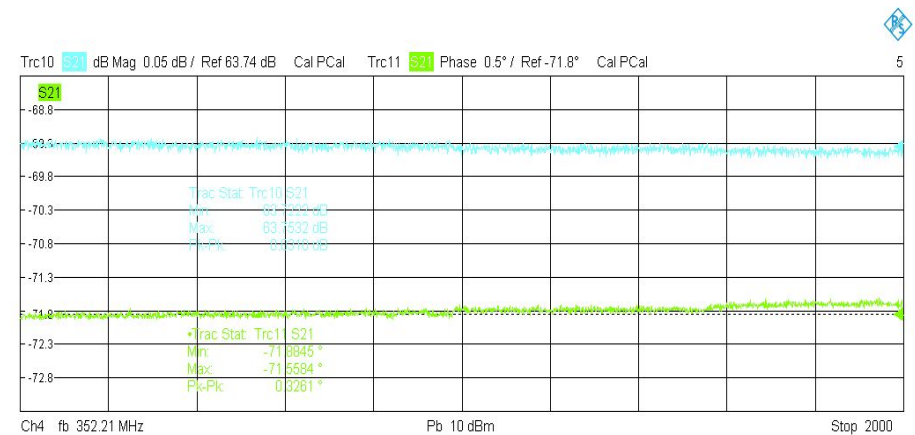


## Pulse to pulse stability

- ✓ amplitude: better than 0.05%
- ✓ phase: better than 0.5%

## Single pulse quality

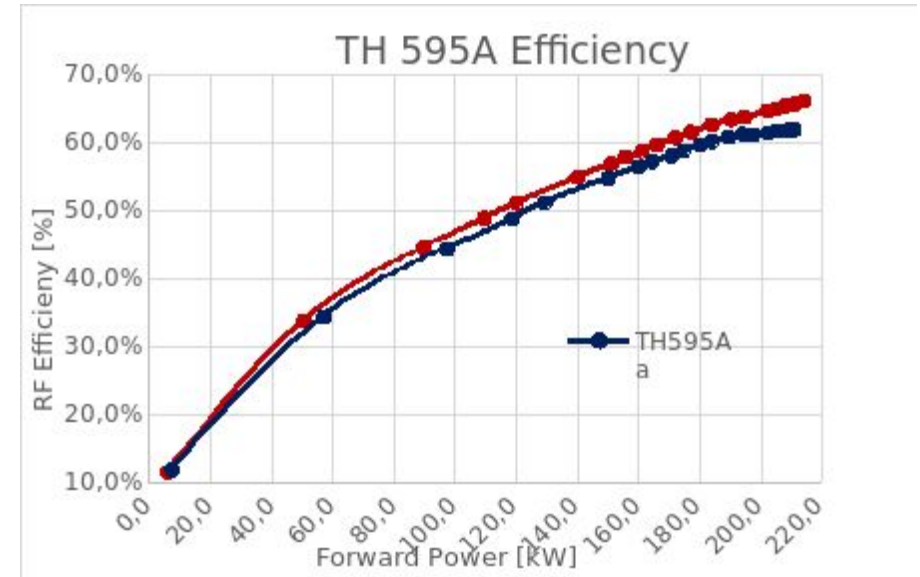
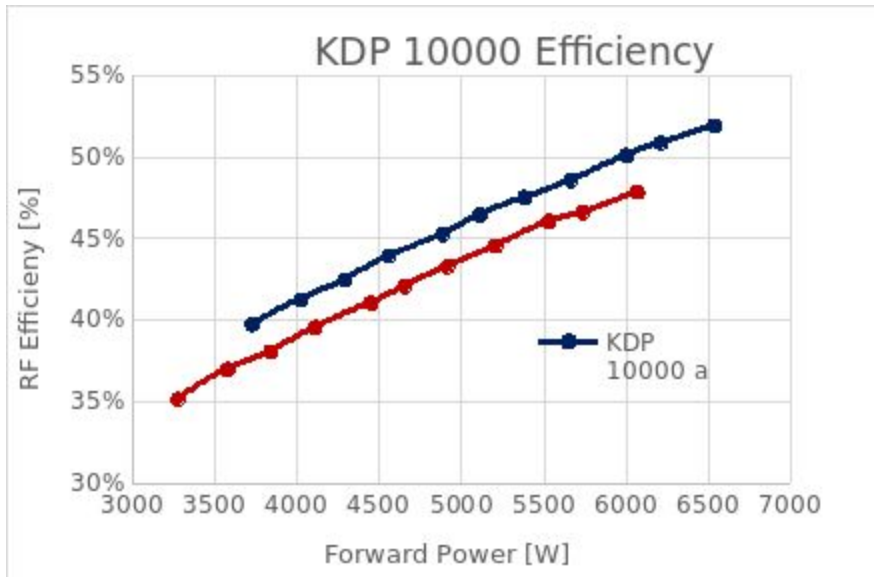
- ✓ analysis in progress
- ✓ specific signal processing software







