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eurostars™

SSPA research activities at FREIA and the Eurostars ENEFRF project

Dragos Dancila on behalf of the FREIA group

June 19, 2018

ARIES Workshop on Energy Efficient RF

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Overview

- Short review of SSPA activities at FREIA
- ENFRF project

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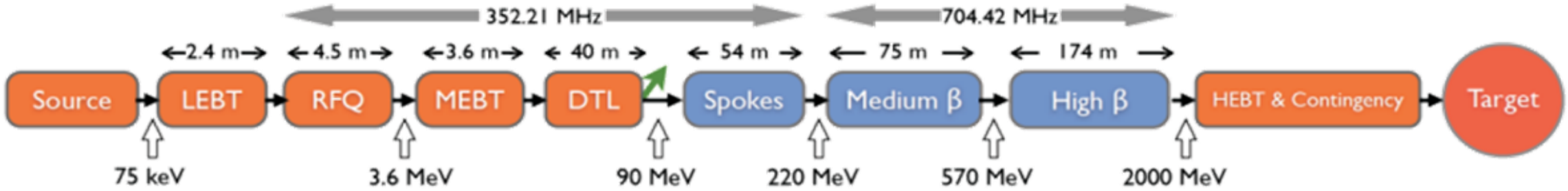
- ENFRF project

Testing prototype superconducting accelerating cavities & RF high power amplifier development

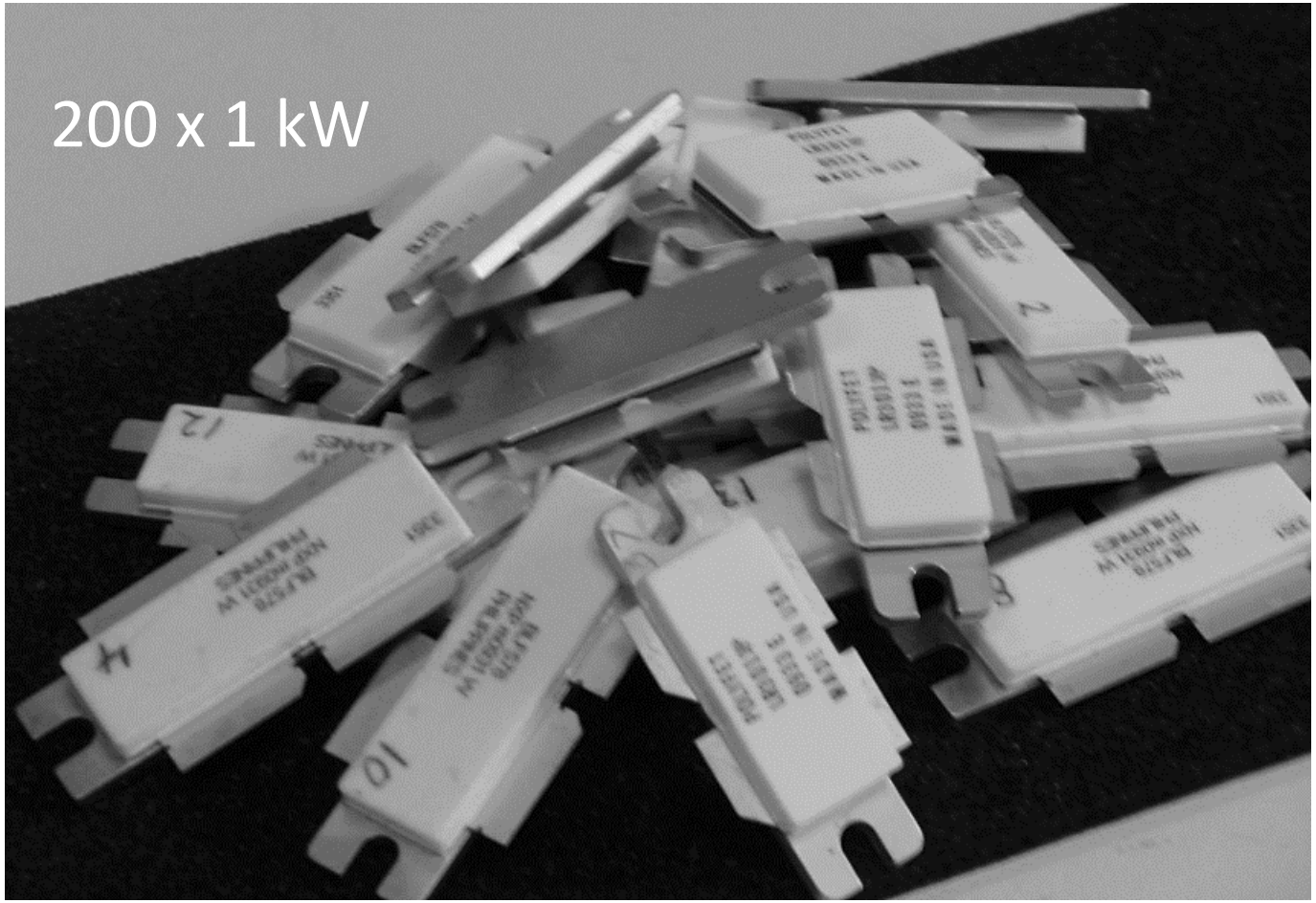
LINAC at ESS :



EUROPEAN SPALLATION SOURCE

superconducting accelerating cavities (26 SC spokes in final LINAC), cryomodules and high power RF stations, development of high power RF stations at ESS specifications **352.21 MHz, 400 kW, 14 Hz, 3.5 ms, 200 kHz bandwidth**

It takes a handful of transistors (200) to replace one tetrode



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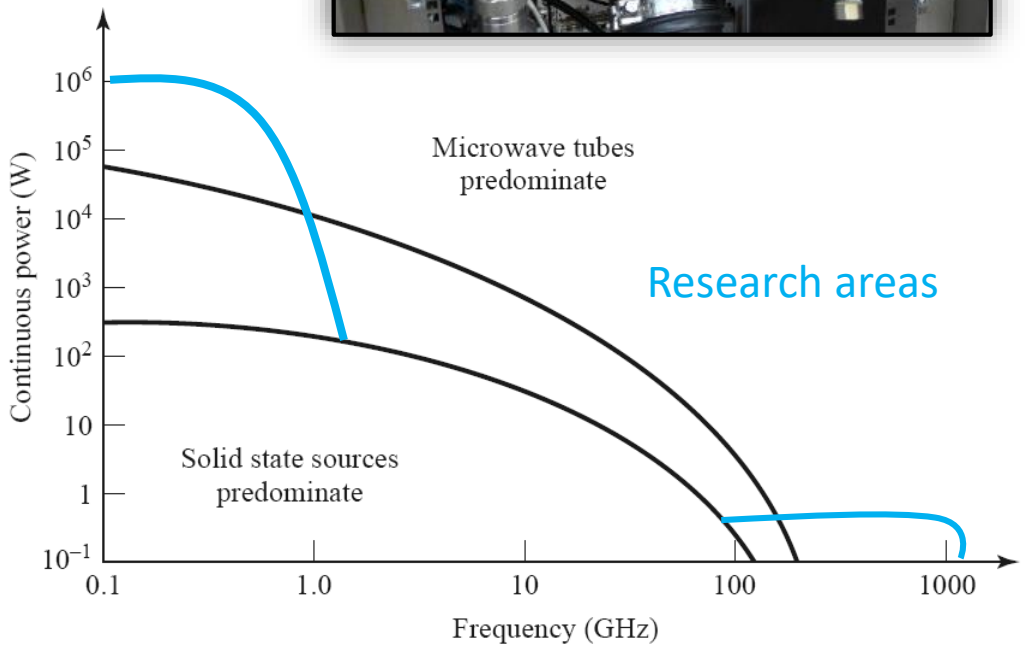
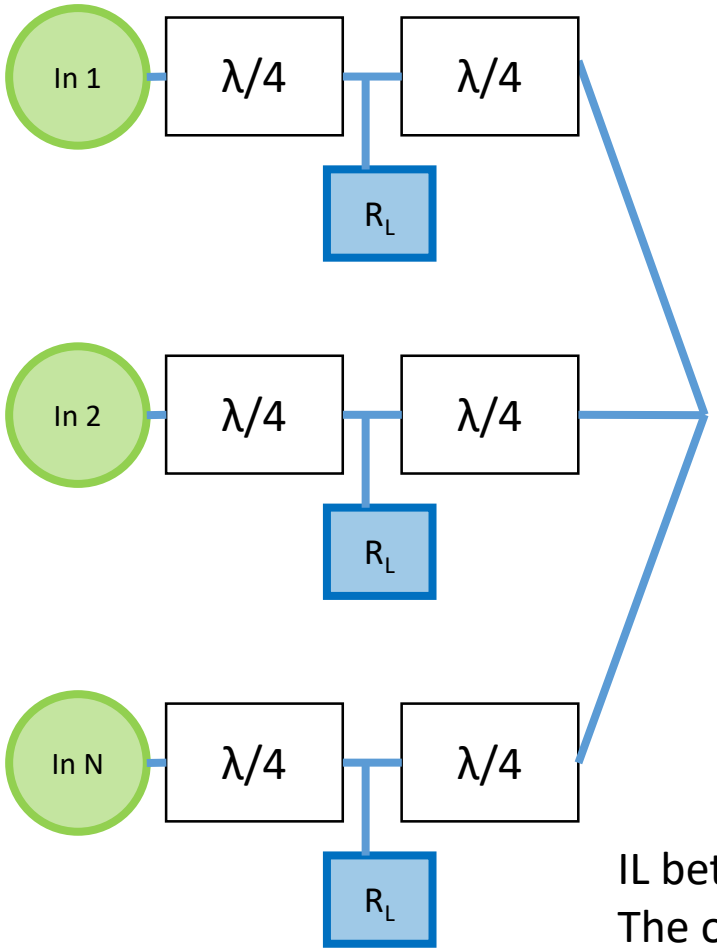


10 kW planar Gysel combiner (352 MHz)



