



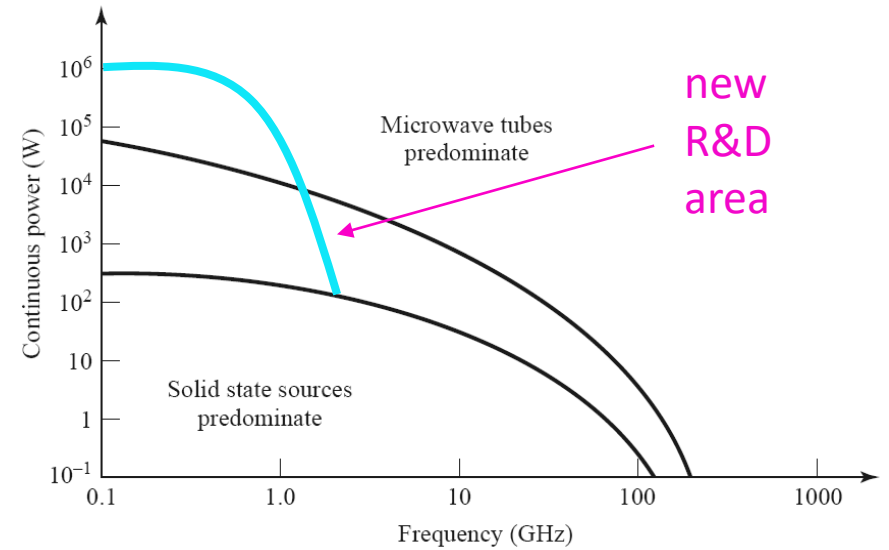
I.FAST 1st Annual Meeting

CERN, May 2-6 -2022

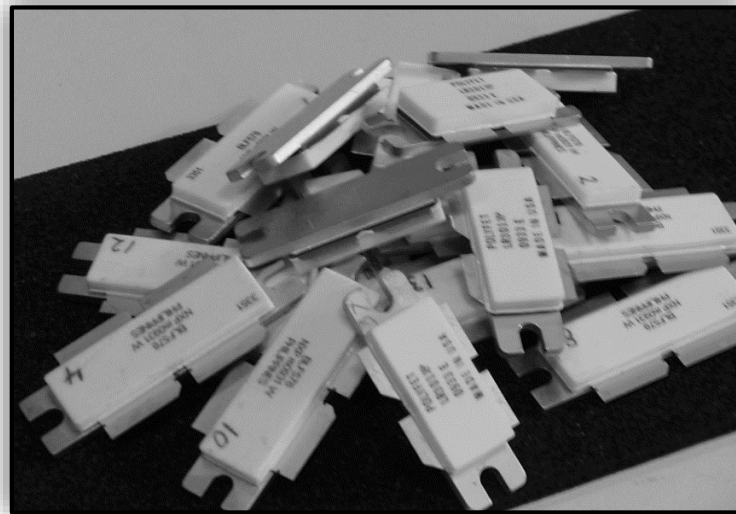
Aireza Mohadeskasaei and [Dragos Dancila](#) (Uppsala University - FREIA)

Scope

Demonstrate the advantages and feasibility of GaN technology for high power and high efficiency amplifiers, as the next building blocks of larger amplifiers for particle accelerators.



D13.3 - Development of a radio frequency amplifier at 750 MHz delivering 1 kW with high efficiency.