# FAT tests - main results - efficiency

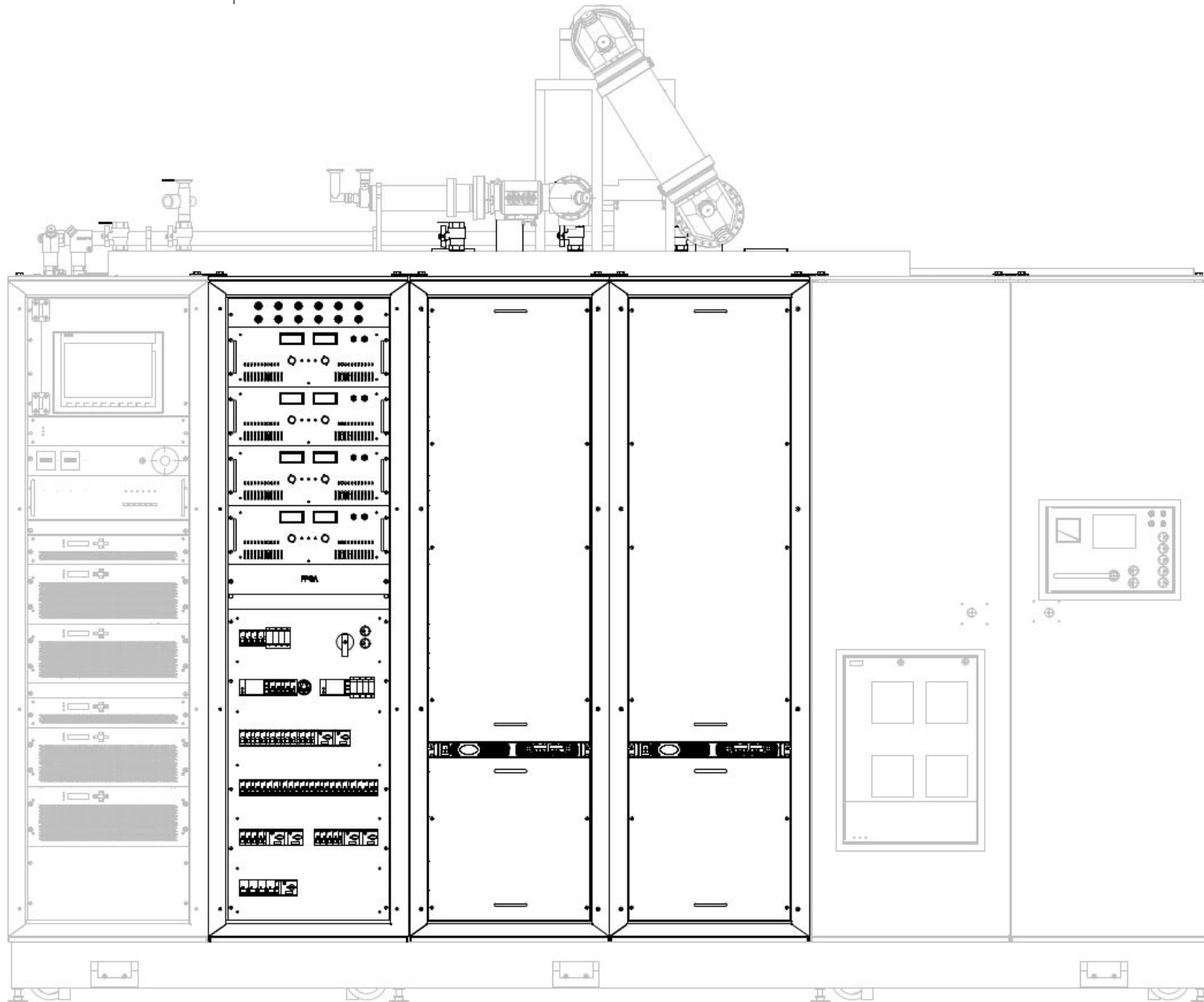


measured wall-plug to RF energy efficiency at 400 kW

$$\eta = 46\%$$



# Tetrode power systems



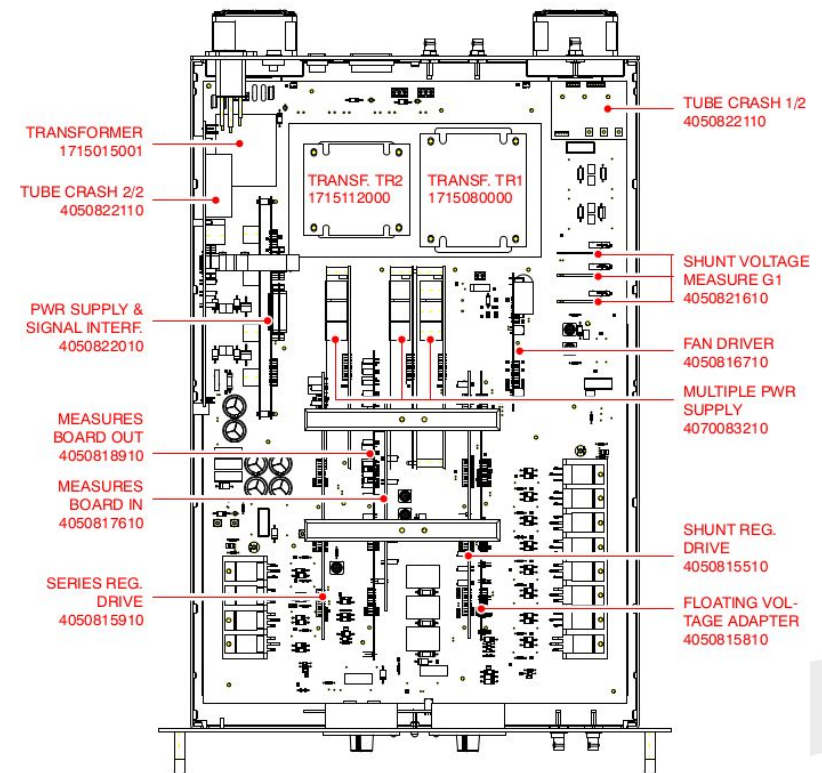
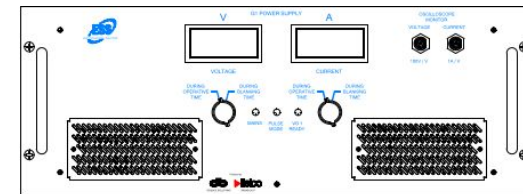


# Grid and filament power supplies

Control (G1 -250/-400 V) and screen (G2 900 V) grids power supplies are custom made by European Science Solutions s.r.l.