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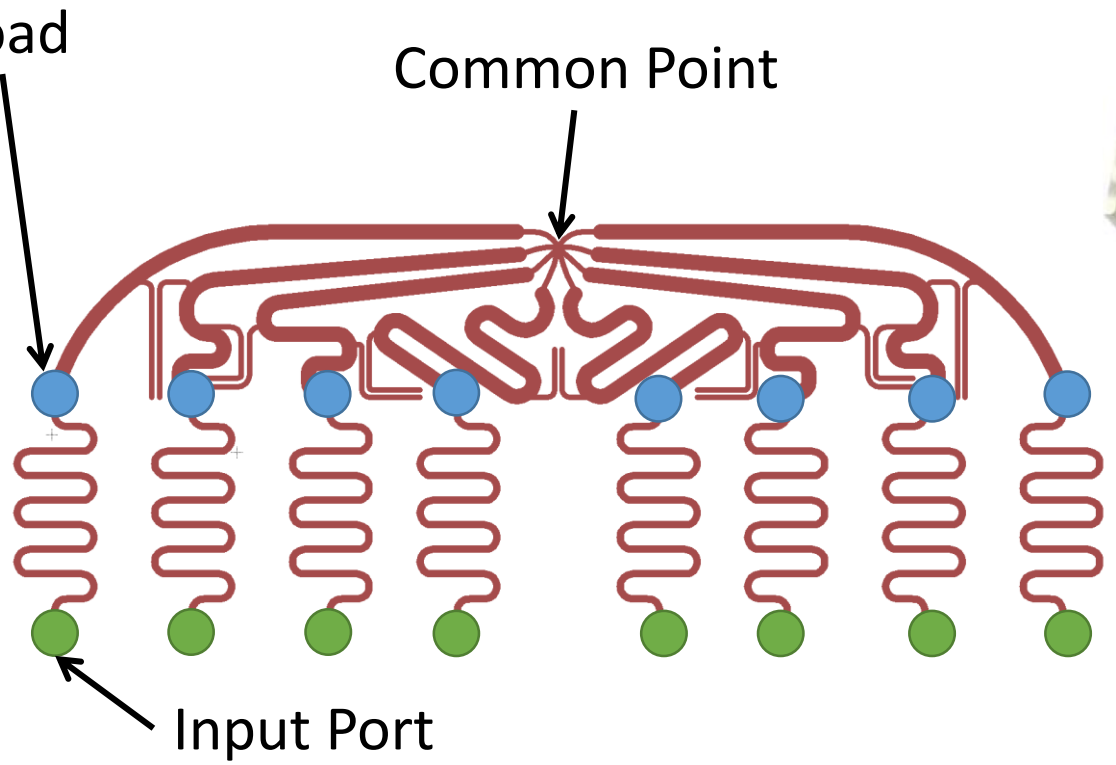
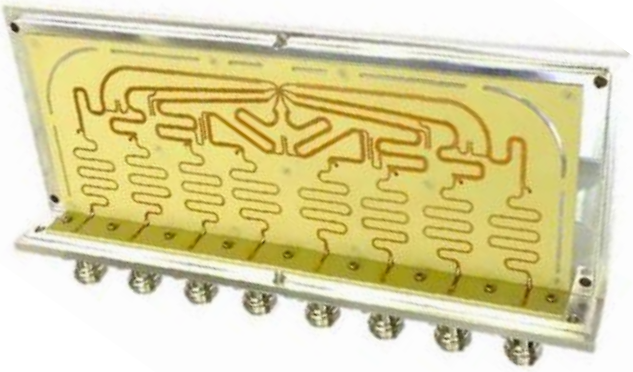
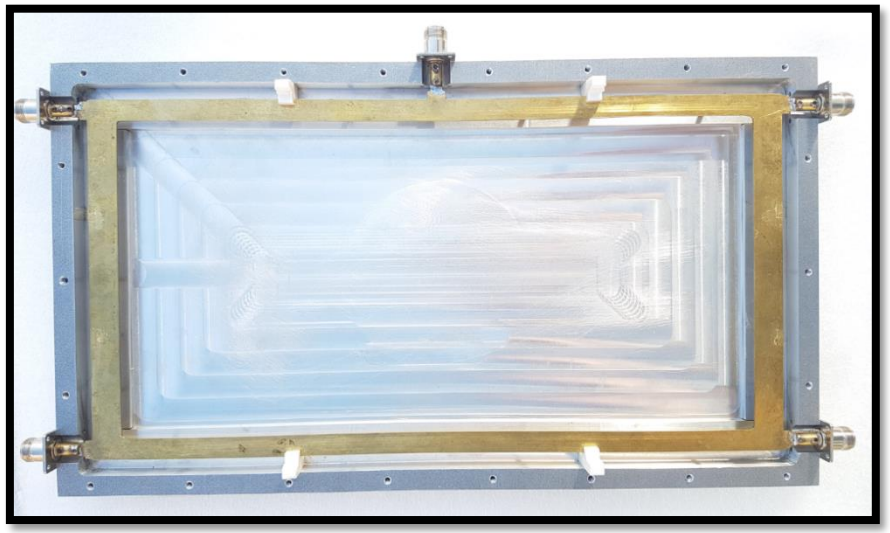


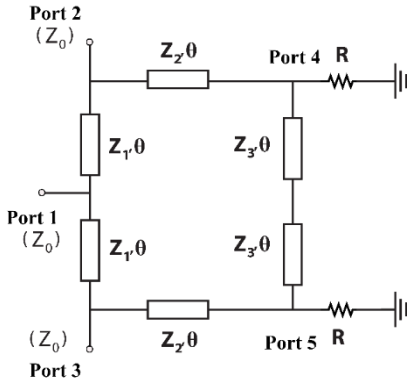


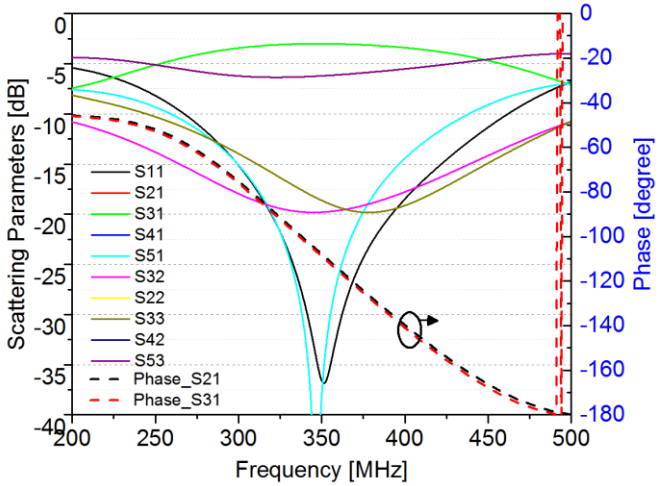
IL between 0.3 and 0.2 dB over 100-MHz bandwidth
The output matching is at –20-dB

M. Jobs, D. Dancila, J. Eriksson and R. Ruber, ”A 8-1 Single Stage 10 kW Planar Gysel Power Combiner at 352 MHz,” IEEE Trans. on Components, Packaging and Manufacturing Technology, , vol. 8, no. 5, pp. 851-857, May 2018.

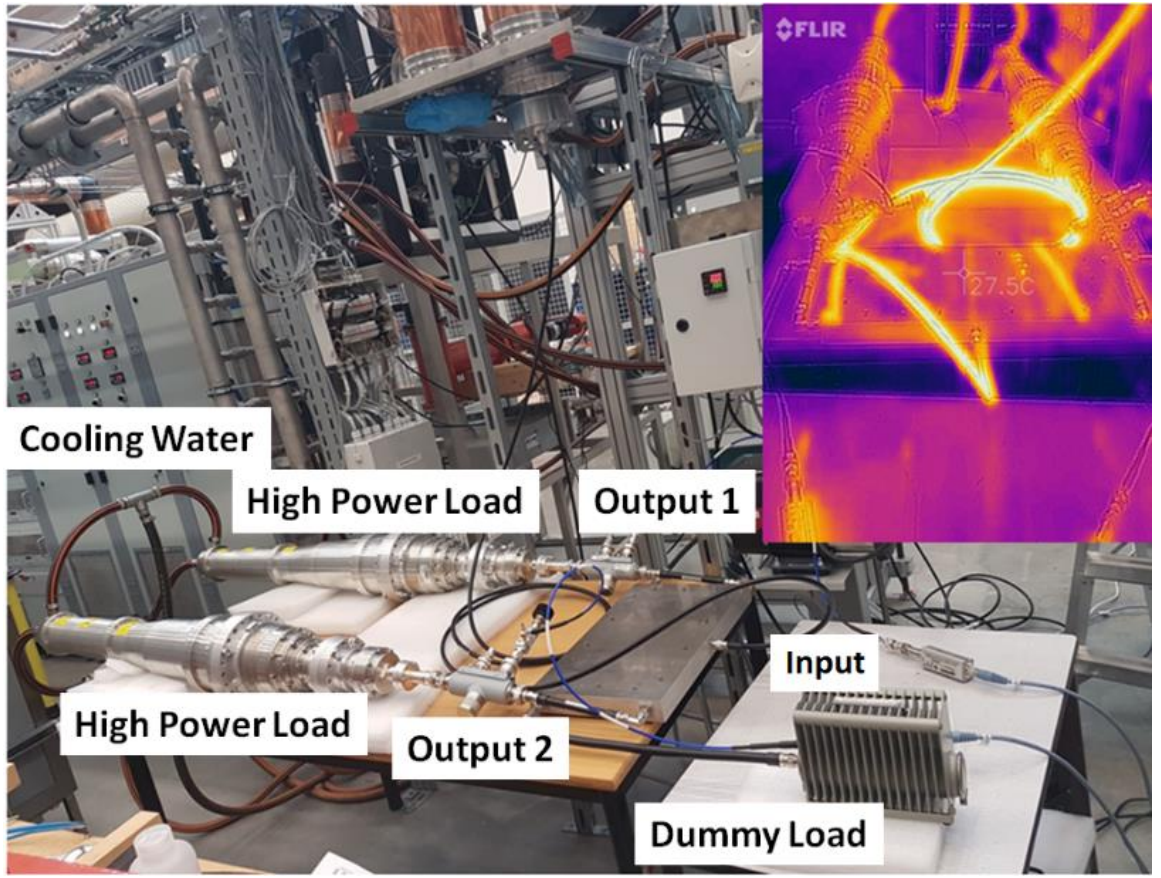
20 kW Gysel combiner (352 MHz)





