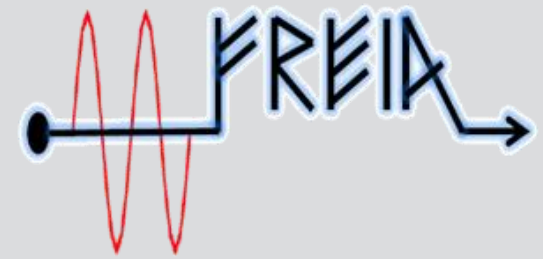




UPPSALA
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Preliminary measurements of eight solid-state modules of the 10 kW pulsed power amplifier at 352 MHz under development at FREIA

Dragos Dancila, Long Hoang Duc, Magnus Jobs, Vitaliy Goryashko, Anders Rydberg, Jörgen Olsson and Roger Ruber

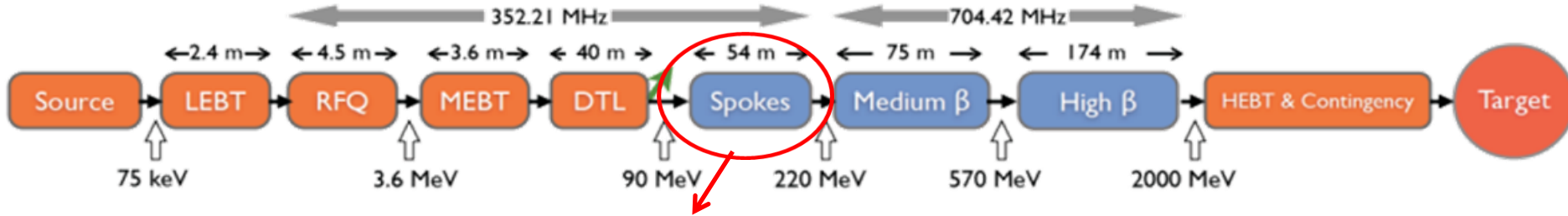
FREIA Laboratory, Uppsala University

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RF Source Development - FREIA



Optimus



Testing prototype superconducting accelerating cavities (26 SC in final LINAC), cryomodules and high power RF stations