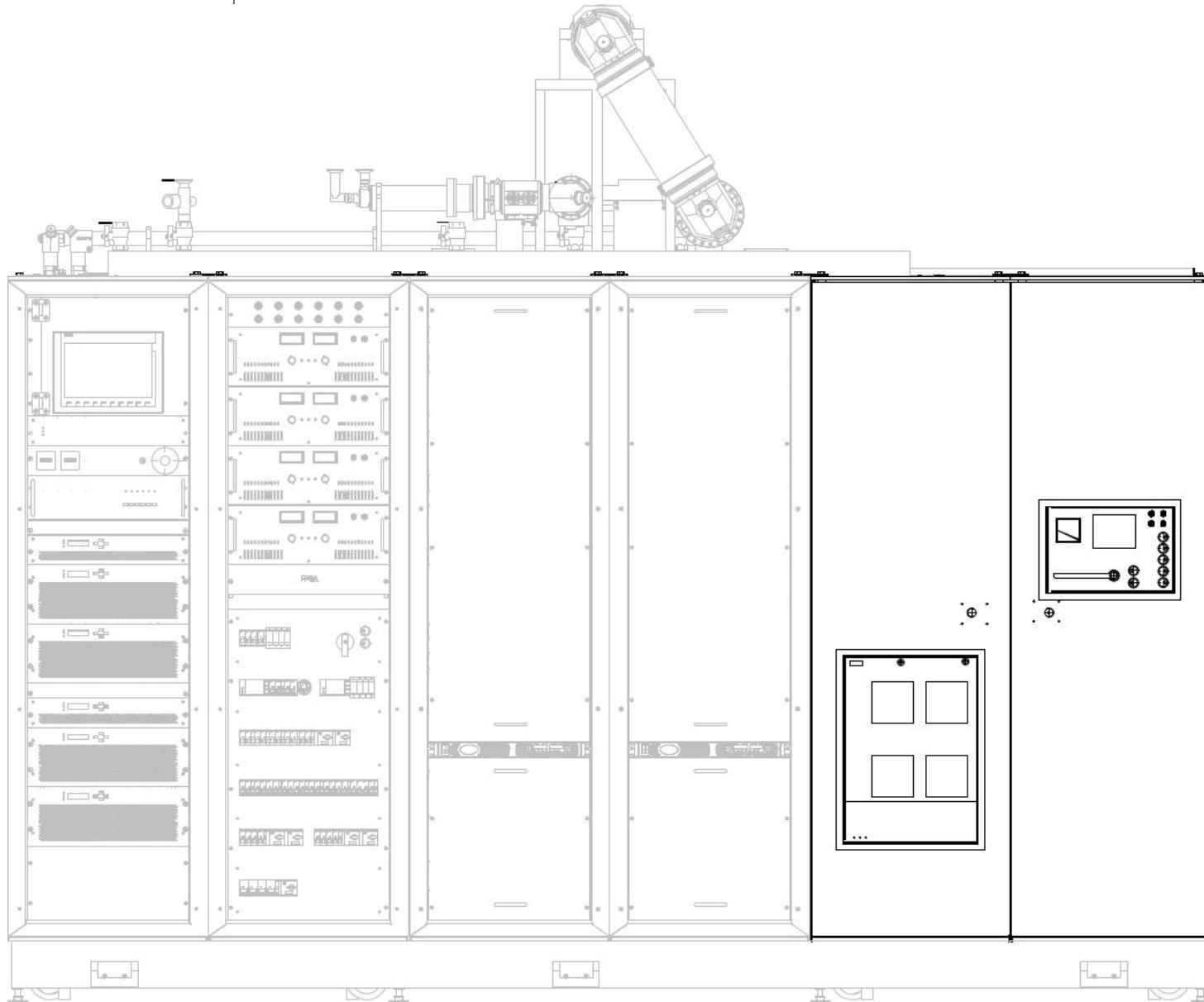
- ✓ G2 intended to be switching, linear instead
- ✓ To maximize efficiency, G1 features blanking outside pulse (up to 90%)

Filament power supply is COTS.