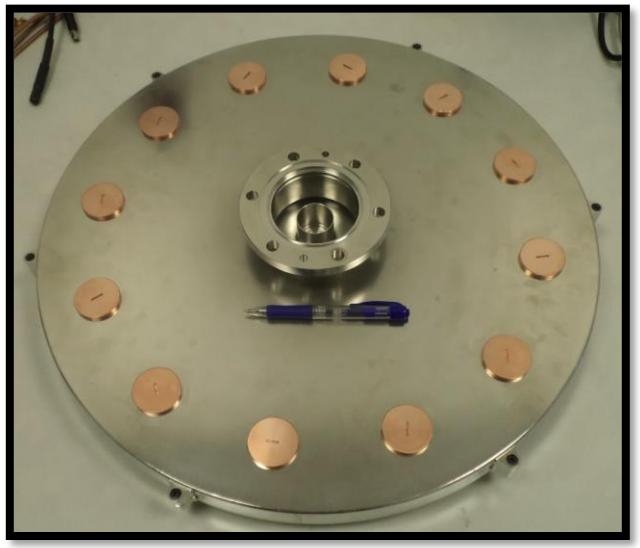


Tested up to 20 kW
IL 0.1 dB

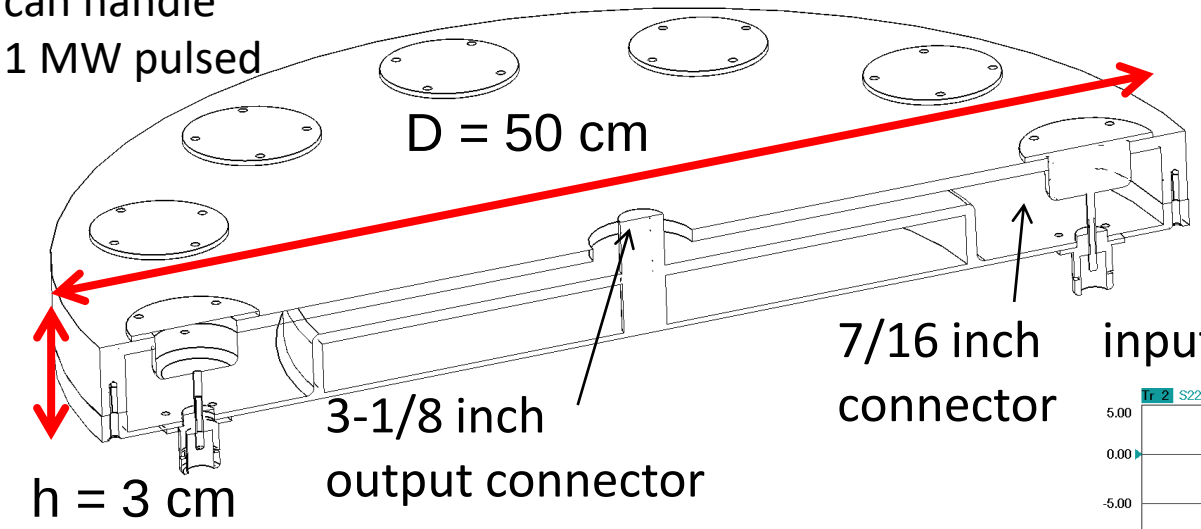


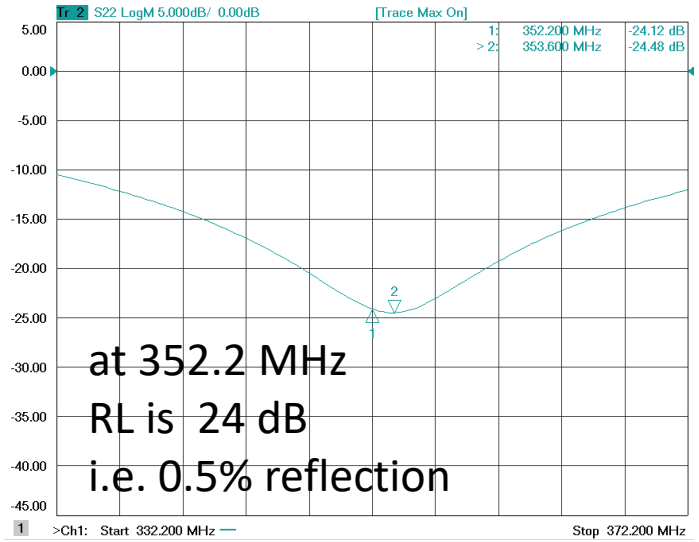
L. Hoang Duc et al., “A new high-power low-loss air-dielectric stripline Gysel divider/combiner for particle accelerator applications at 352 MHz,” 2017, Journal of Engineering.

100 kW non-resonant power combiner with door-knob couplers (352 MHz)

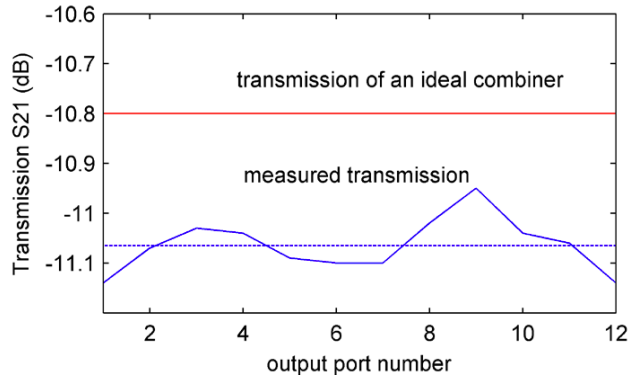


can handle
1 MW pulsed





at 352.2 MHz
RL is 24 dB
i.e. 0.5% reflection

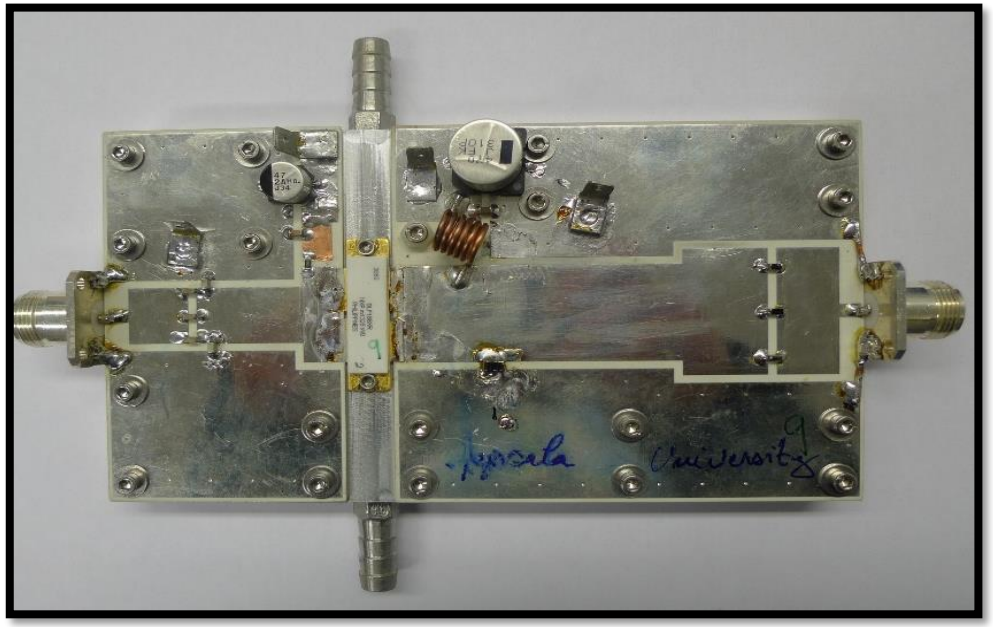


at 352.2 MHz
IL is 0.3 dB i.e. 6% losses

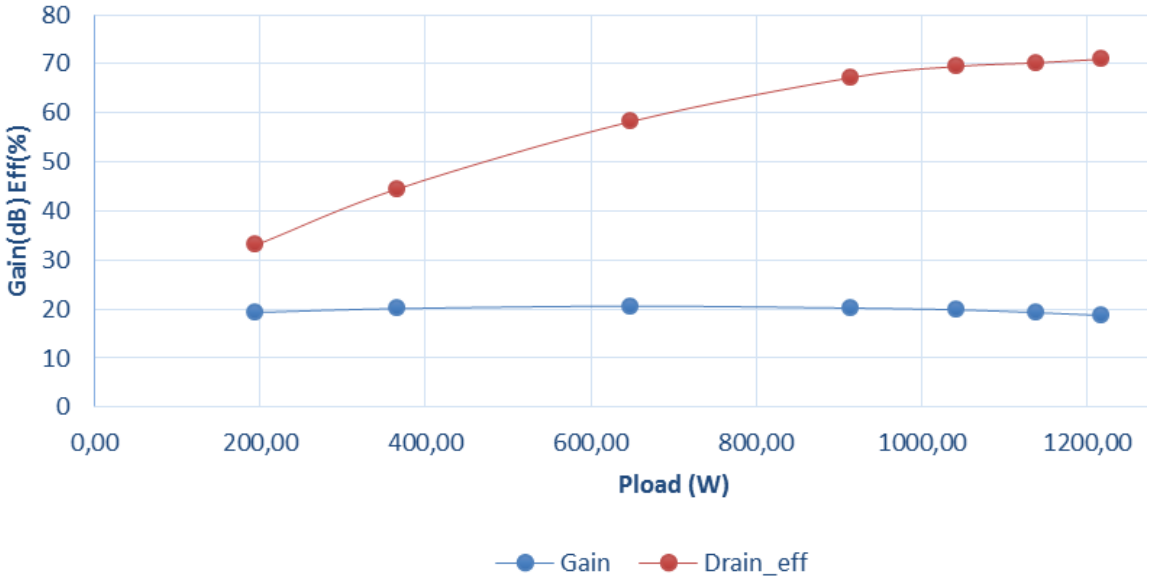
See poster outside

V. A. Goryashko, D. Dancila, A. Rydberg, R. Yogi & R. Ruber (2014): A megawatt class compact power combiner for solid-state amplifiers, Journal of Electromagnetic Waves and Applications.

Single ended RF power amplifier – 1250 W and 70% efficiency at 352 MHz

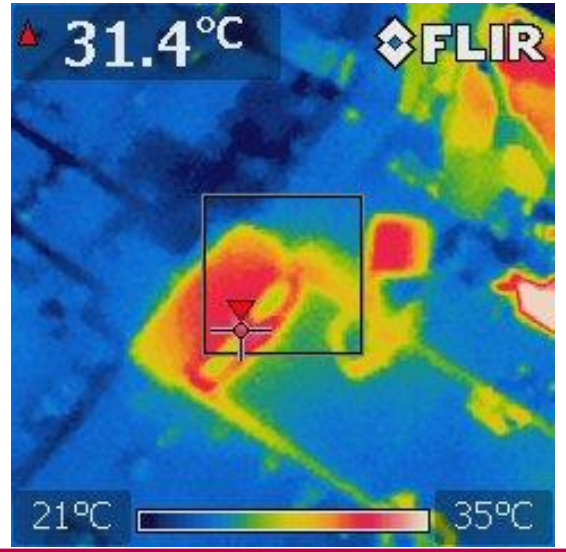


L. Haapala, A. Eriksson, L. D. Hoang and D. Dancila, “Kilowatt-level power amplifier in a single-ended architecture at 352 MHz,” 2016, Electronics Letters, Vol. 52, no 18, p.1552-1553.