- High power RF stations at ESS specifications

352.21 MHz, 400 kW, 14 Hz, 3.5 ms, 200 kHz bandwidth



ESS - Lund



Uppsala University



Cryogenics

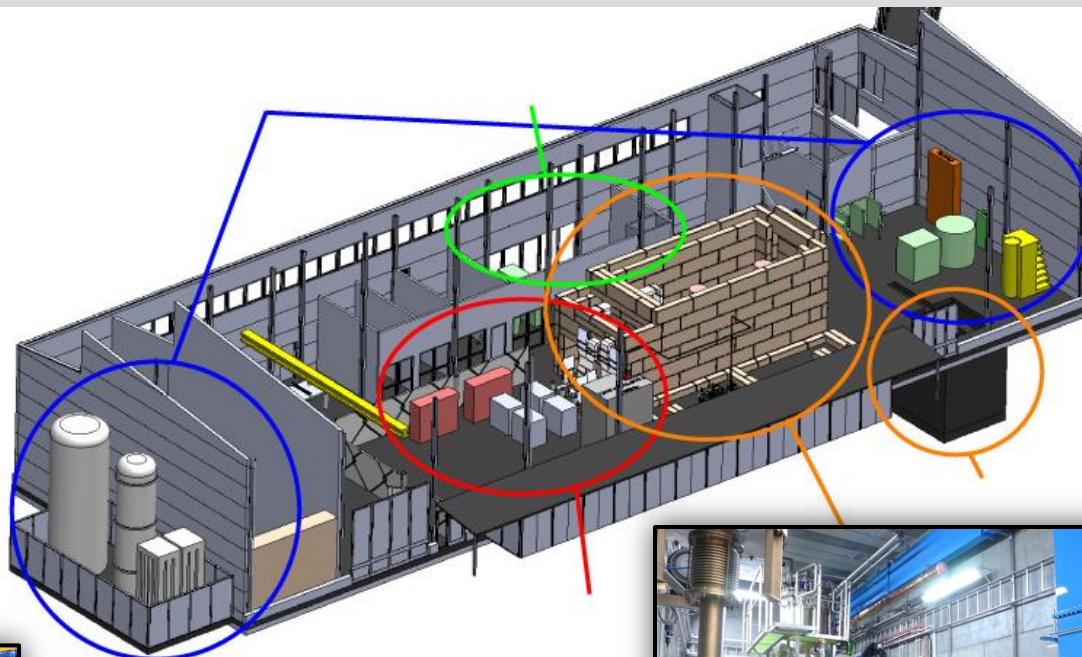


- Liquid Nitrogen
- Helium liquefaction (150 l/h)
- 2000 l storage dewar

RF Power Stations



- 400 kW 3.5 ms pulses at 14Hz
- Dual TH595 tetrodes
- Load pull



Spoke Cavity

- Operating at 352.21 MHz
- $Q > 10^9$
- Operating gradient 9 MV/m

Control System

- Closed-loop LLRF system
- Cryogenics control



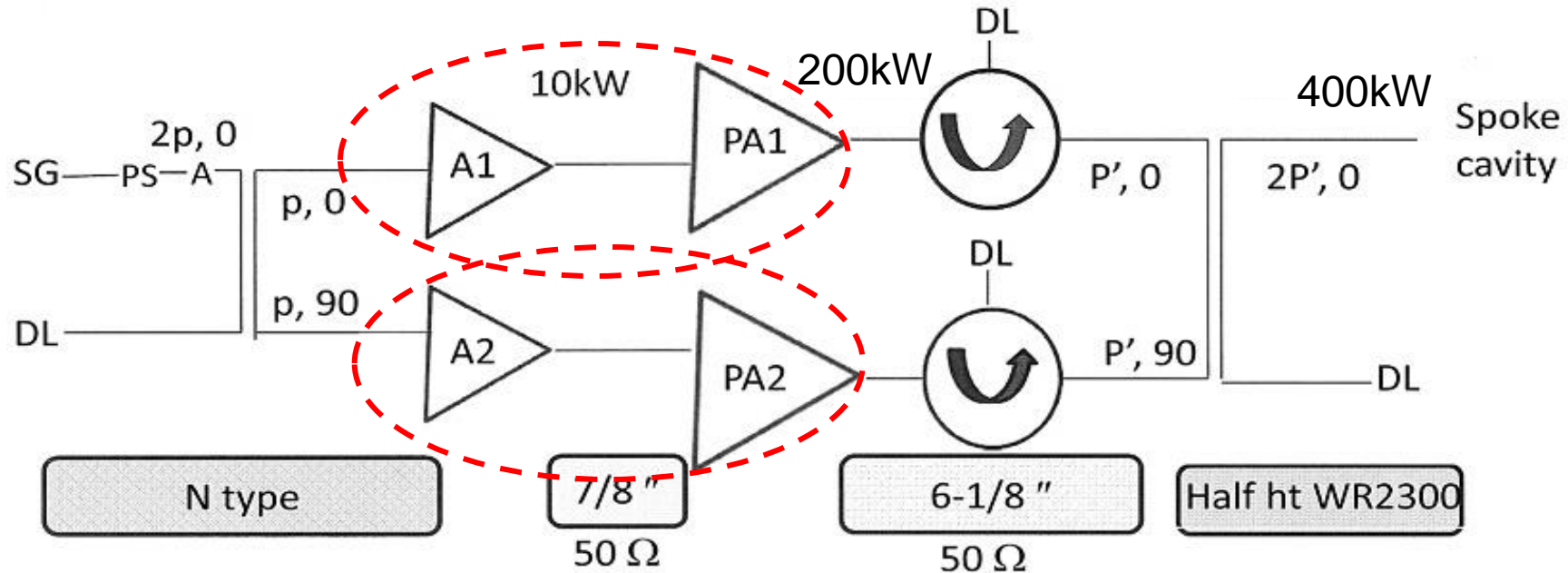
Horizontal Cryostat

- Operating at 1.8 to 4.5 K
- 16 mbar pressure

400kW RF Stations

- Tetrode based (Dual TH595)
- 400 kW 3.5 ms pulses at 14Hz
- 20 kV 40 A anode power supplies
- Class AB
- Cost Efficient/Reliability
- Efficiency a key-parameter



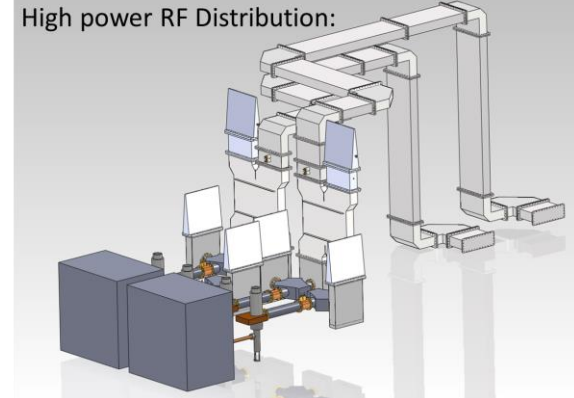


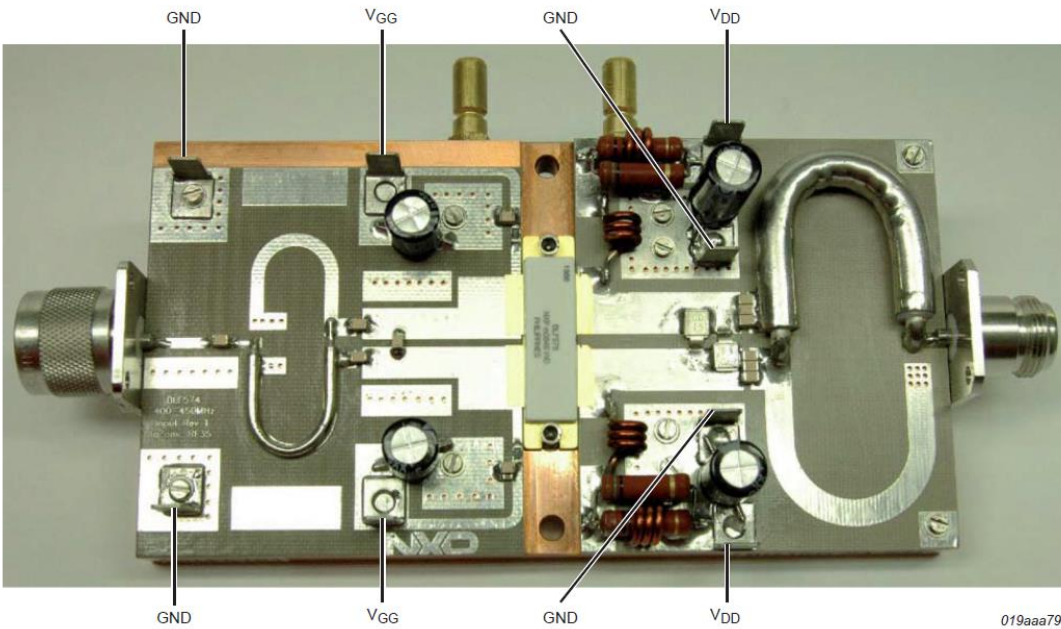
- No presurization and ferrite dummy loads
- Power Distribution at 3 levels
 - Half height WR2300: 400kW
 - 6-1/8 inch, $50\ \Omega$ coax: 200 kW
 - 7/8 inch, $50\ \Omega$ coax: 10 kW
- Pre amp. Efficiency: 50 - 55 % (class AB)
- Amp. Efficiency > 67 % (class AB)

TH 595

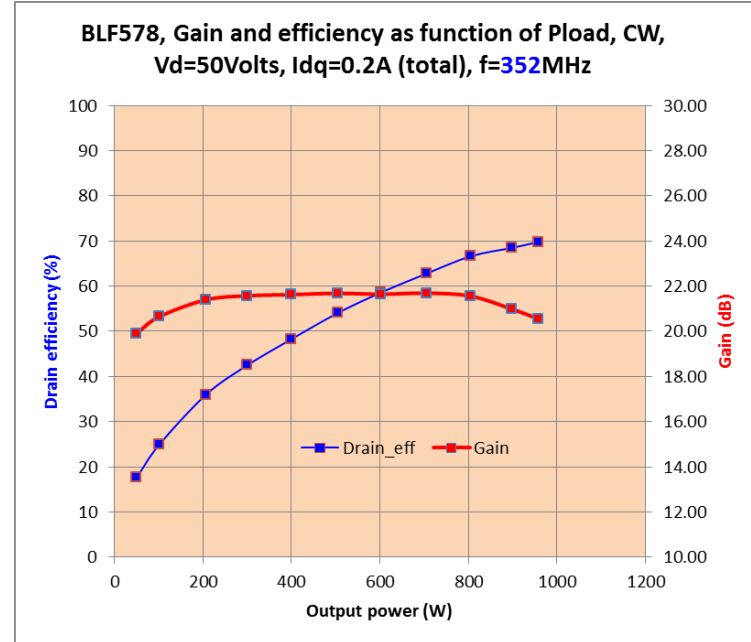


High power RF Distribution:



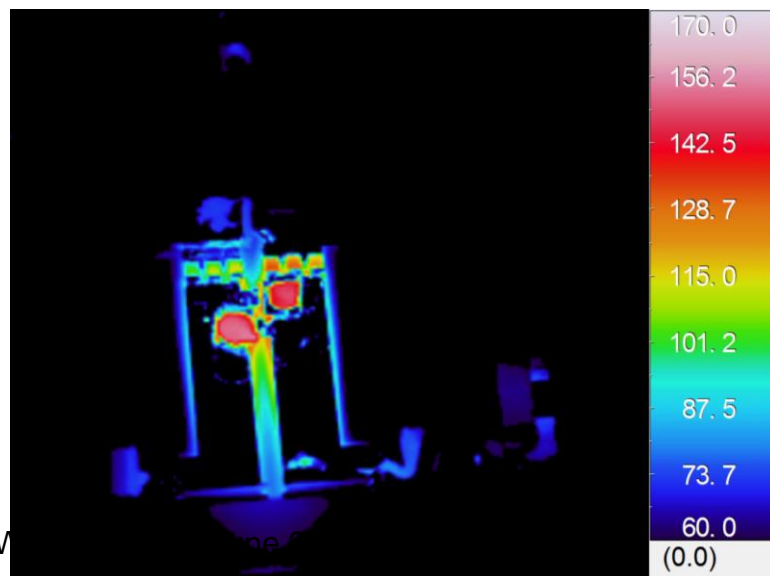


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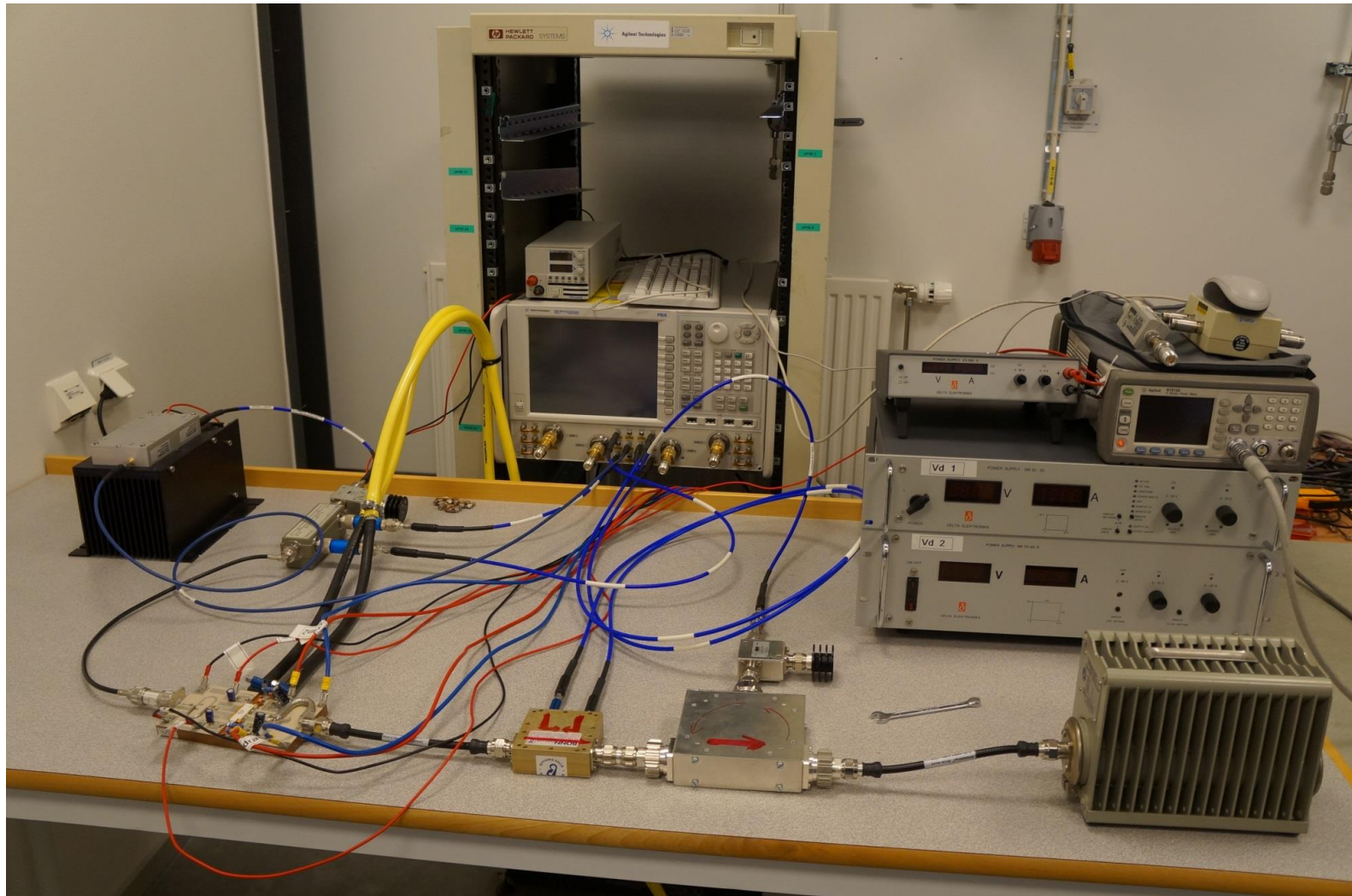
AN10967 is a demo board designed and manufactured by NXP for the BLF578 LDMOS transistor.

- push-pull configuration, class AB
- delivering 1000 W in CW
- Max efficiency: 70%
- Gain: 20 dB
- Highest temp spot: 145C (15l/min water)