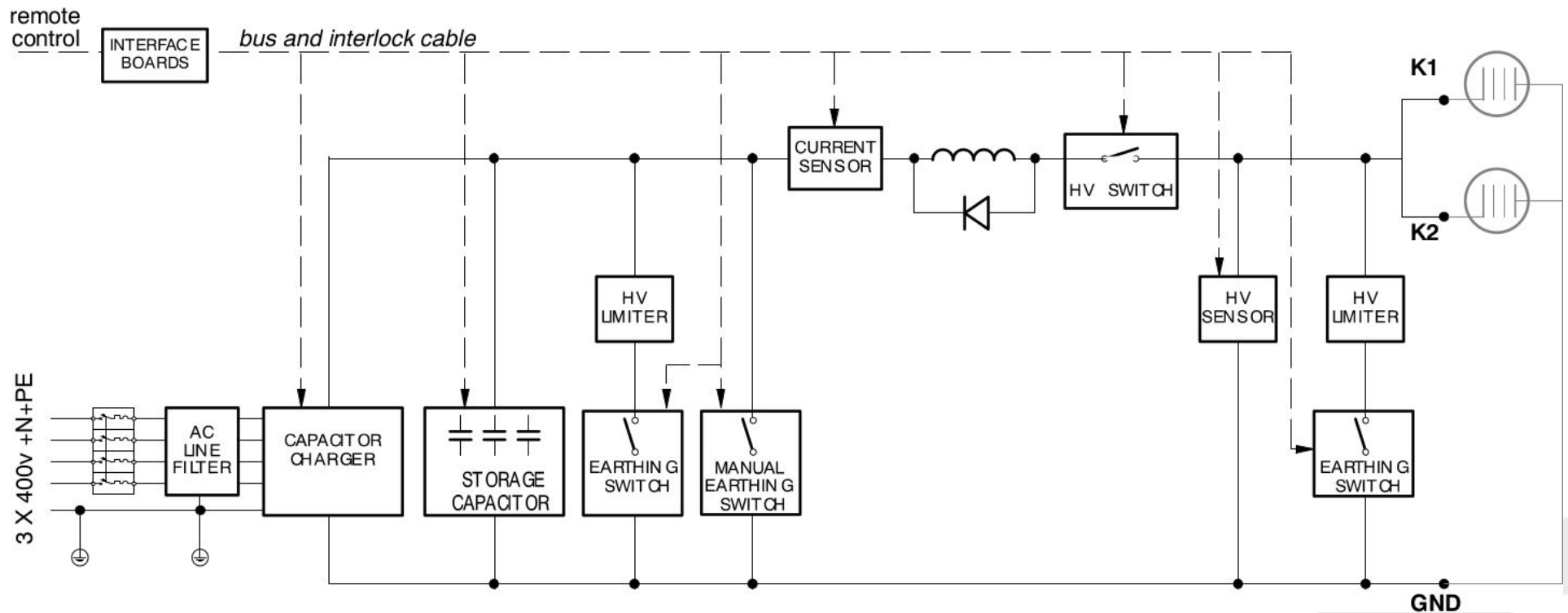


# Anode supply (modulator)





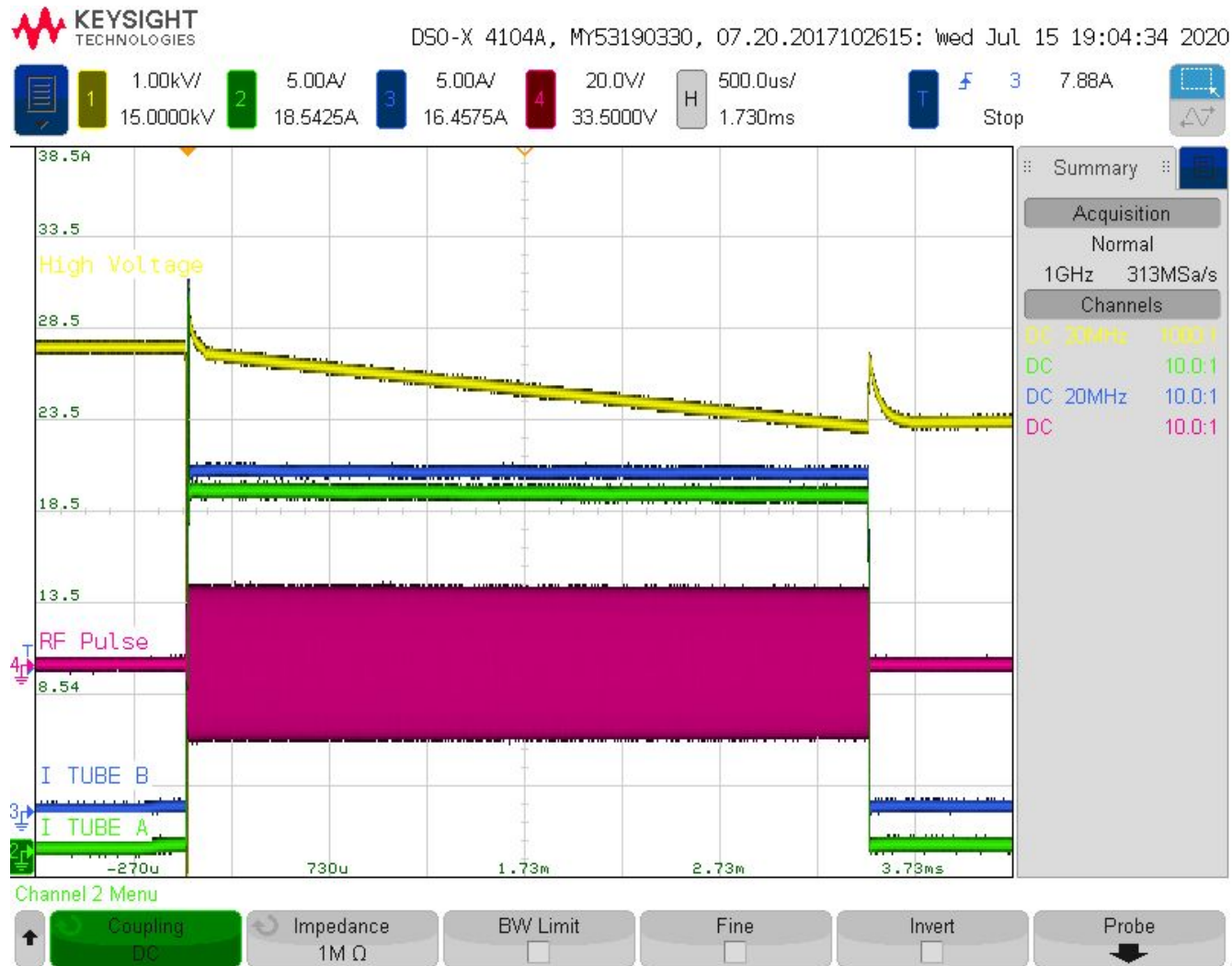
# Anode supply (modulator)