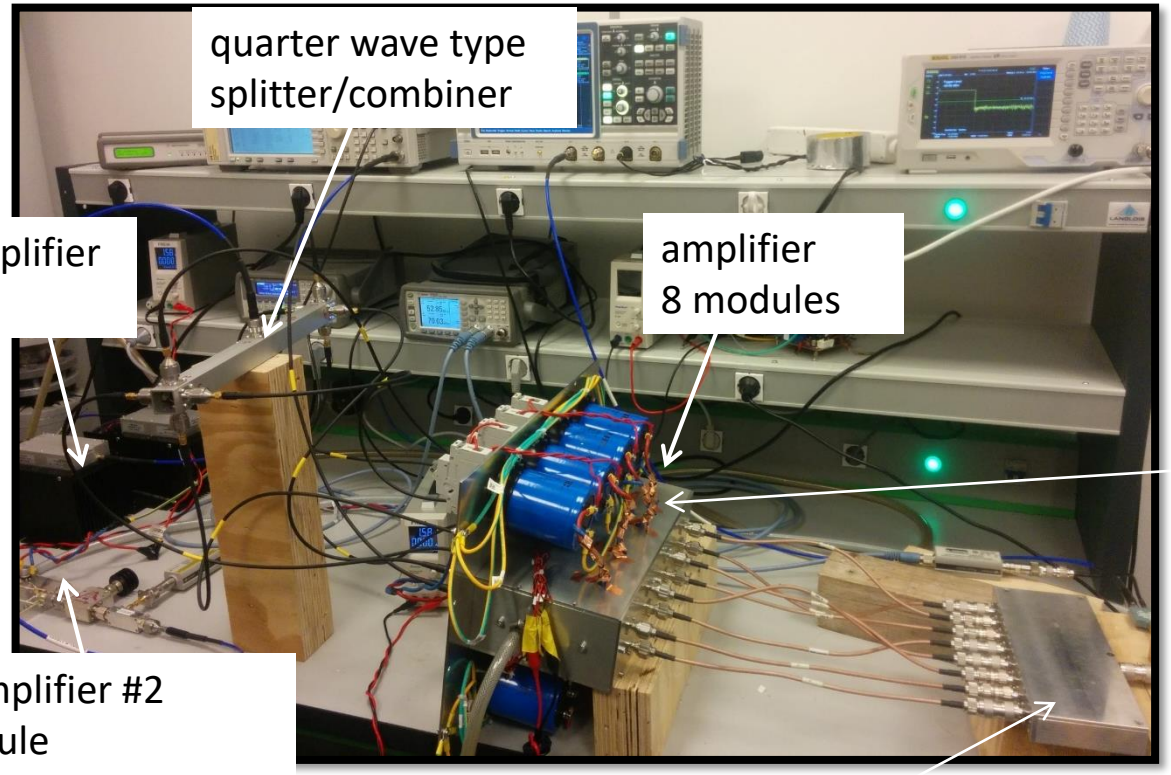


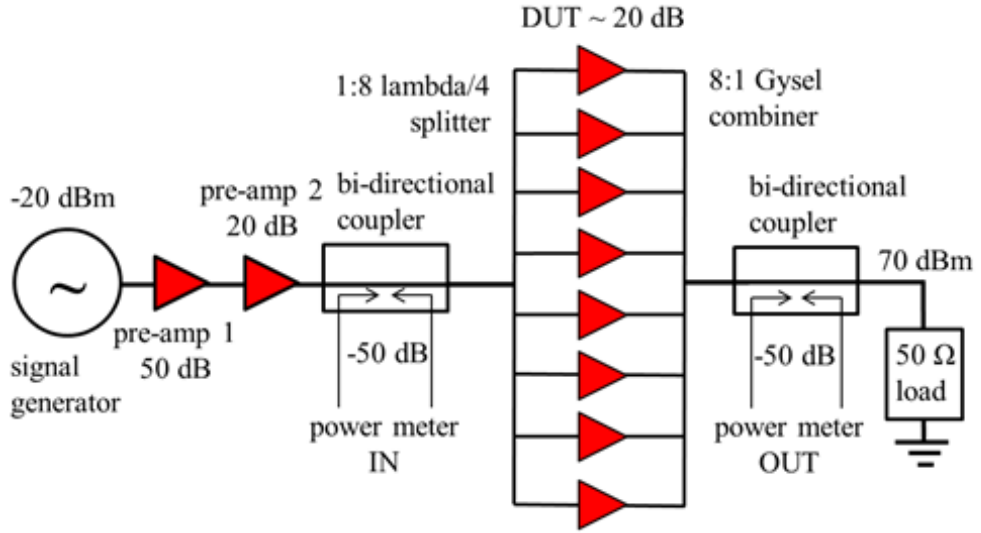
quiescent drain current, I_{Dq}=0.1 A and drain voltage, V_{DS}=50 V.

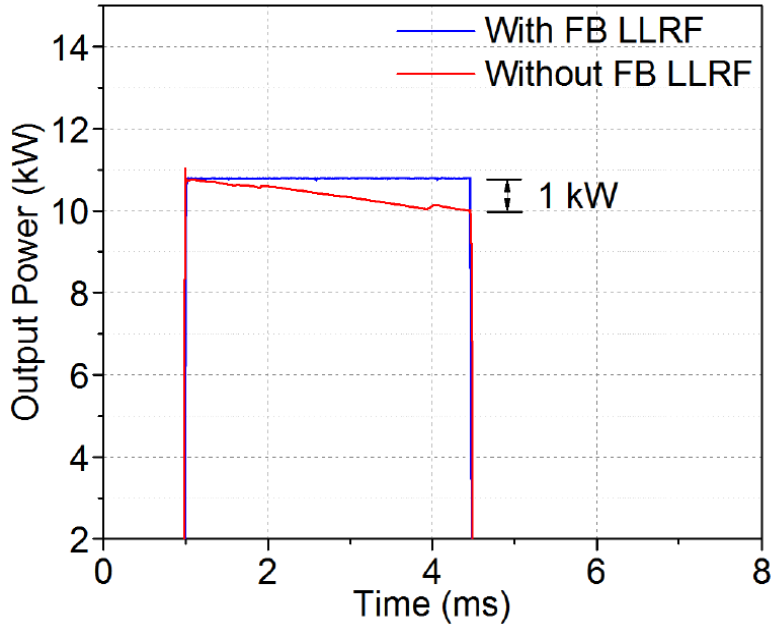
temperature rises for only few degrees, to about 30°C



10 kW SSPA power amplifier at 352 MHz







D. Dancila et al, "A compact 10 kW solid-state RF power amplifier at 352 MHz," 2017 IOP Conf. Series: Journal of Physics: Conf. Series, vol. 874

Energy efficient charging of ESS superconductive cavity resonators with SSPA

Nuclear Instruments and Methods in Physics Research A 801 (2015) 78–85

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journal homepage: www.elsevier.com/locate/nima

Minimization of power consumption during charging of superconducting accelerating cavities

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IOT
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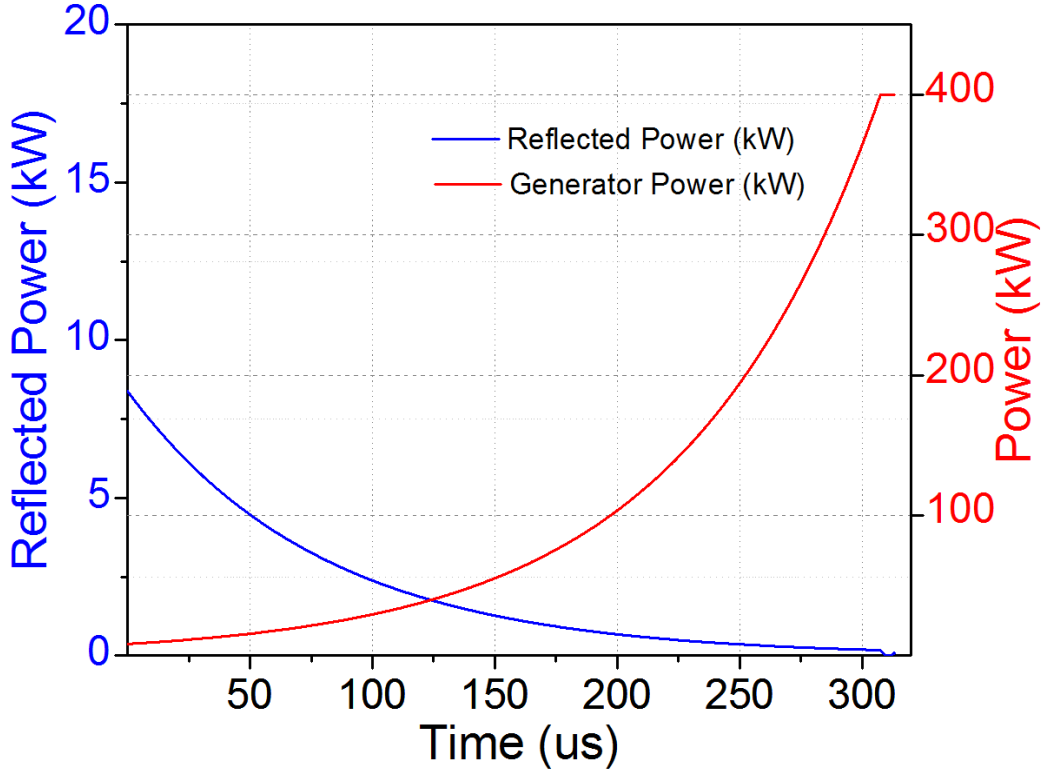
Doherty architecture
Solid-state

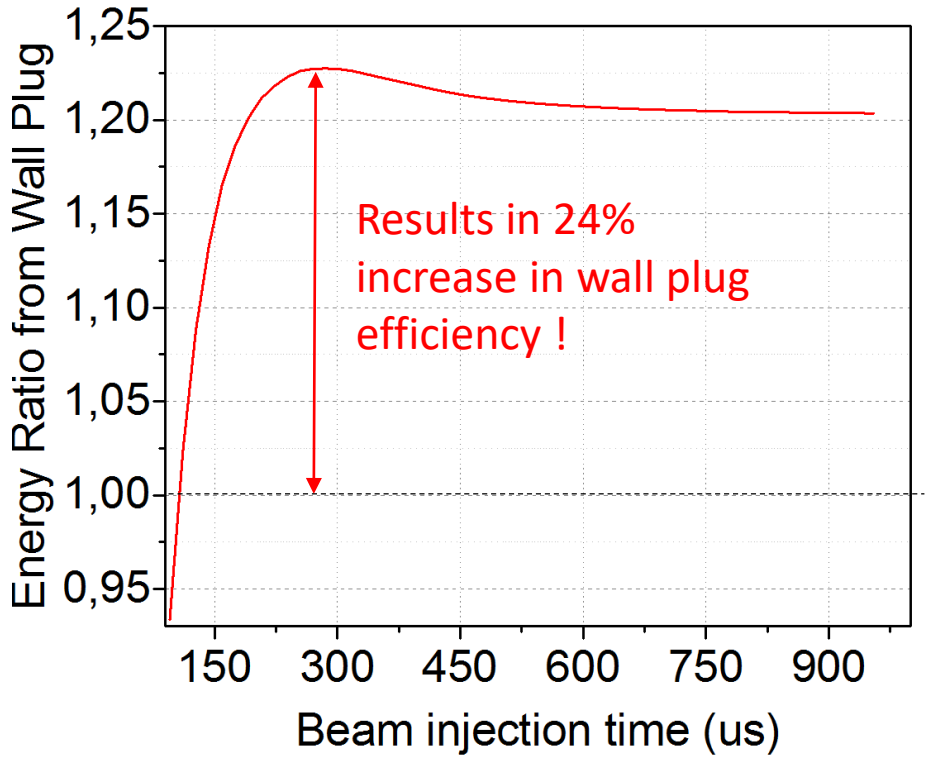
ABSTRACT

The radio frequency cavities, used to accelerate charged particle beams, need to be charged to their nominal voltage after which the beam can be injected into them. The standard procedure for such cavity filling is to use a step charging profile. However, during initial stages of such a filling process a substantial amount of the total energy is wasted in reflection for superconducting cavities because of their extremely narrow bandwidth. The paper presents a novel strategy to charge cavities, which reduces total energy reflection. We use variational calculus to obtain analytical expression for the optimal charging profile. Energies, reflected and required, and generator peak power are also compared between the charging schemes and practical aspects (saturation, efficiency and gain characteristics) of power sources (tetrodes, IOTs and solid state power amplifiers) are also considered and analysed. The paper presents a methodology to successfully identify the optimal charging scheme for different power sources to minimize total energy requirement.

We implemented this reference with SSPA.

Energy efficient charging of ESS superconductive cavity resonators with SSPA





Minimization of power consumption during charging of superconducting accelerating cavities A. K. Bhattacharyya, V. Ziemann, R. Ruber, and V. Goryashko Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 801:78-85, 2015.