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

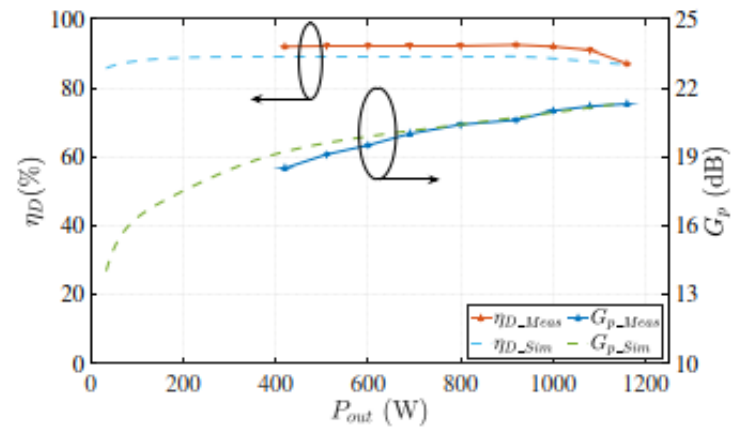
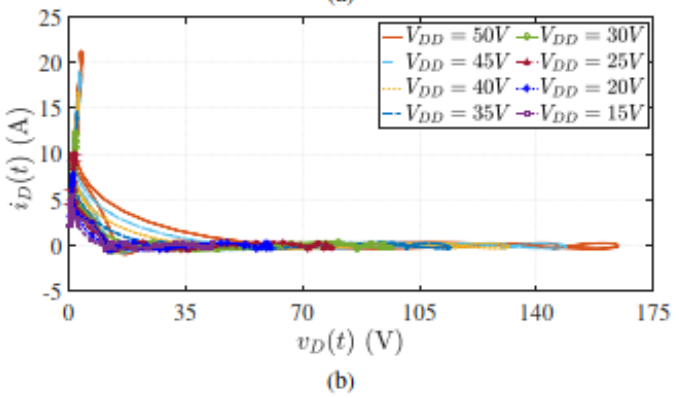
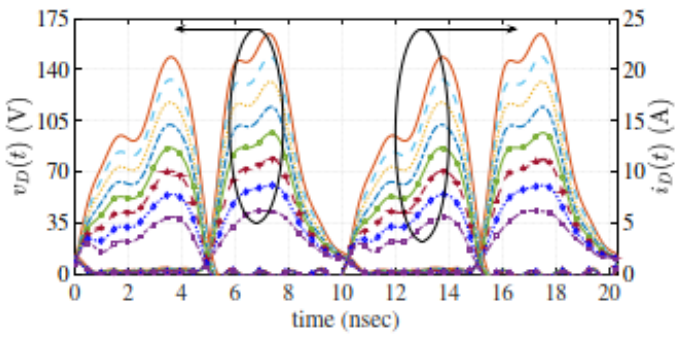
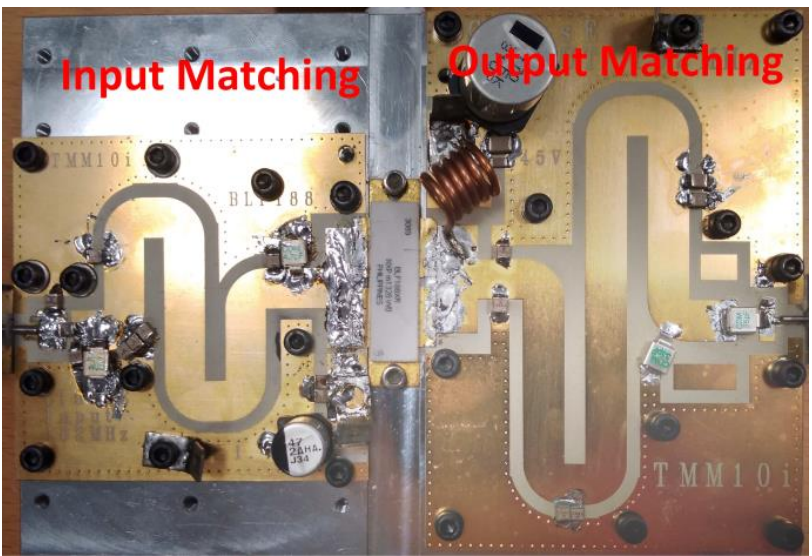
State of the Art