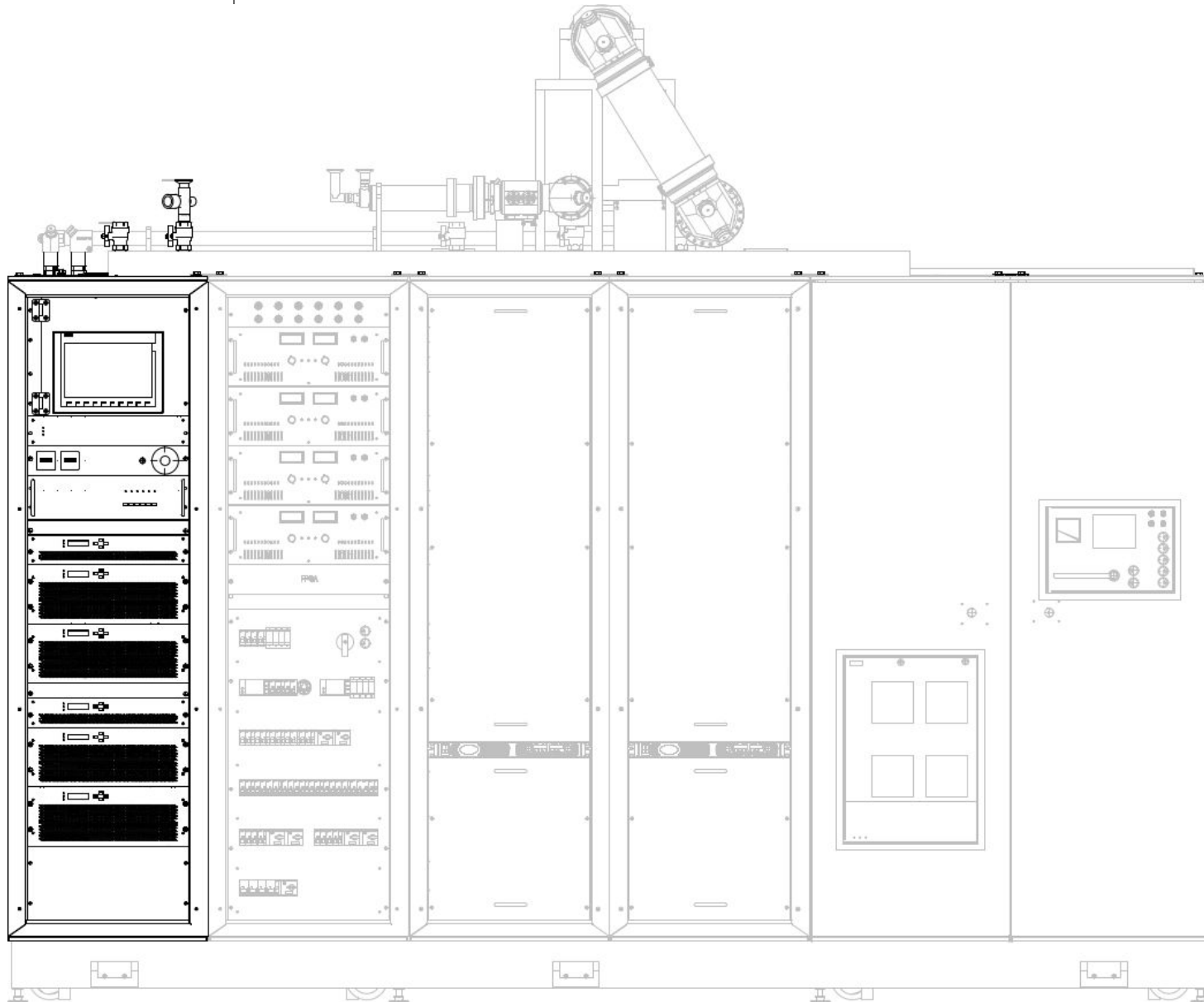
# Anode supply (modulator)

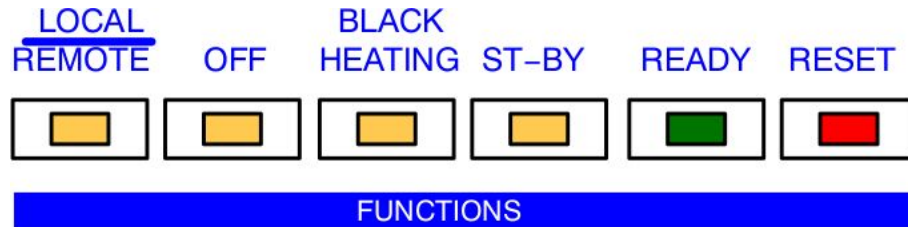




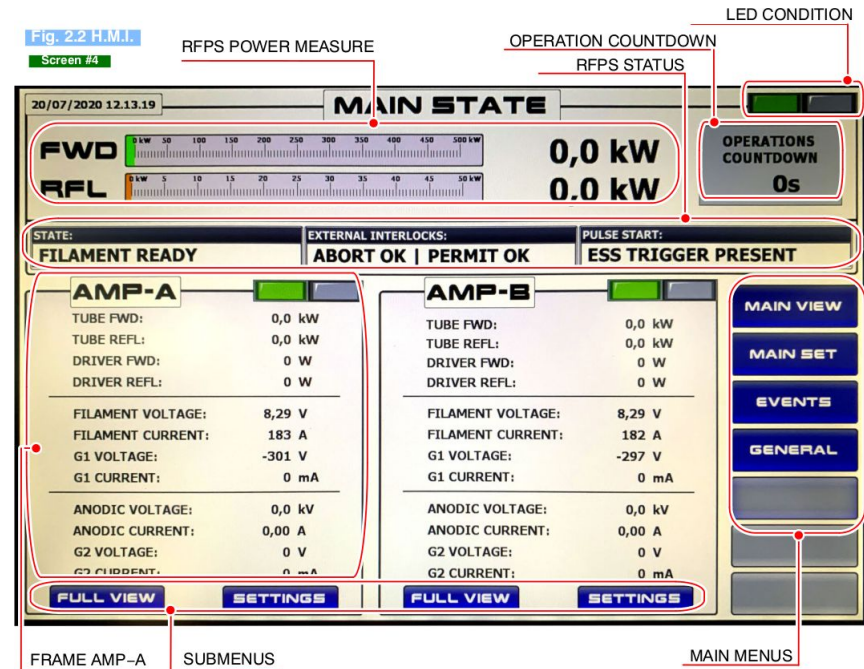
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# Supervisory Control System