Long at Swedish Microwave Conference, Lund. 2018 (first results) for IEEE Transactions on Microwave Theory and Techniques

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Overview

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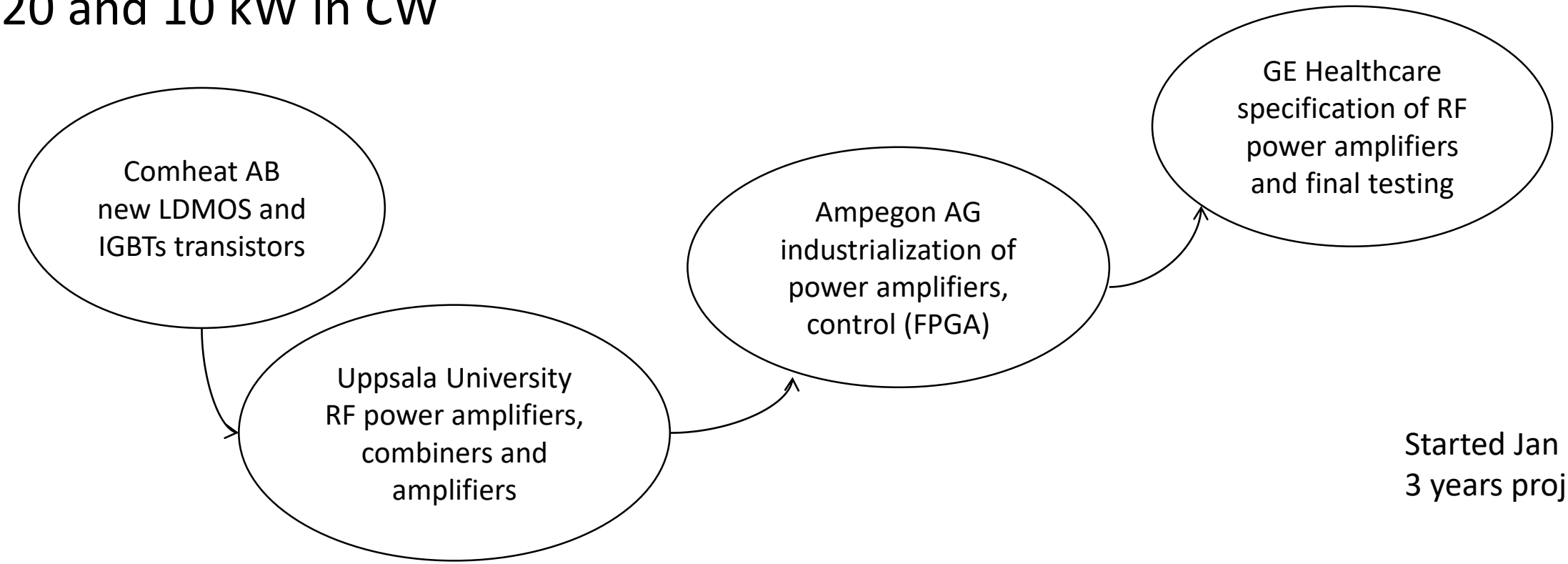
Purpose and goals – ENEFRF project

Develop the next generation RF-sources for isotope producing cyclotrons based on transistor technology at 27 and 101 MHz for 20 and 10 kW in CW



Started Jan 2018
3 years project

Positron Emission Tomography (PET)

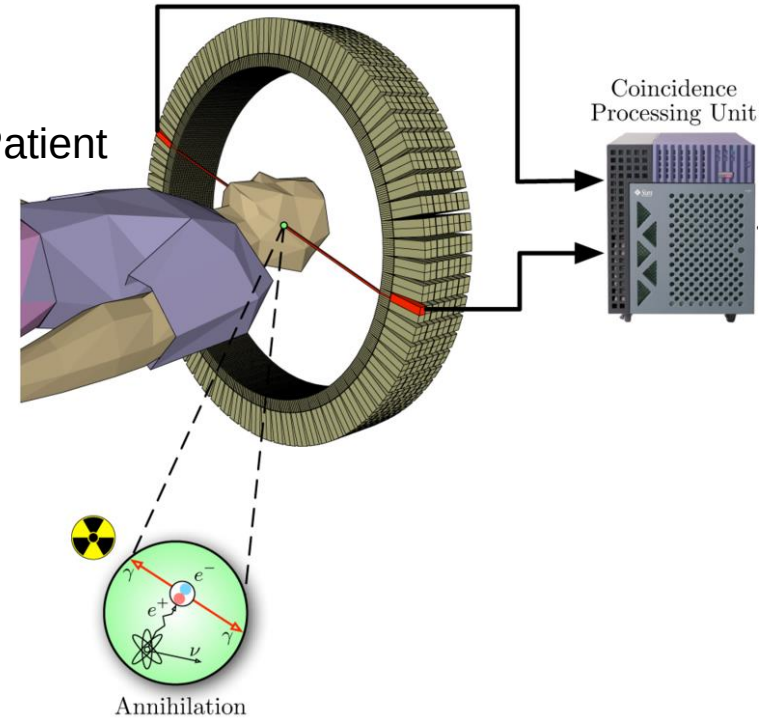
Cyclotron

Nuclide

Chemistry system

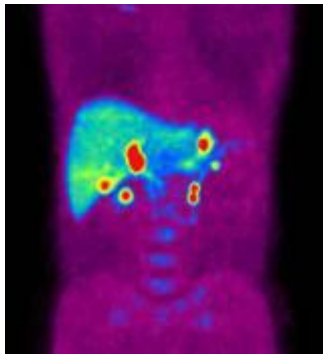
Molecule

e.g. F-18 labeled fluorodeoxyglucose (FDG)