No.	Operating class	F_{\min} (MHz)	F_{\max} (MHz)	Operation Voltage (V)	P_{out} (dBm)	Gain (dB)	PAE_{\min} (%)	Chip	F_{\max} of chip (MHz)	$V_{\text{DS max}}$	Technology	Package	Institution
2020[8]	Class E	400	-	145	63.6	22	70	-	-	500	GaN	Die	Integra Tech. - CA
2018[9]	Class E	680	750	28	47	-	80	CGH35030F	3900	120	GaN	packaged	U. of Cantabria
2018[10]	Class E	100	-	50	60.8	-	82	BLF188XR	600	135	LDMOS	packaged	FREIA – Uppsala U.
2017[11]	Harmonic tuned	420	450	75	60	40 (two stages)	75	-	-	-	GaN	Packaged	Integra Tech. – CA
2017[12]	Class E	670	900	28	44.7	-	70	CGH35030F	3900	120	GaN	packaged	U. of Cantabria
2016[13]	Class F	704	-	-	58	-	79	-	-	-	GaN	packaged	Green Mountain Radio Research
2016[14]	Class F	550	950	28	40	15	75	CGH40010F	4000	120	GaN	packaged	U. of Calgary
2011[15]	Class F	550	1100	28	40	10	74	CGH40010F	4000	120	GaN	packaged	Cardiff U.



GaN transistors from e.g. Ampleon, Qorvo, Cree - Wolfspeed, NXP Semiconductors, Infineon, etc. are available at high power.

SSPA design principles at 100 MHz – 1kW – 93% eff. waveform engineering



$$v_D(t) = V_{DD} \cdot [1 - \sqrt{2} \cos(\omega t) + 0.5 \cos(2\omega t)] \cdot [1 + \sin(\omega t)] \quad (1)$$

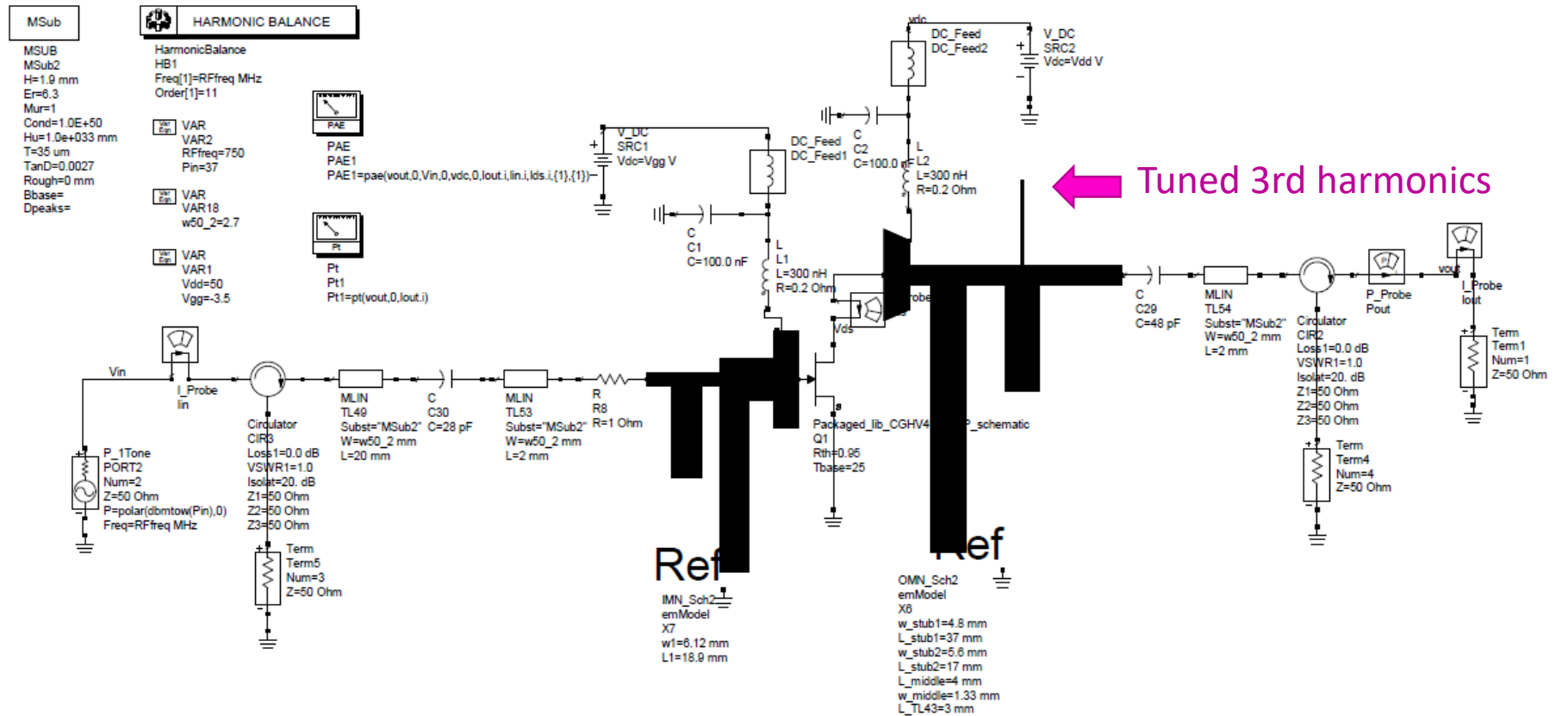
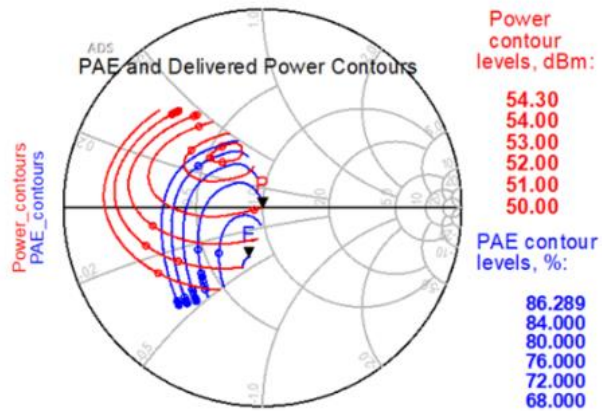
$$i_D(t) = I_{max} \cdot [0.274 + 0.406 \cos(\omega t) + 0.117 \cos(2\omega t) - 0.075 \cos(3\omega t) - 0.077 \cos(4\omega t) + 0.003 \cos(5\omega t) + \dots] \cdot [1 + 0.34 \sin(\omega t)] \quad (2)$$