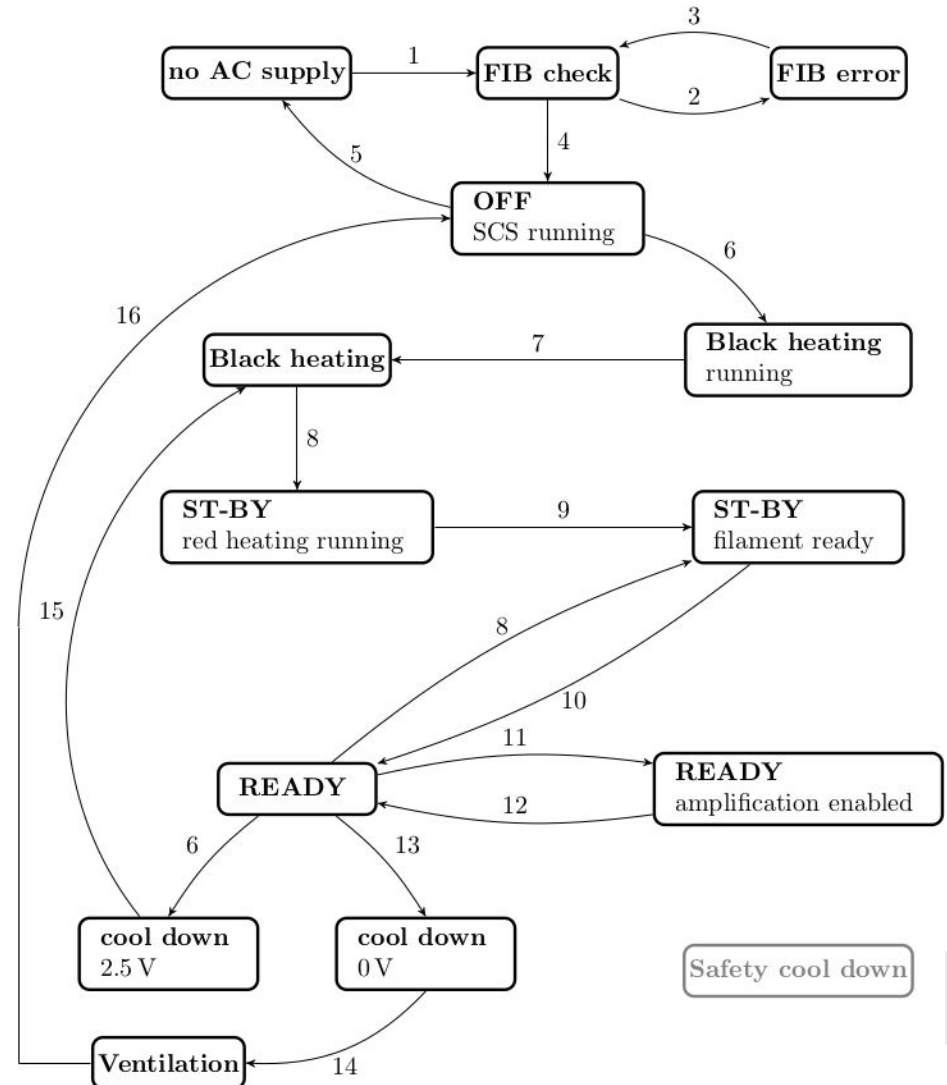
- ✓ simple control interface: only 3 operational conditions
- ✓ User-friendly Human Machine Interface



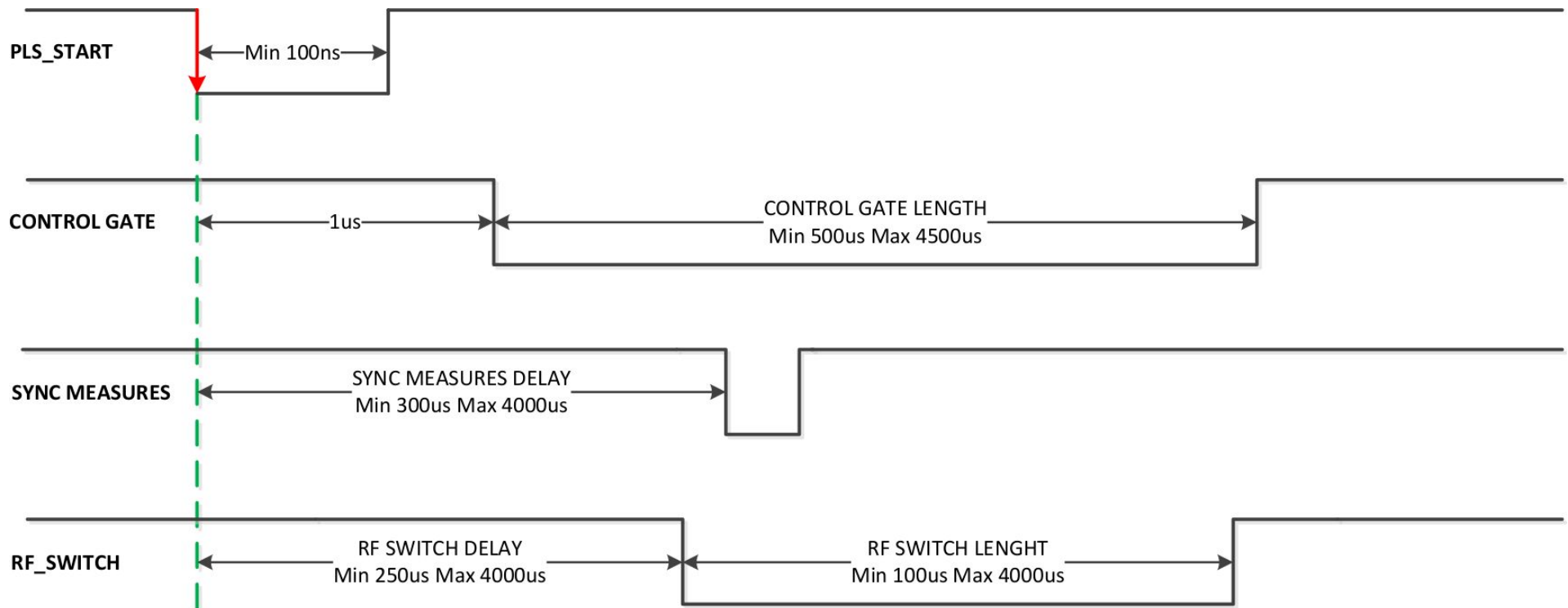
The SCS handles also the following situations:

- ✓ pulsed operation is ensured even if input is CW
- ✓ pulse repetition rate between 0.5 Hz and 14 Hz is accepted

- ✓ all tetrode procedures (power up, power down, emergency shut down) *implemented in a twin scenario*
- ✓ features black heating to avoid unnecessary thermal cycling of tetrodes