RF power amplifier

PET/CT

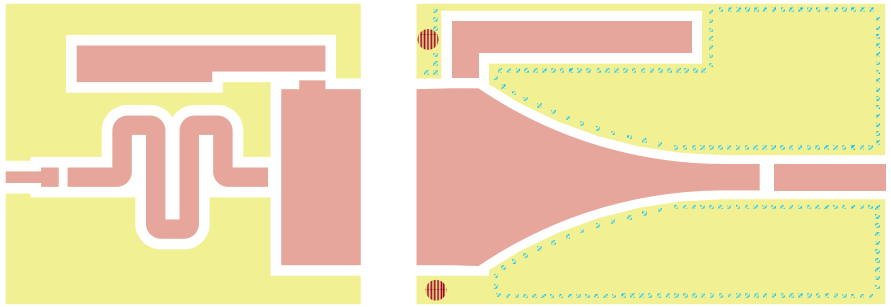


PET

Images

Curtesy of GE

Development of a new amplifier concept



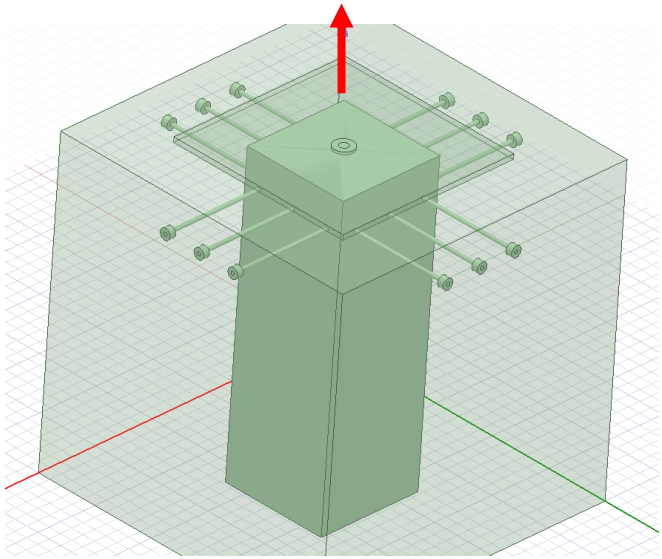
12 x output on 5 Ω

+

impedance transformation with a λ/4 coaxial cable 50 Ω

+

1 output on 50 Ω



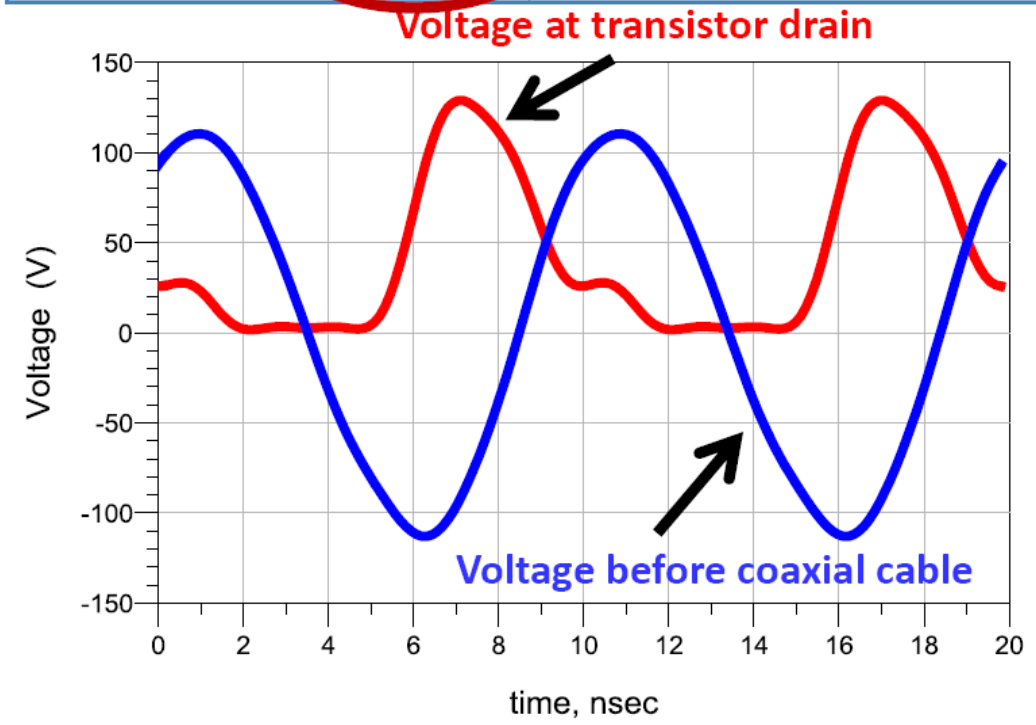
12 inputs on 500 Ω

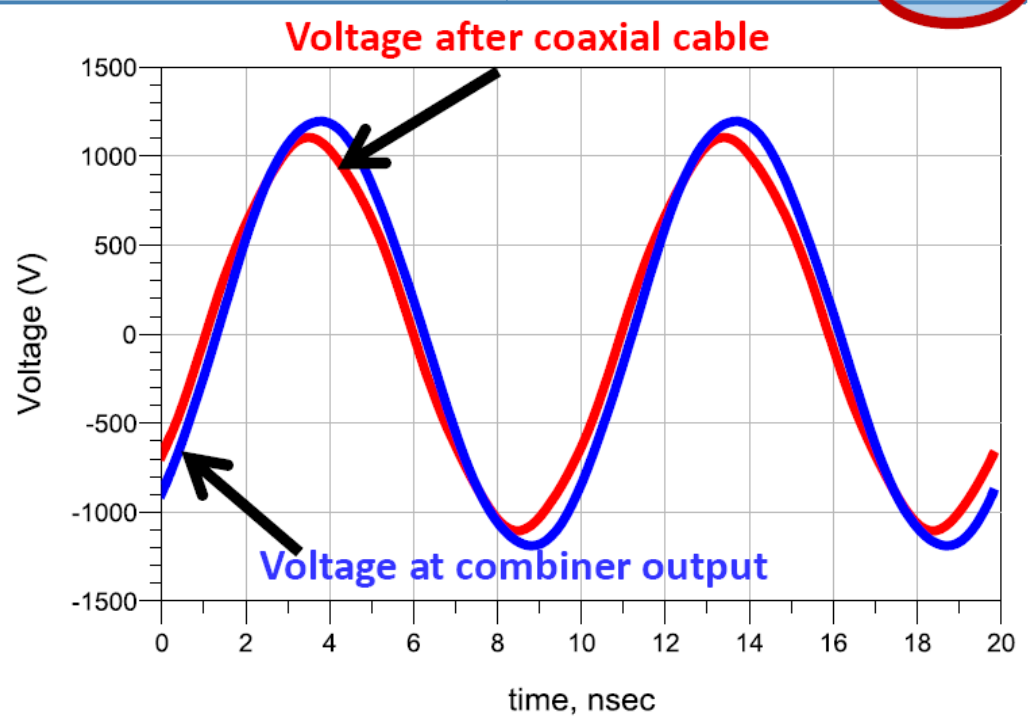
A. Backlund and D. Dancila, ”System and method for amplifying and combining radiofrequency power”, Patent 325942-1US (553-2069US1) filled 27 Nov. 2018.
A. Backlund and D. Dancila, “Radiofrequency power combiner or divider having a transmission line resonator”, Patent 325672-1US (553-2061US1) filled 10 Sep. 2018.

Co-simulation of 12 amplifiers and combiner for cyclotron impedance at 50 Ohm

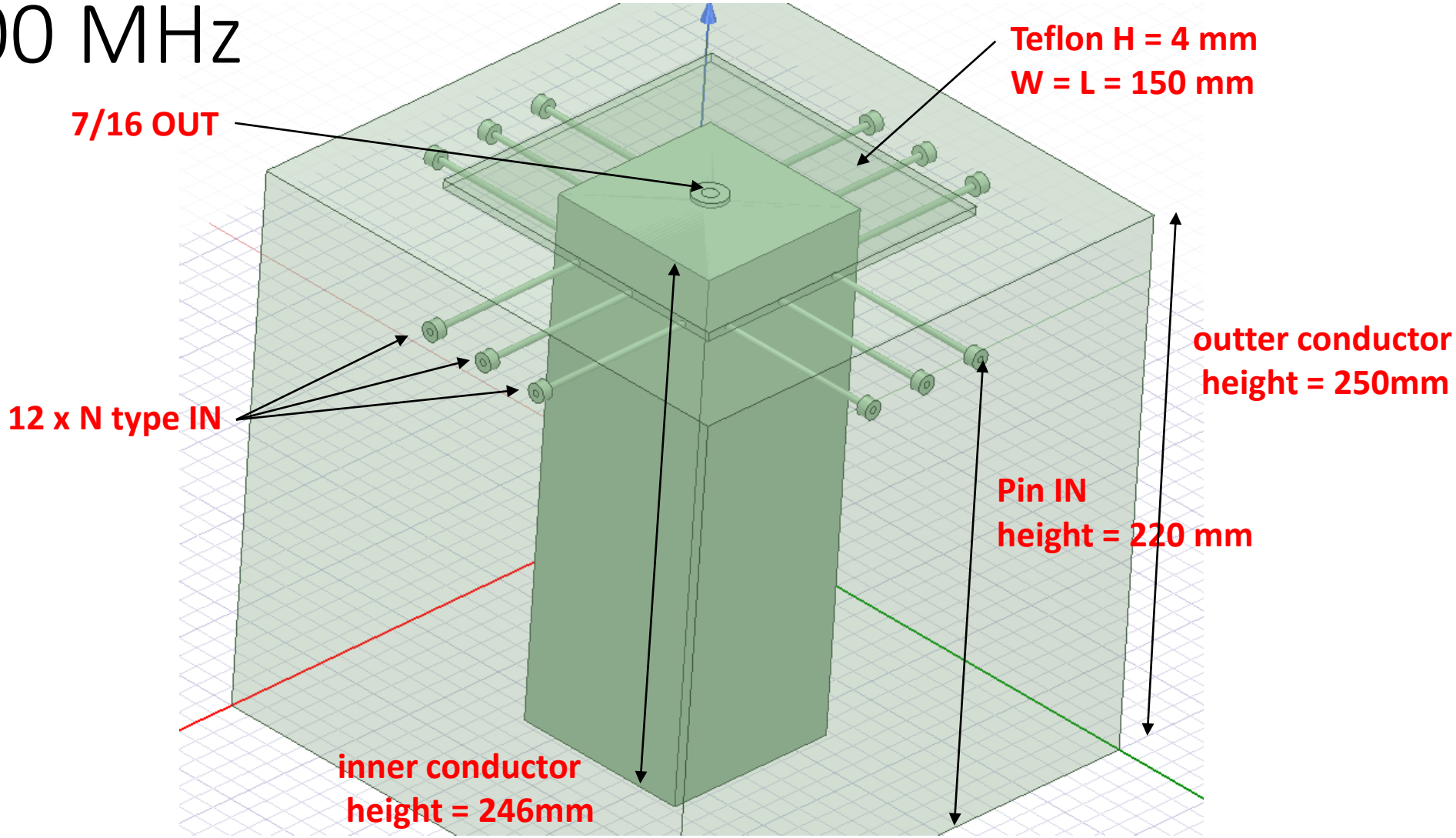
SIMULATED PERFORMANCE @ P3dB

Pout_Watts_Fet2[_3dB_fet3]	Gt_Fet2[_3dB_fet3]	IRL_Fet2[_3dB_fet3]	Deff_Fet2[_3dB_fet3]
14391.892	22.089	-17.125	85.190

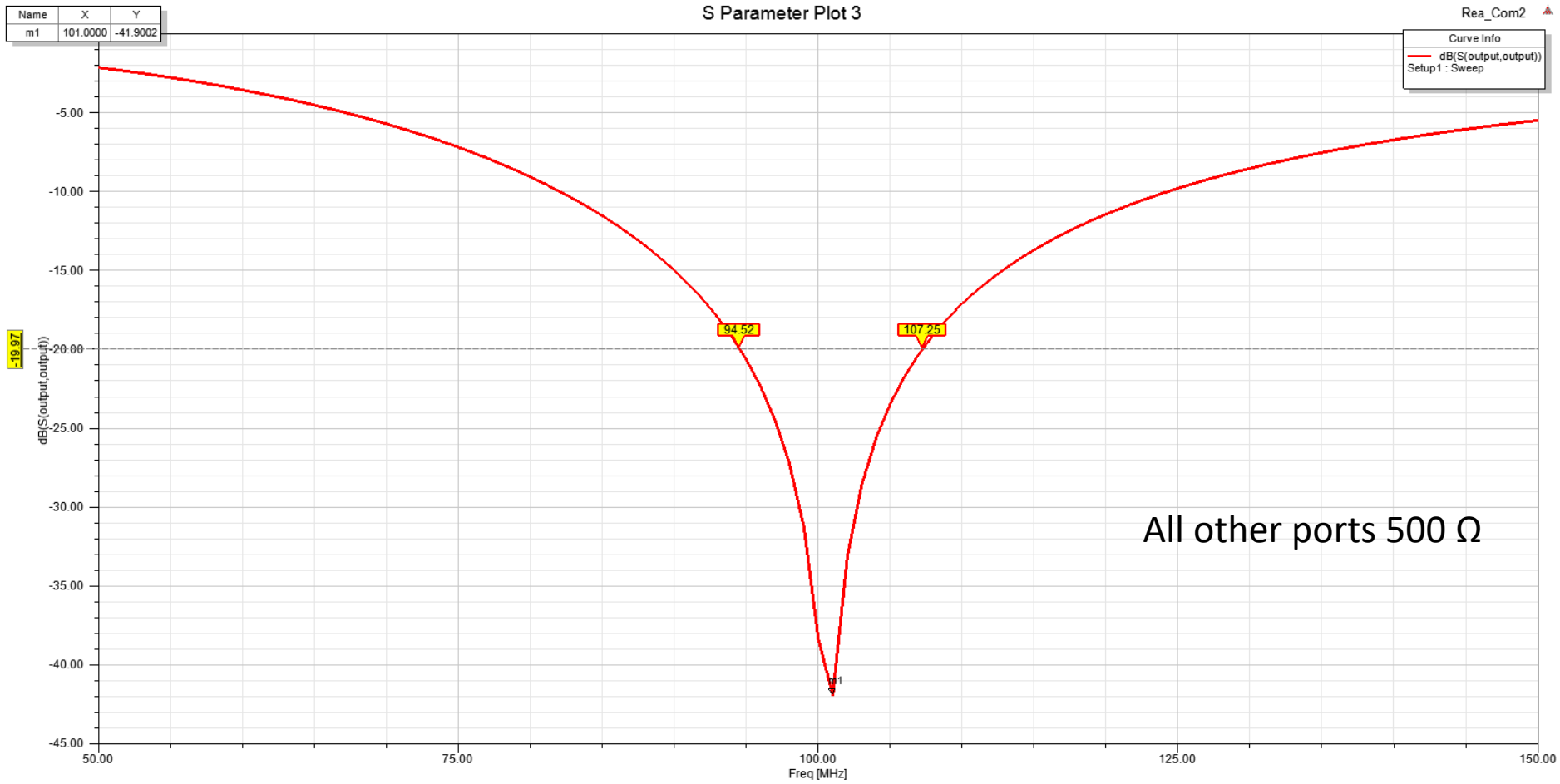




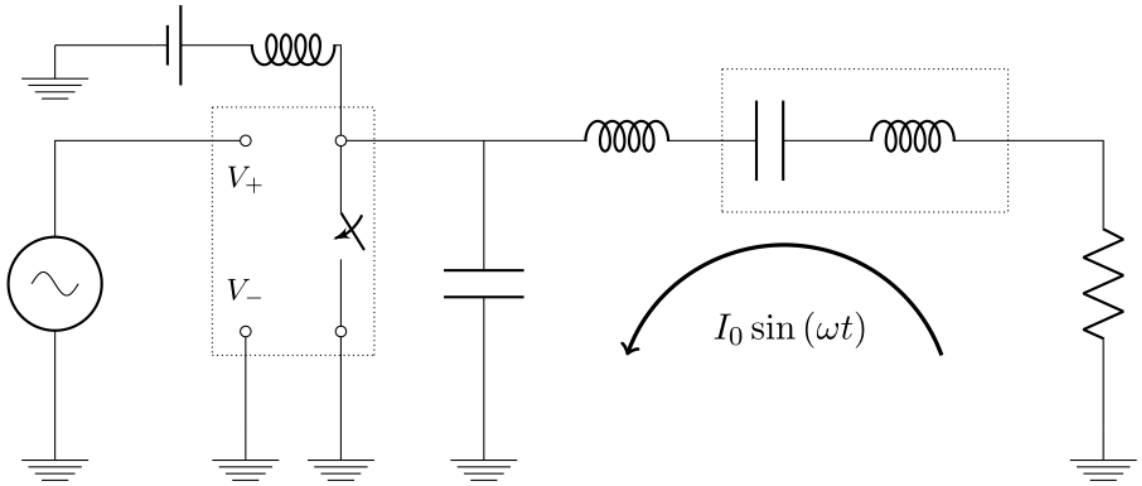
Compact resonant cavity combiner at 100 MHz