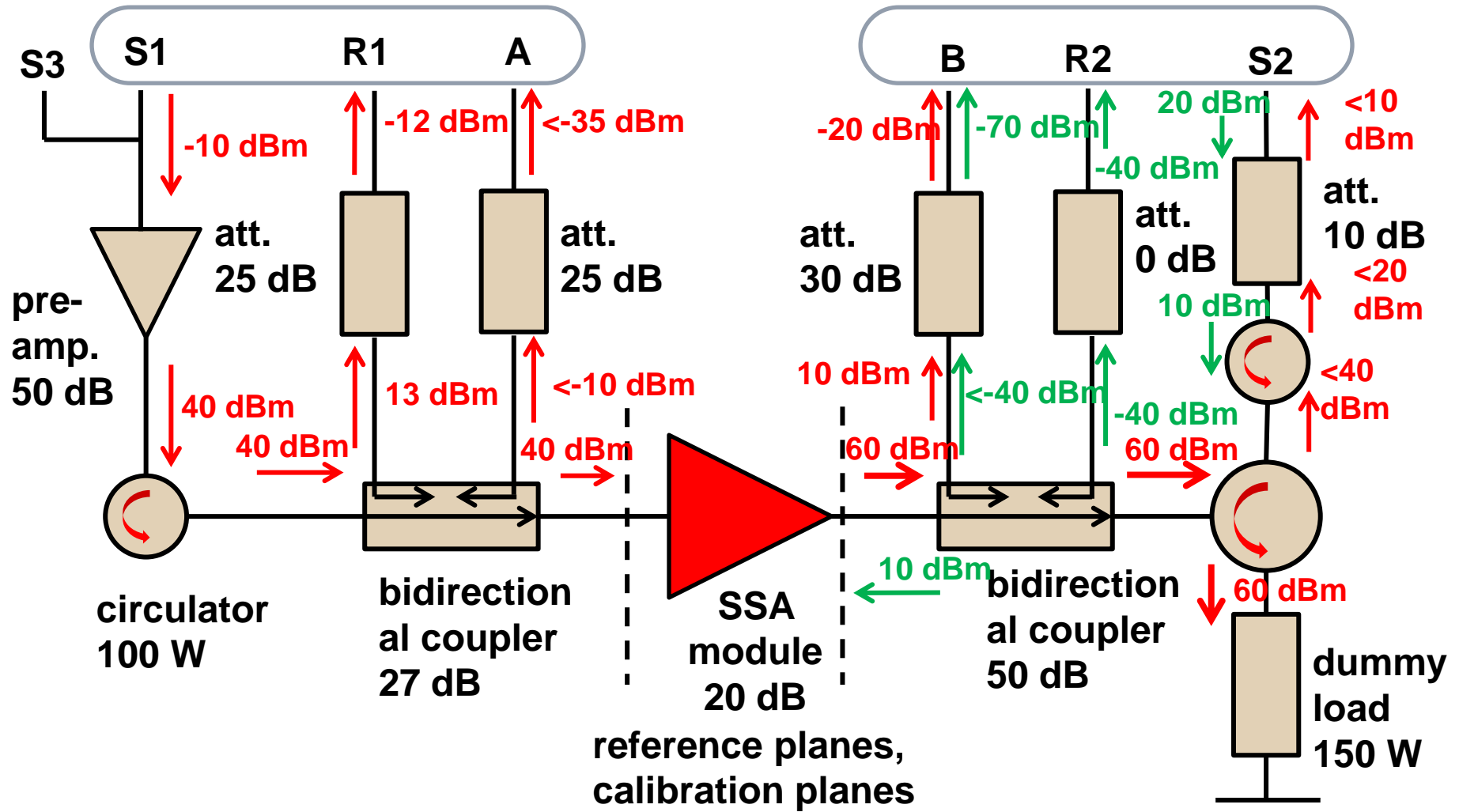




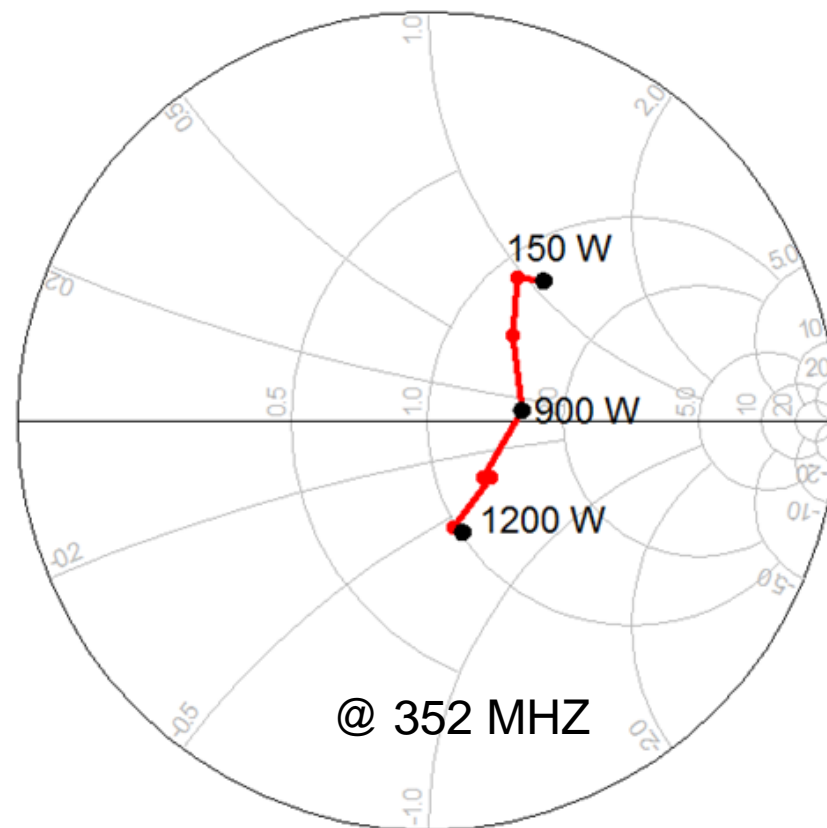
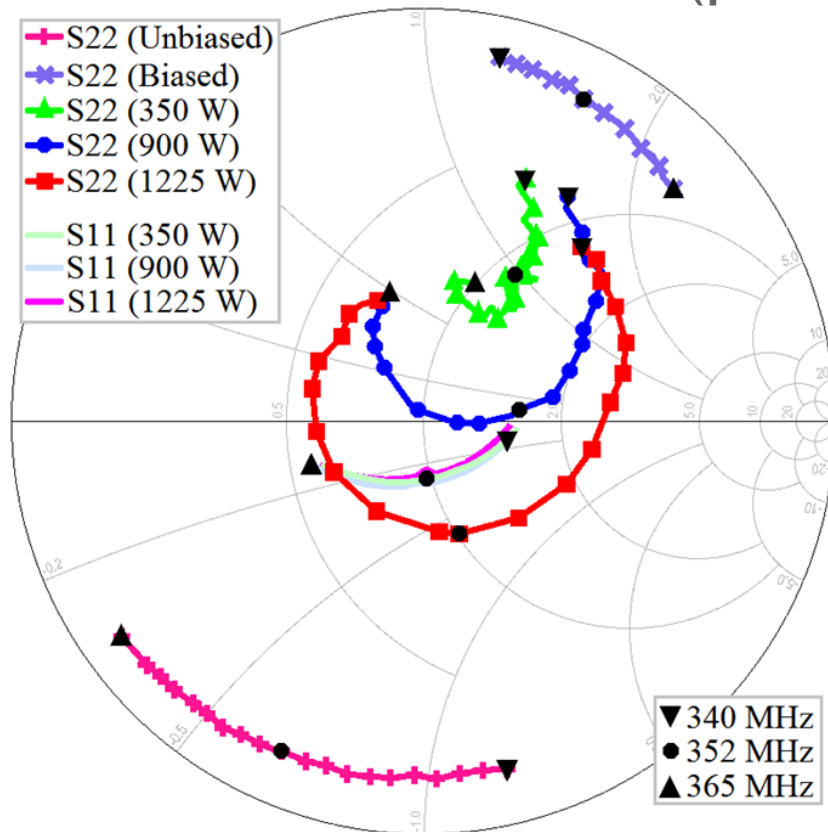
1kW level Hot S-parameters measurements (pulsed)



1kW level Hot S-parameters measurements (pulsed)