## Control of pulsed operations - concept





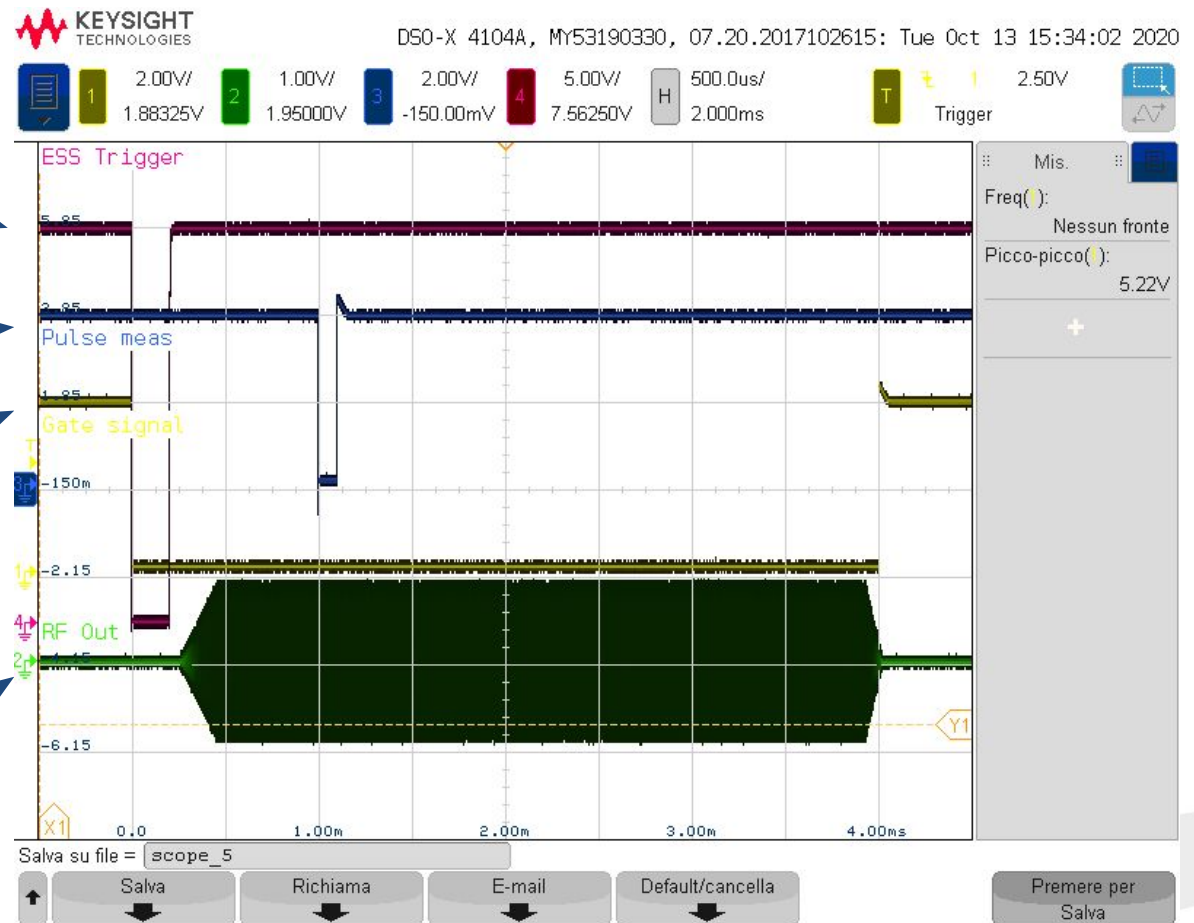
## Control of pulsed operations - implementation

External  
trigger

Pulse  
measure

Gate  
control

RF output  
(switch)



## Personal Safety

- ✓ Slow signals
  - Reaction time  $\approx$  ms
  - Triggered by human action (emergency button)

## Equipment Safety

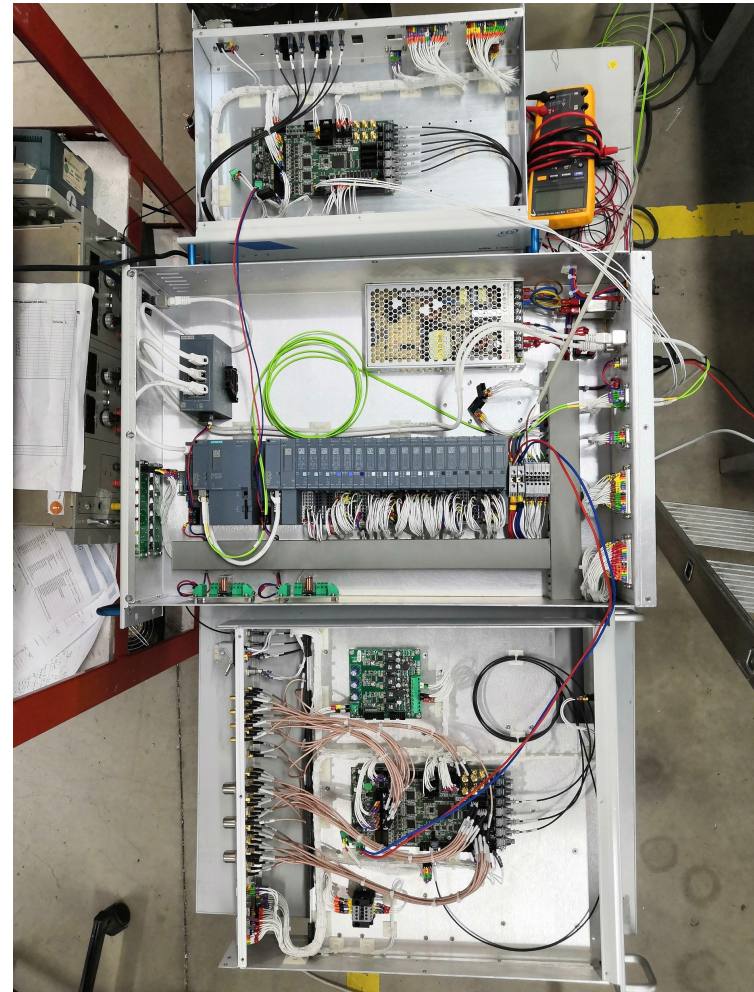
- ✓ Fast signals
  - Reaction time  $\approx$   $\mu$ s ( $\ll$  pulse duration)
  - Triggered by amplifier or anode supply failures
  - Compliant with safety requirements of TH595A
- ✓ Slow signals
  - Reaction time  $\approx$  ms
  - Failure of ancillary systems or power supplies