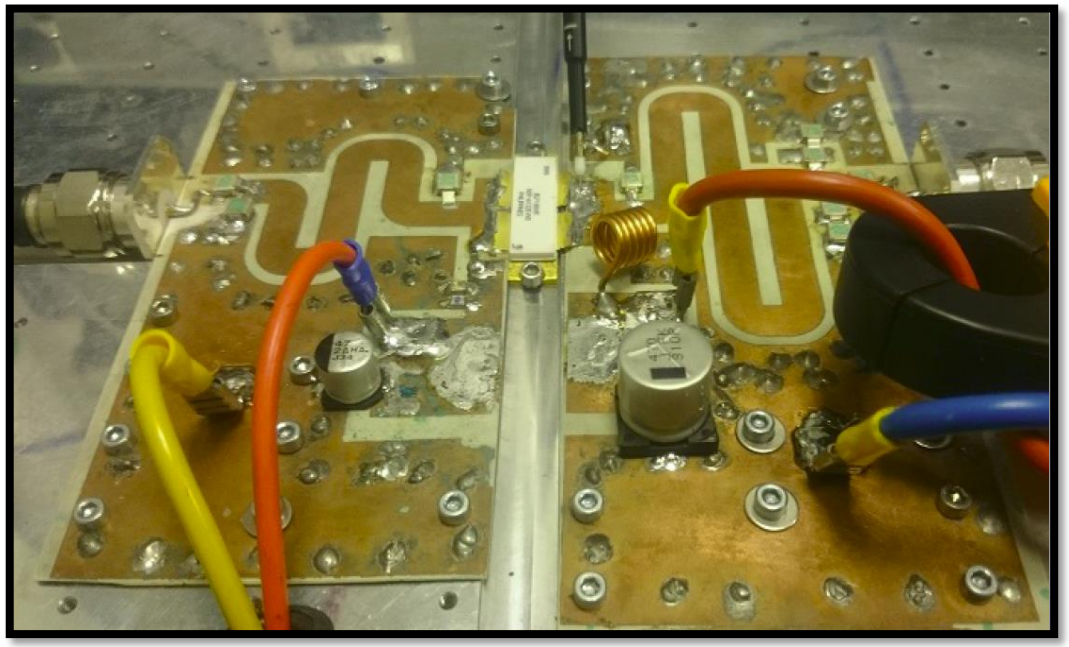


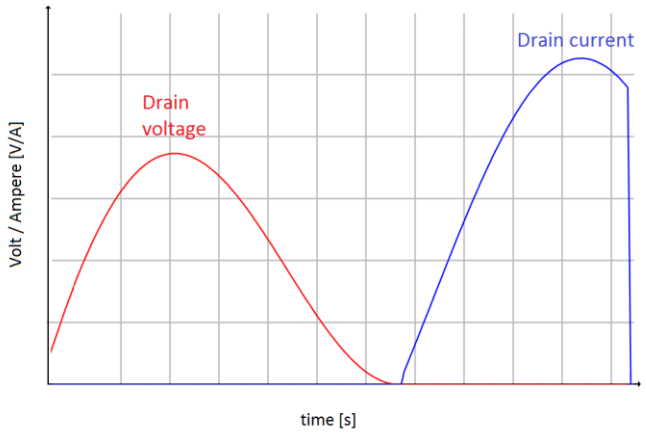
Simulation results (S11) – output port 500 Ω

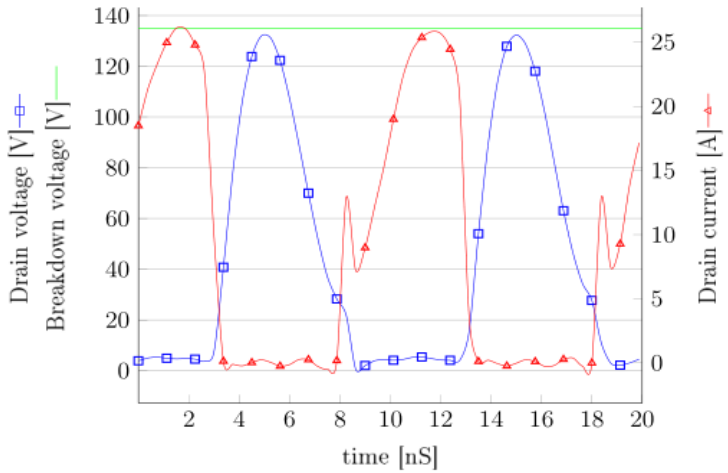


SSPA class E 100 MHz – 1kW – 87% eff.





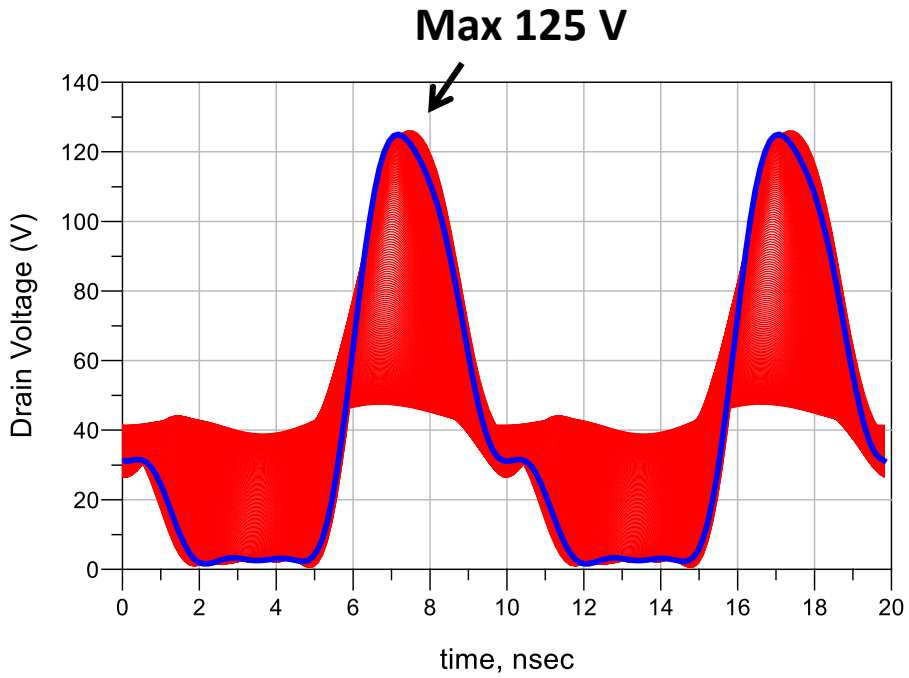


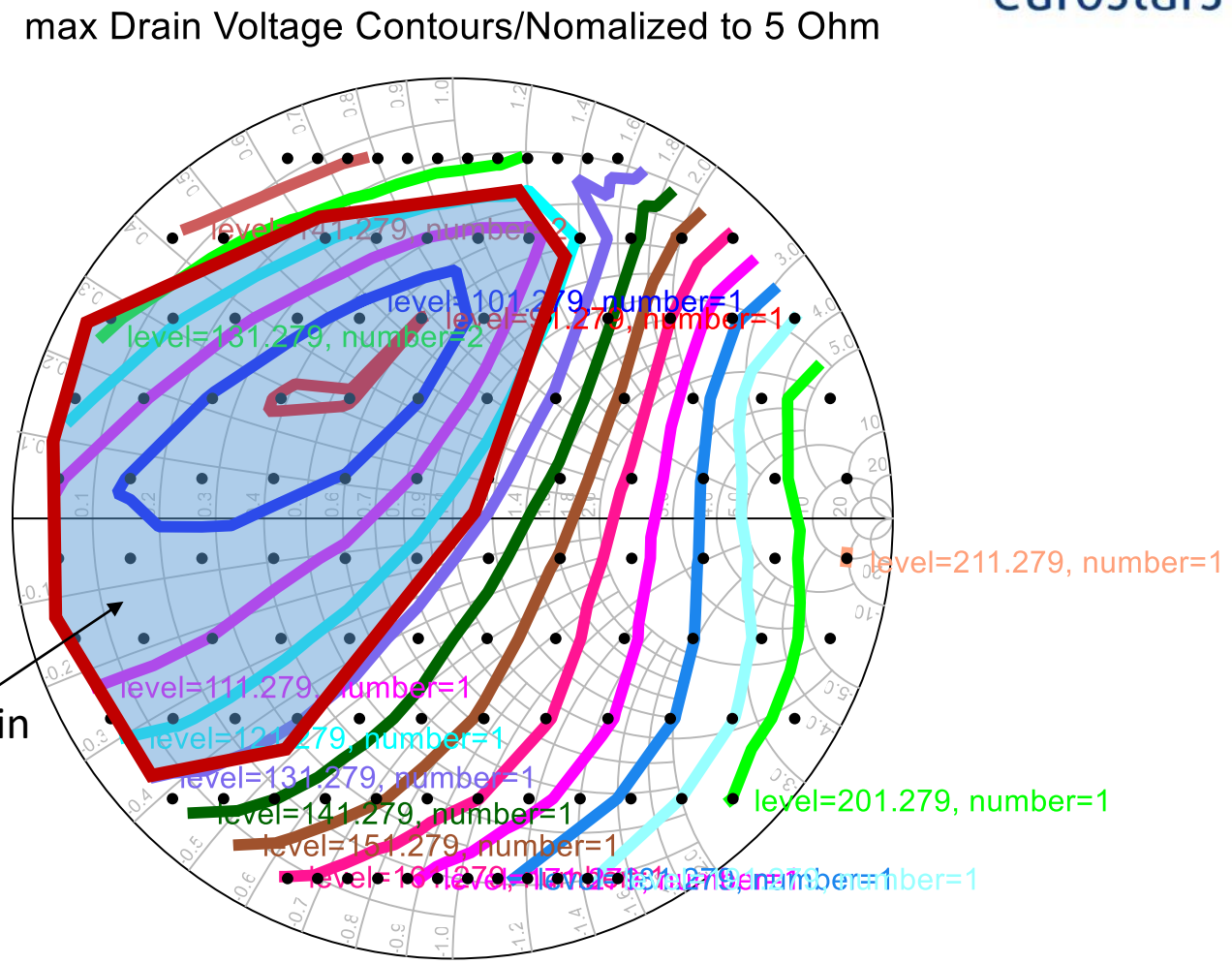


measured 1010 W peak output power 87%
22 dB gain at 102 MHz (V_{ds} peak = 140.5 V)
5% duty cycle, using 3.5 ms pulses at 14 Hz