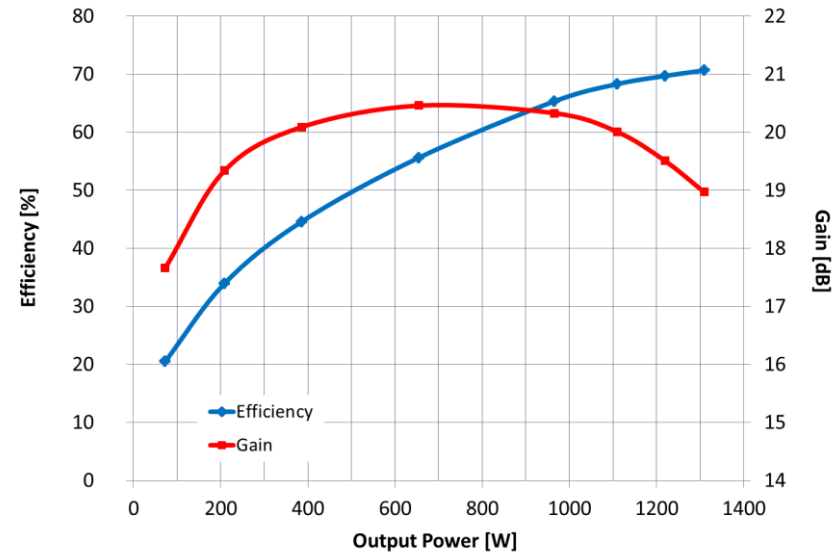
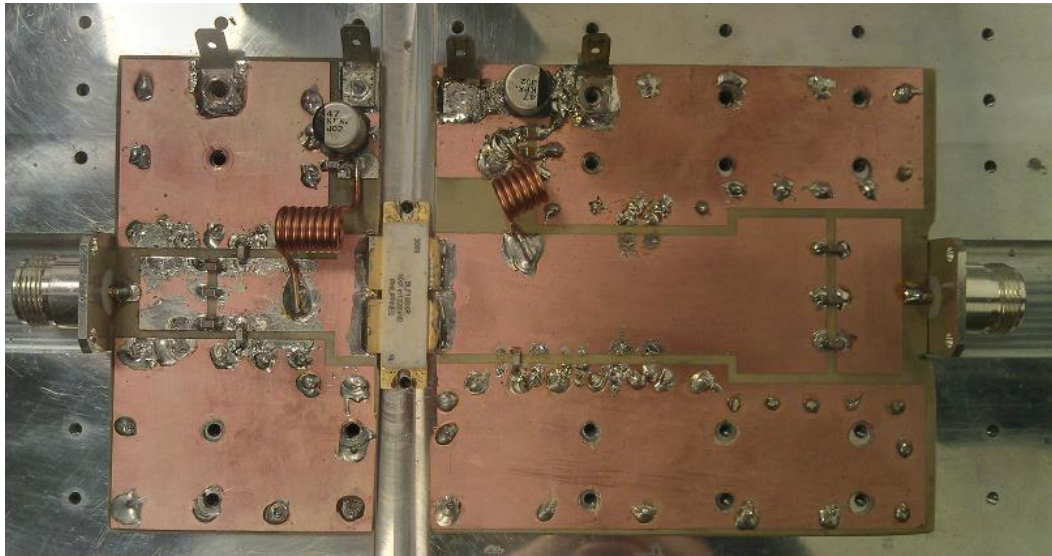
1kW level Hot S-parameters measurements (pulsed)



- Using Hot S-parameters measurements we can characterize the output impedance at different output power levels.
- The impedance is changing quite dramatically with the output power and this needs to be taken in to account for power combination.

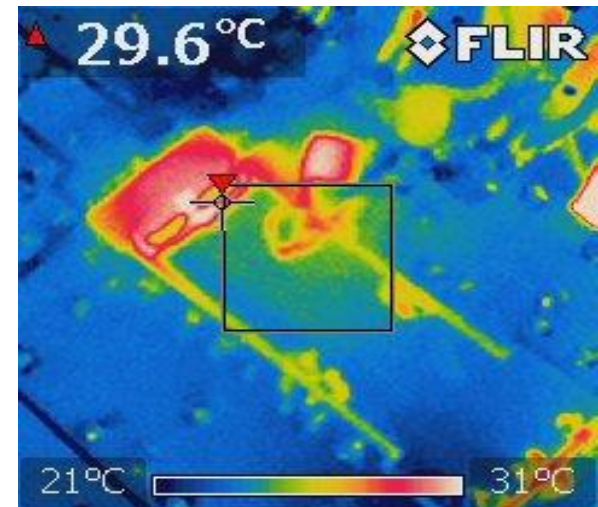
(BLF578 measurements realized in pulsed mode with ESS parameters)

SSA development at UU: single ended RF power amplifier – 1250 W and 70% efficiency

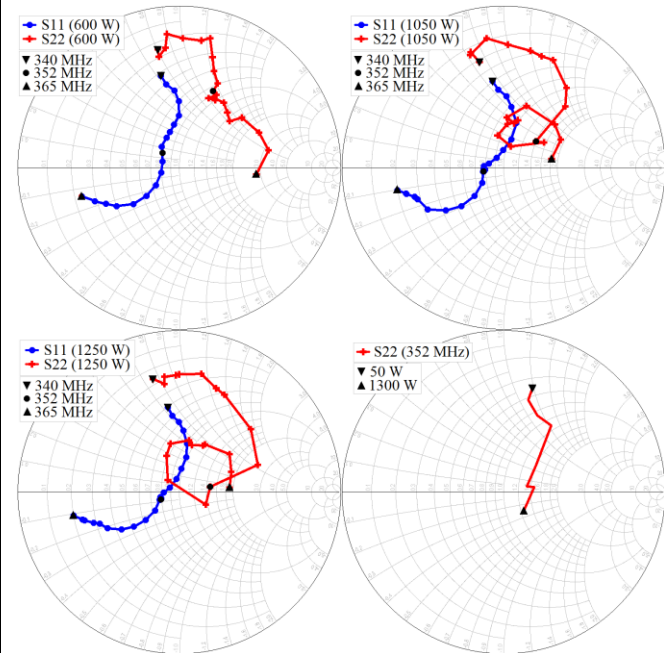
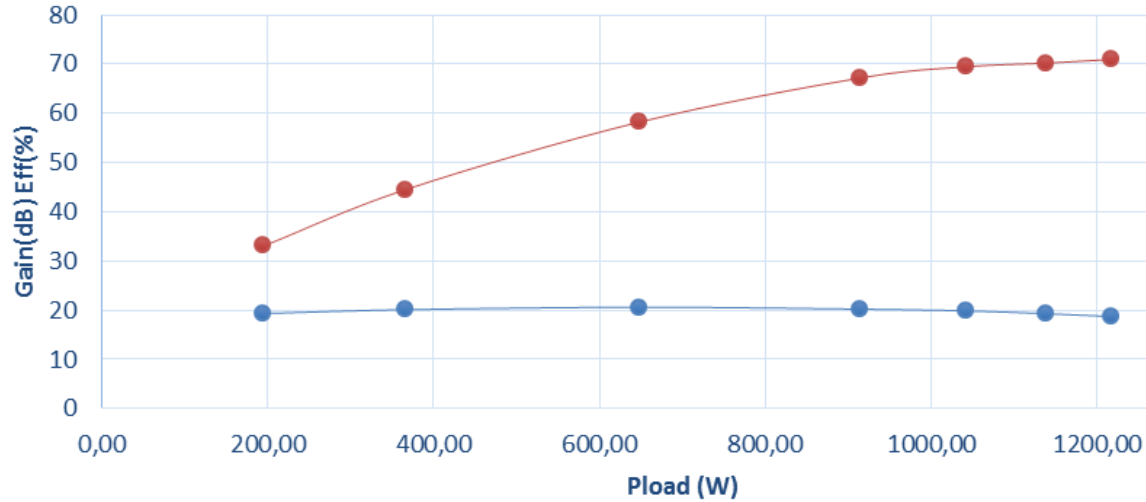
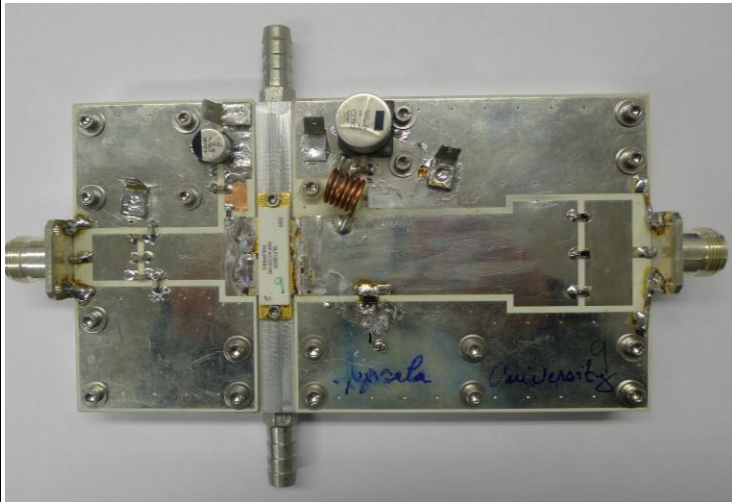
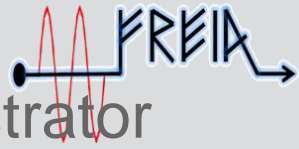