$$Z_{nf_0} = -\frac{V_{d,n}}{I_{d,n}}$$

R. Tong, O. Bengtsson, A. Bäcklund and D. Dancila, "Highly Efficient Kilowatt Power Amplifier Module as RF Source for Radioisotope Production Cyclotron System", IEEE Transactions on Microwave Theory and Techniques, 2021.

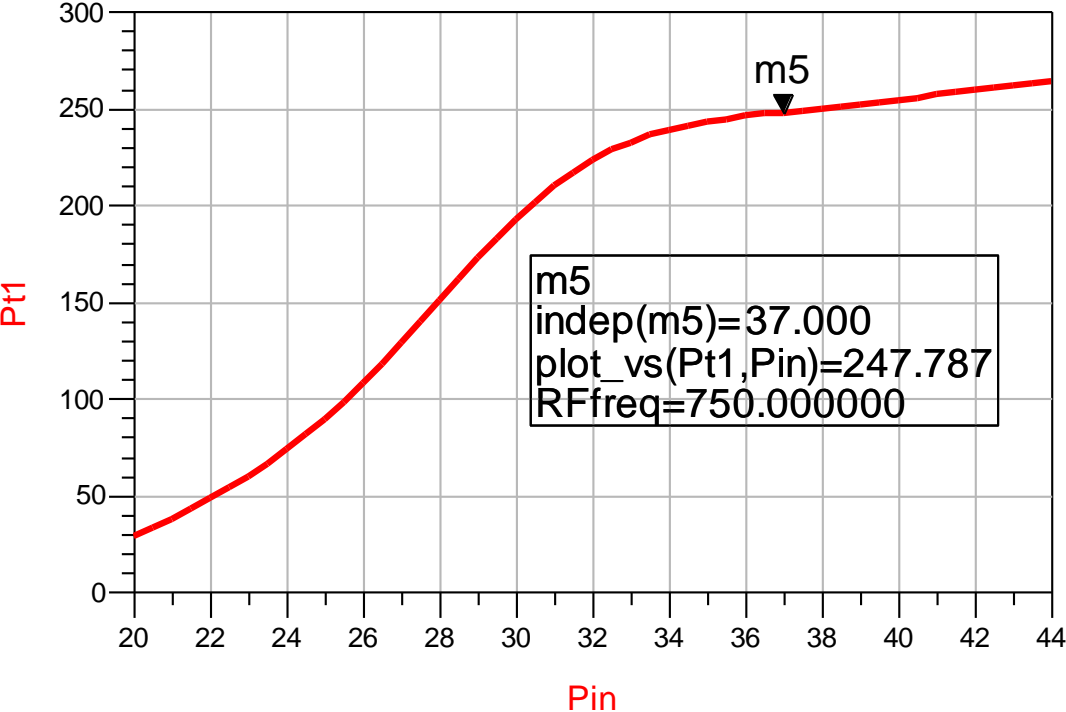
Load pull simulations and harmonics optimization