## Personal Safety

- ✓ PLC based
- ✓ Objective:
  - RFPS shut down

## Equipment Safety

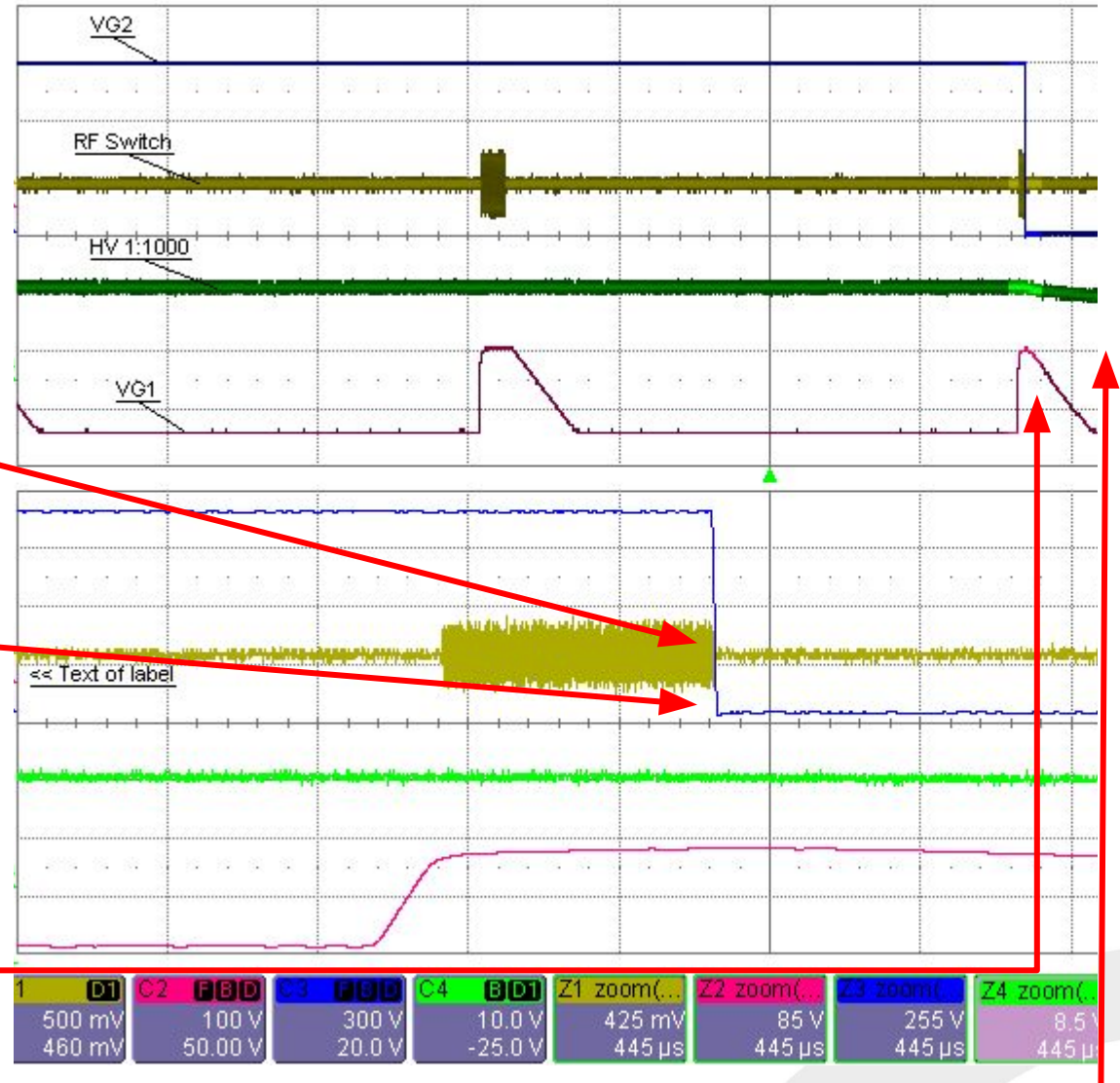
- ✓ FPGA based modules
- ✓ Objective:
  - remove RF driving signal
  - bring the RFPS in a safe status



## Example of fast interlock

Anomaly on FPGA  
module triggers:

- ✓ RF switch opened  
(40 ns)
- ✓ G2 inhibited  
( $< 5 \mu\text{s}$ )
- ✓ G1 from biasing to  
blanking
- ✓ HV turned off



RFPSs are supplied to ESS ERIC in the framework of an In-kind contribution

- ✓ Procurement contract of 26 RFPS awarded to European Science Solutions s.r.l.
- ✓ Procurement contract of 52 tetrode-cavity sets awarded to Thales Electron Devices Sas

Management efforts aimed to:

- ✓ keep the procurement of RFPS and T-C sets in sync to avoid delivery delays
- ✓ streamline paperwork and administrative duties between entities not bounded by commercial agreements in the context of italian public procurement law



## ✓ RFPS01

- completed Factory Acceptance Testing in July 2020
- delivered to ESS ERIC in early August 2020
- completed Site Acceptance Testing in October 2020

## ✓ RFPS02-26

- manufacturing in progress
- delivery in small batches
- production reviews on a regular basis

## ✓ Tetrode-Cavities sets

- Set 01 completed Factory Acceptance Testing in mid 2019
- manufacturing of sets 02-52 ahead of RFPS manufacturing schedule





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- European Spallation Source ERIC
- European Science Solutions s.r.l.