Tested in pulsed mode with ESS characteristics (14 Hz, 3.5 ms) delivering up to 1300 W.

- BLF188XR - excellent ruggedness
- Max efficiency: 71%
- Gain: 19 dB (at 1.5 dB compression)
- Highest temp spot: 30 °C (15l/min water)
- Excellent nonlinear behavior: second harmonic at -34dBc - no balun



Single ended RF power amplifier – 1250 W and 70% efficiency – 8 amplifiers for 10 kW demonstrator

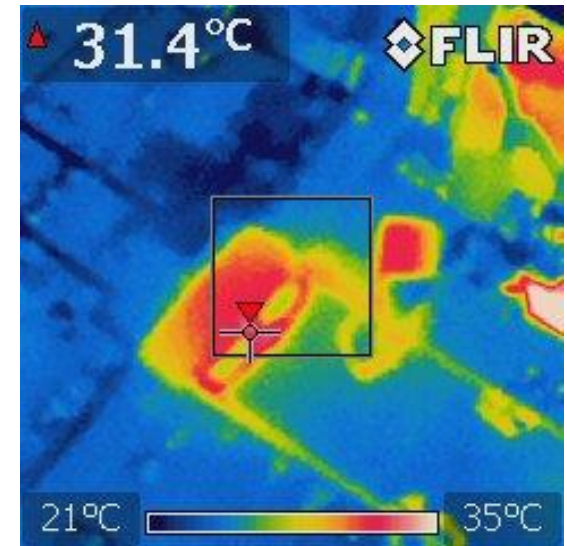


quiescent drain current, $I_{Dq}=0.1$ A and drain voltage, $V_{DS}=50$ V.

temperature rises for only few degrees, to about 30°C

Hot S-parameters measured at different output power at 352MHz

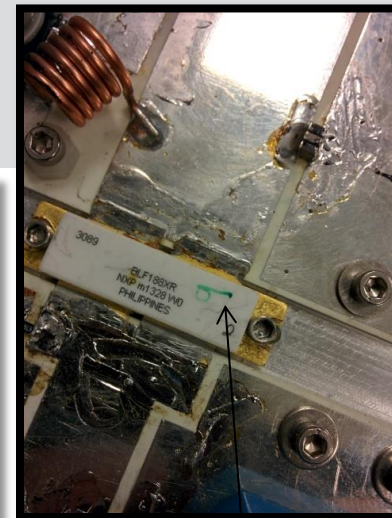
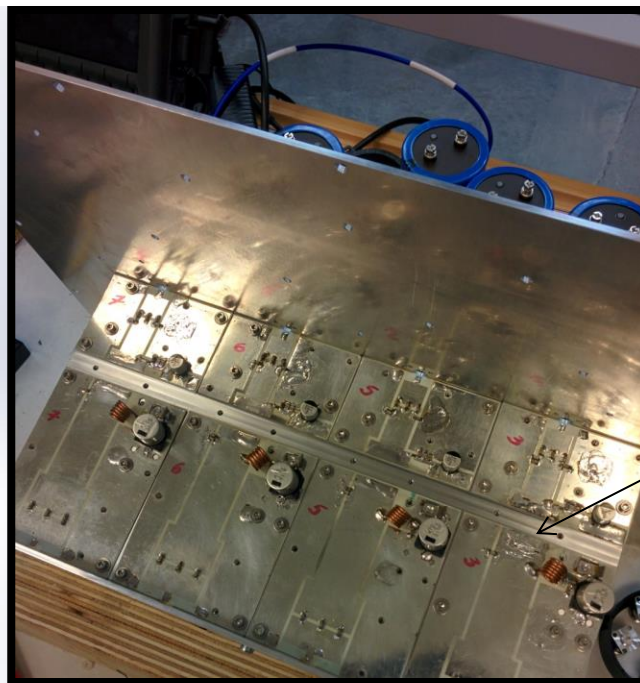
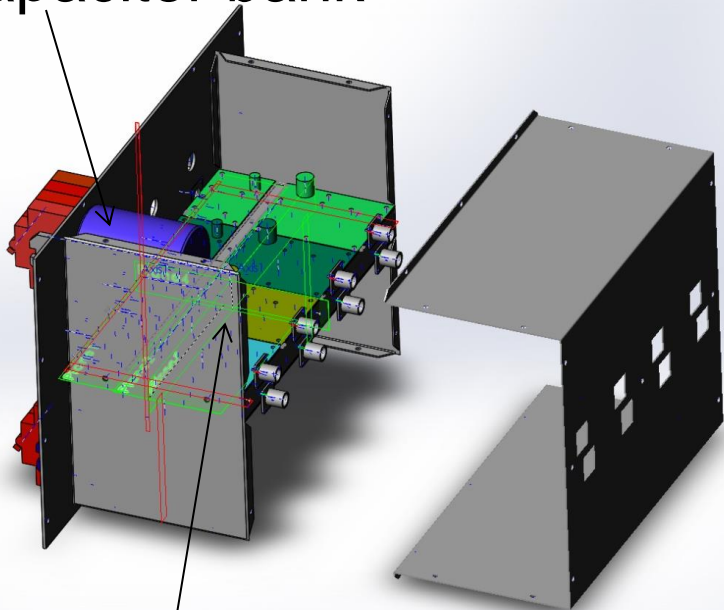
● Gain ● Drain_eff