The maximum efficiency and output power are easily shifted by varying stub length, and so the practical implementation of the PA will meet the targeted specifications.

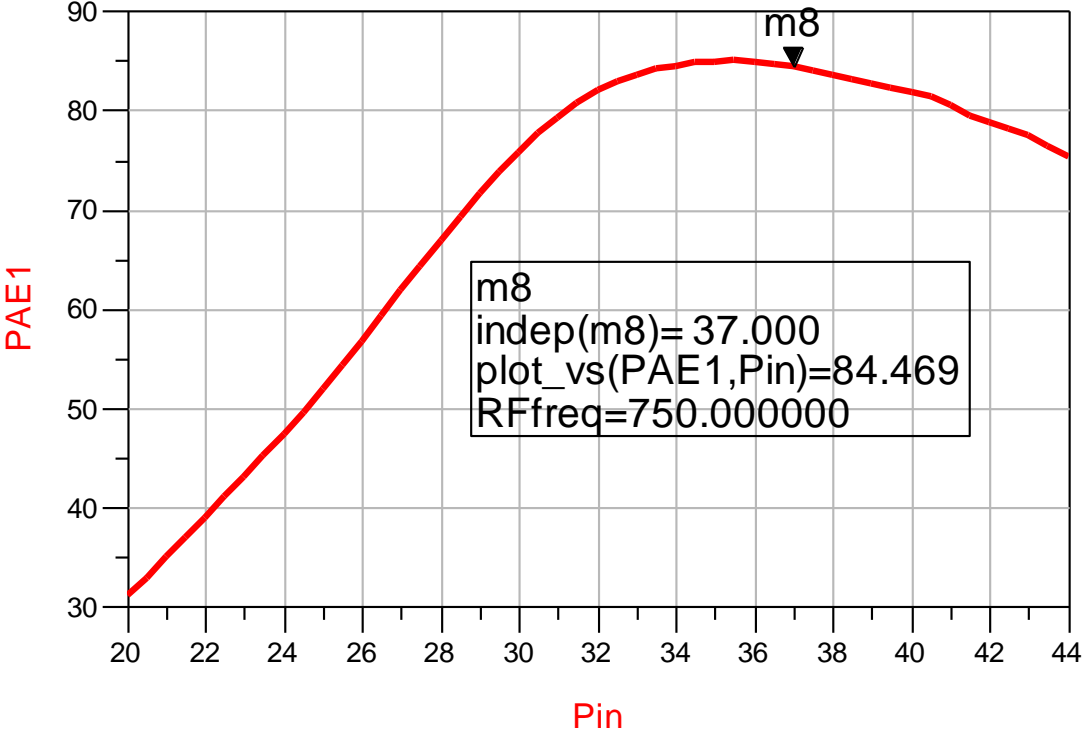
Simulation results of the GaN amplifier at 750 MHz