Renbin EUMW 2019

Load Pull for cyclotron operation

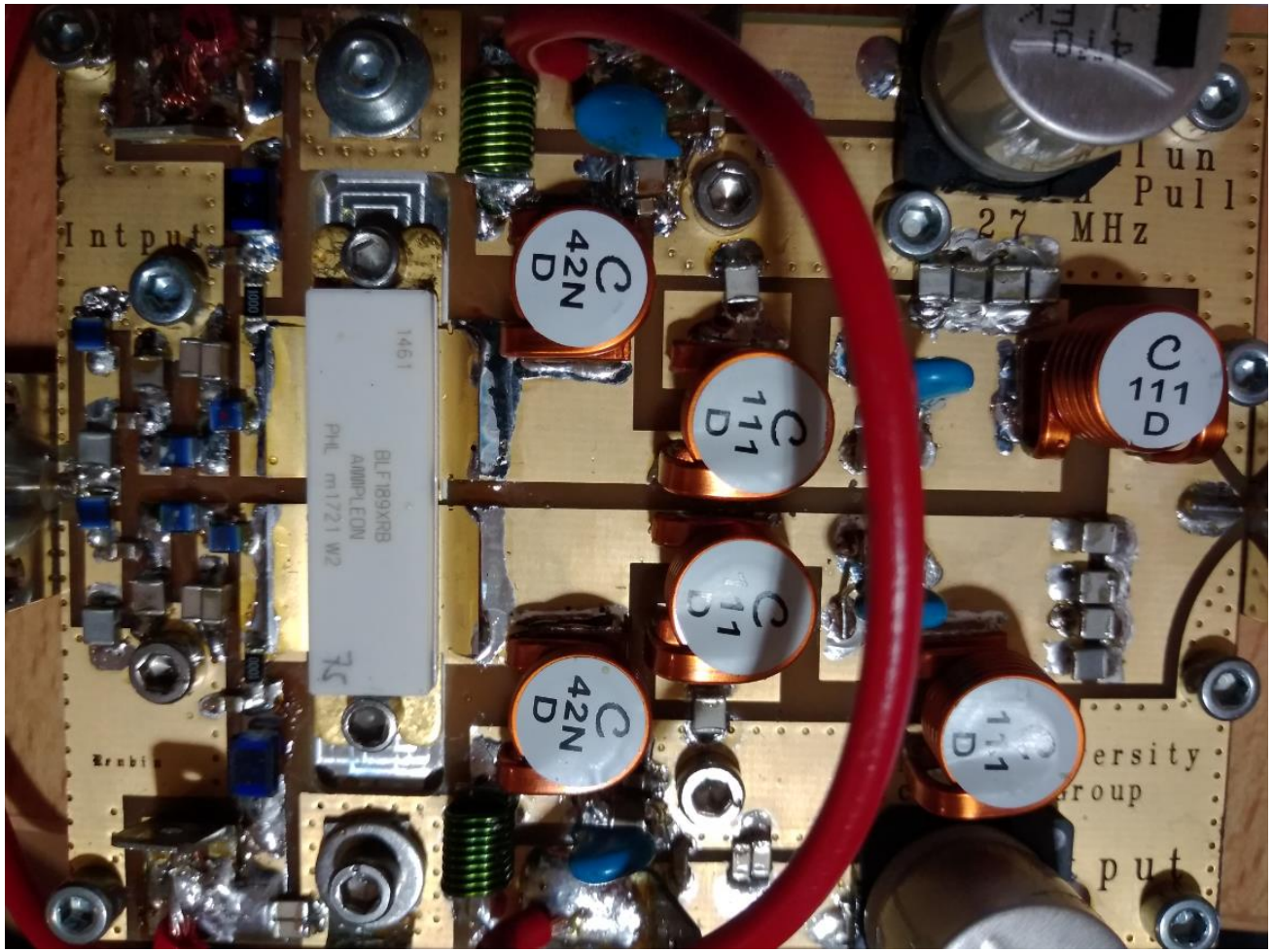


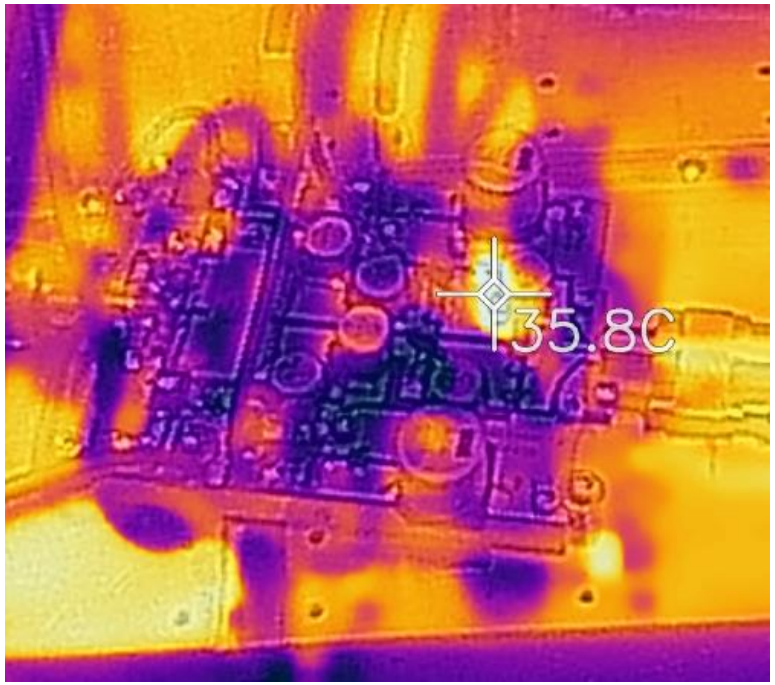


acceptable drain voltage region

Cyclotron impedances are between 50 and 0 Ohm
- not all phases are considered
- after impedance transformation - 5 Ohm
- SSPA design for 5 to 0 Ohm region

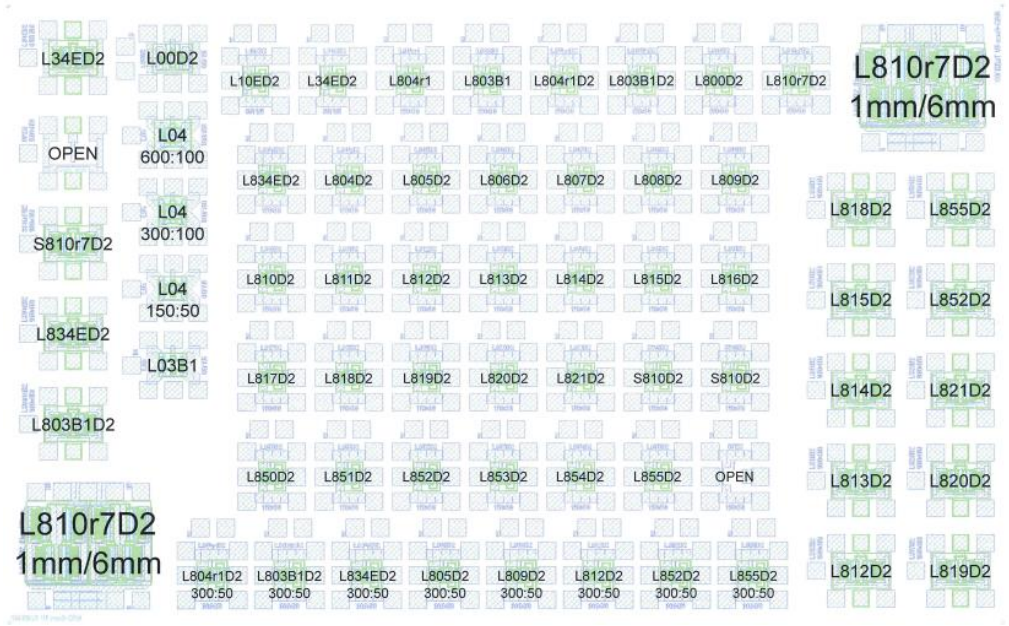
Lumped balun amplifier 27 MHz – 1 kW

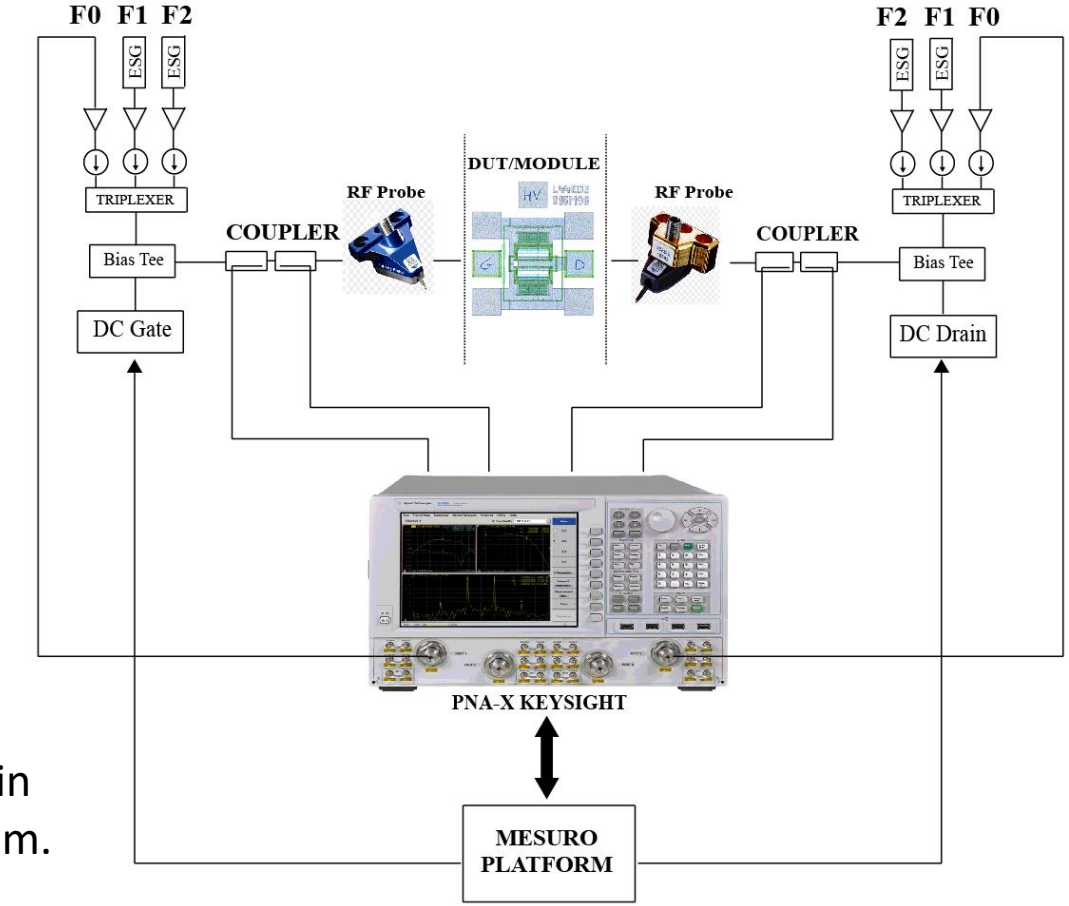




Bias: VDD=43V, Idq=~300mA
1 kW output power, 20 db gain

Collaboration with Comheat AB on LIGBT transistor developement





Collaboration is also ongoing with Ferdinand Braun Inst. Berlin on the developement of a MHz load-pull measurement system.

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Thanks for your attention !

Questions ?