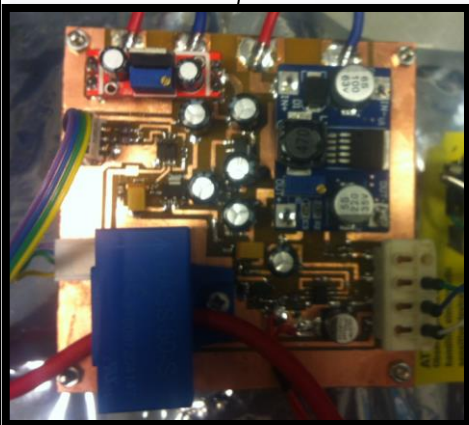
10 kW – SSA demonstrator

capacitor bank



8 x 1.25 kW

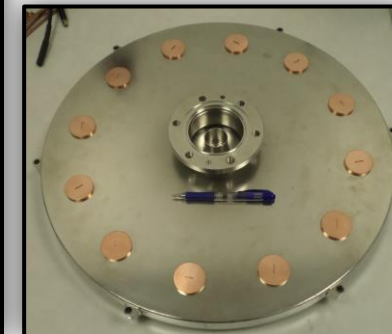
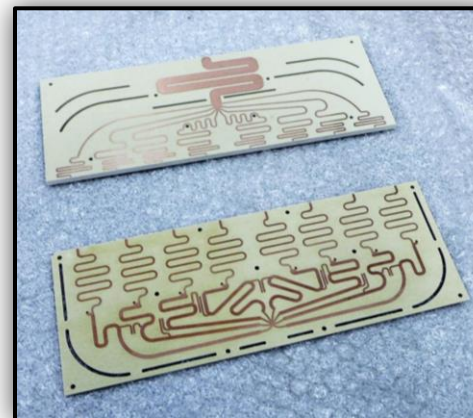
Combiners
Planar and WG



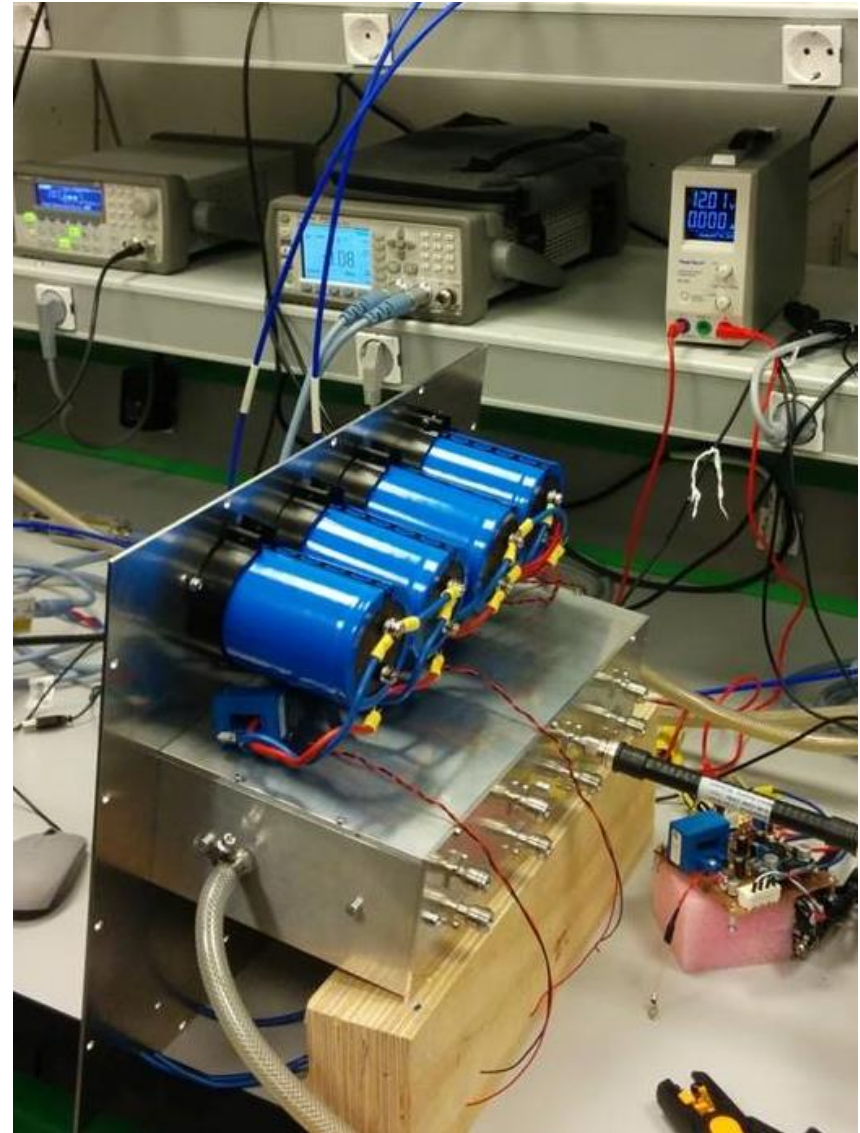
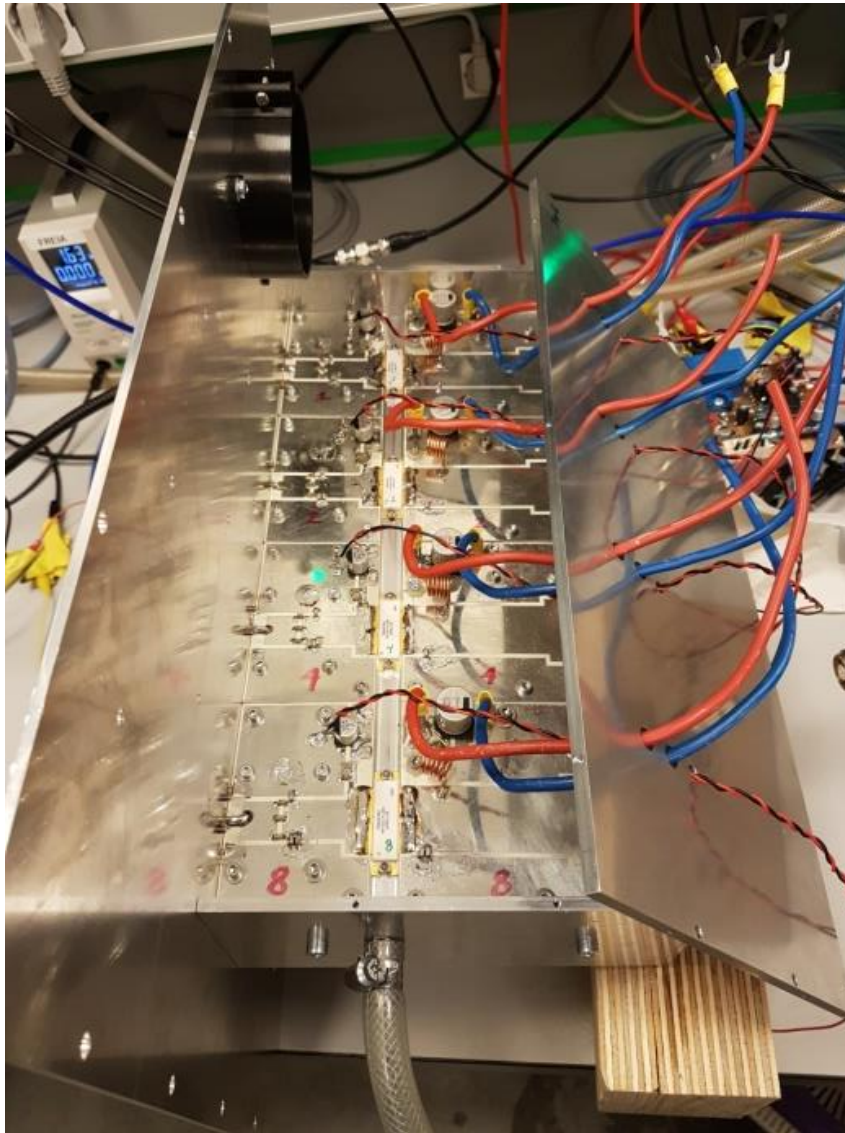
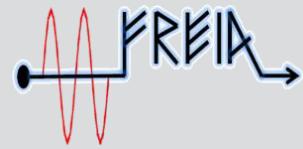
Monitoring circuits:

- drain voltage
- drain current
- temperature

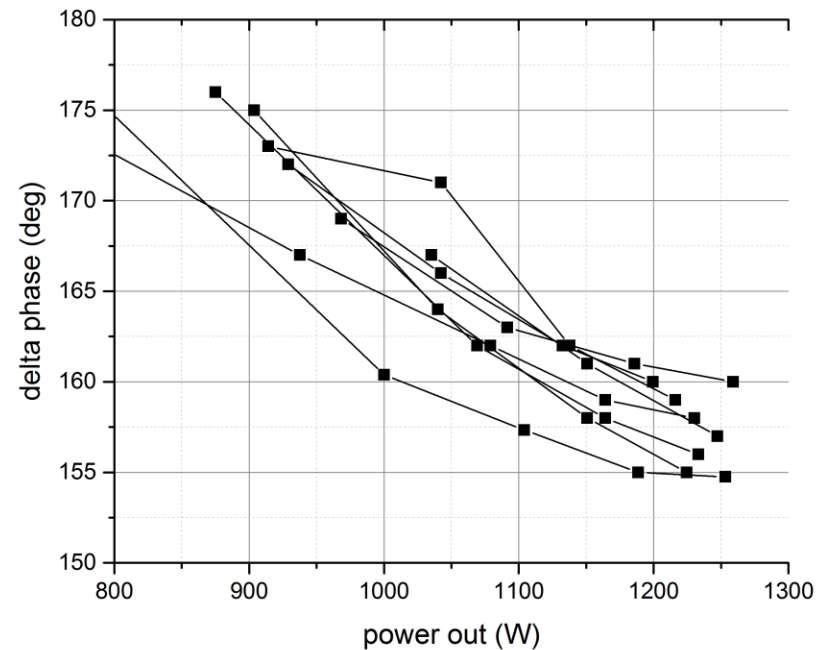
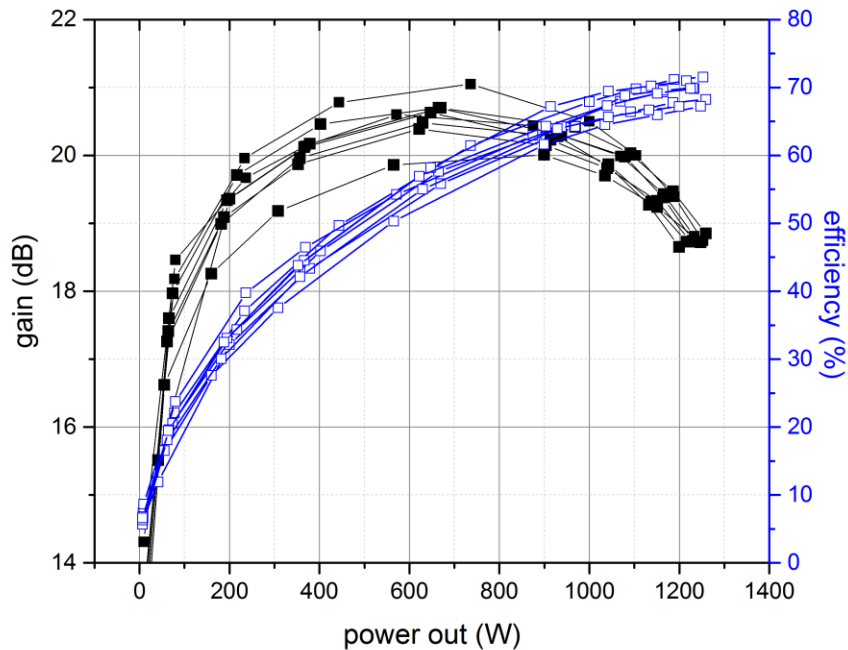
See talk "Time domain characterization of high RF pulsed power solid state amplifiers for linear accelerators"



10 kW amplifier under construction



Drain, efficiency and phase of the 8 modules of the 10 kW amplifier demo



A small variation in both gain (< 0.5 dB) and phase ($< 5^\circ$) is measured for the 8 modules of the 10 kW demonstrator.

Efficiency is around 70% at 1250 W (pulsed conditions 14 Hz, 3.5 ms)

Phase measurements performed using the hot S-parameters set-up.

- A single ended high RF power Solid-State Amplifier was successfully designed and manufactured producing 1.25 kW with an efficiency of 70% at 352 MHz, in ESS operational mode (14 Hz, 3.5 ms). This is a simple and robust design minimizing manufacturing cost towards mass fabrication and industrialization. Joint UU - Ampleon application note.
- Measurement methods have been developed and implemented allowing hot S-parameters measurements.
- A 10 kW demonstrator, using 8 modules is presently under fabrication at FREIA. Monitoring circuits and power combiners are under development.
- A small variation in both gain (< 0.5 dB) and phase ($< 5^\circ$) is measured for the 8 modules of the 10 kW demonstrator under construction at FREIA.
- Strategy for the near future: highly efficient class E amplifiers at 750 MHz (for medical RFQ – CERN); 100 MHz for GE's cyclotron - nucleotides production; possibly 400 MHz (for CERN crab cavity); back-to-back test of 100 kW combiner using one RF station); development of Latch-Free LIGBT/IGBT high power transistors at UU – Comheat AB (compared with LDMOS, saturation current is 15-30 times higher).

Joint UU - Ampleon application note on BLF188XR's site





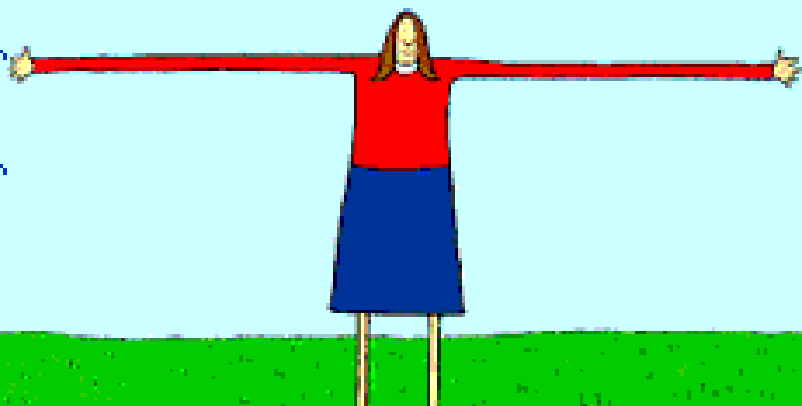
THANKS

For the warm welcome!

t h i s m u c h !

For Listening.....

Questions?



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