Output power versus input power



Pout=247 W (54 dBm) @ Pin=37 dBm
Gain = 17 dB

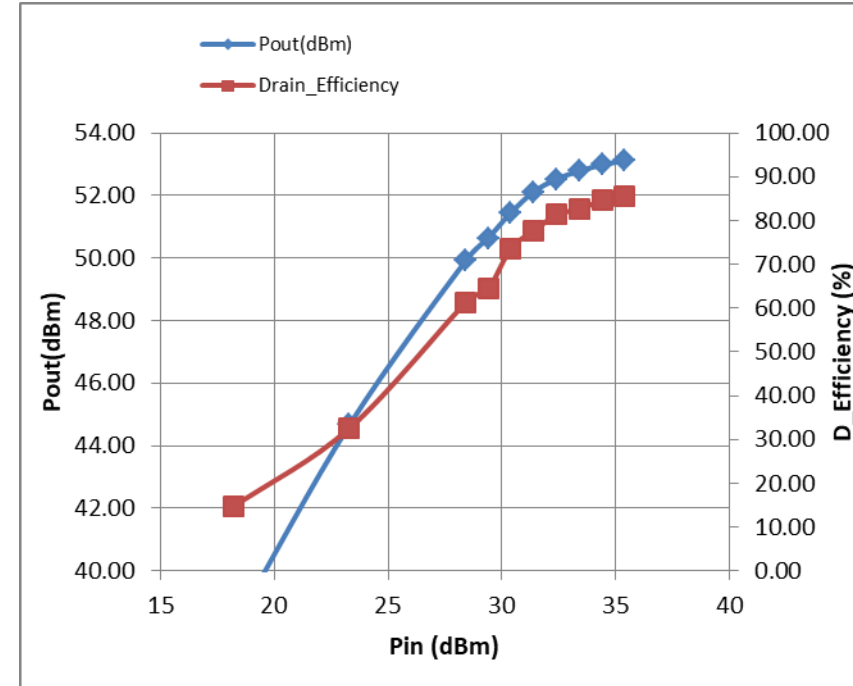
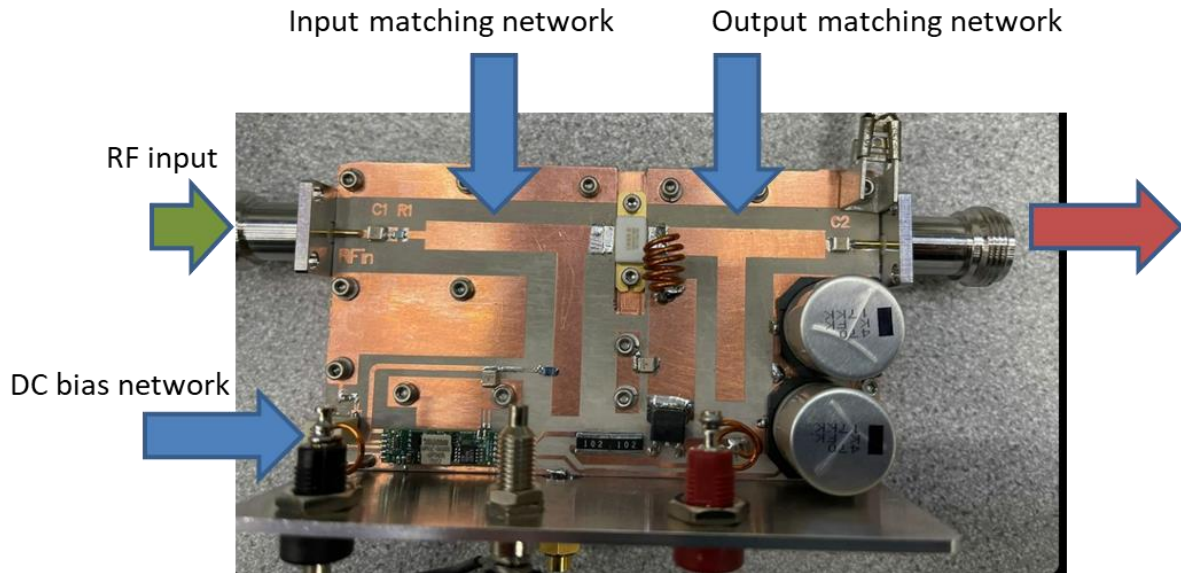
Power added Efficiency (PAE) versus input power



PAE = 84.5 % @ Pin=37 dBm

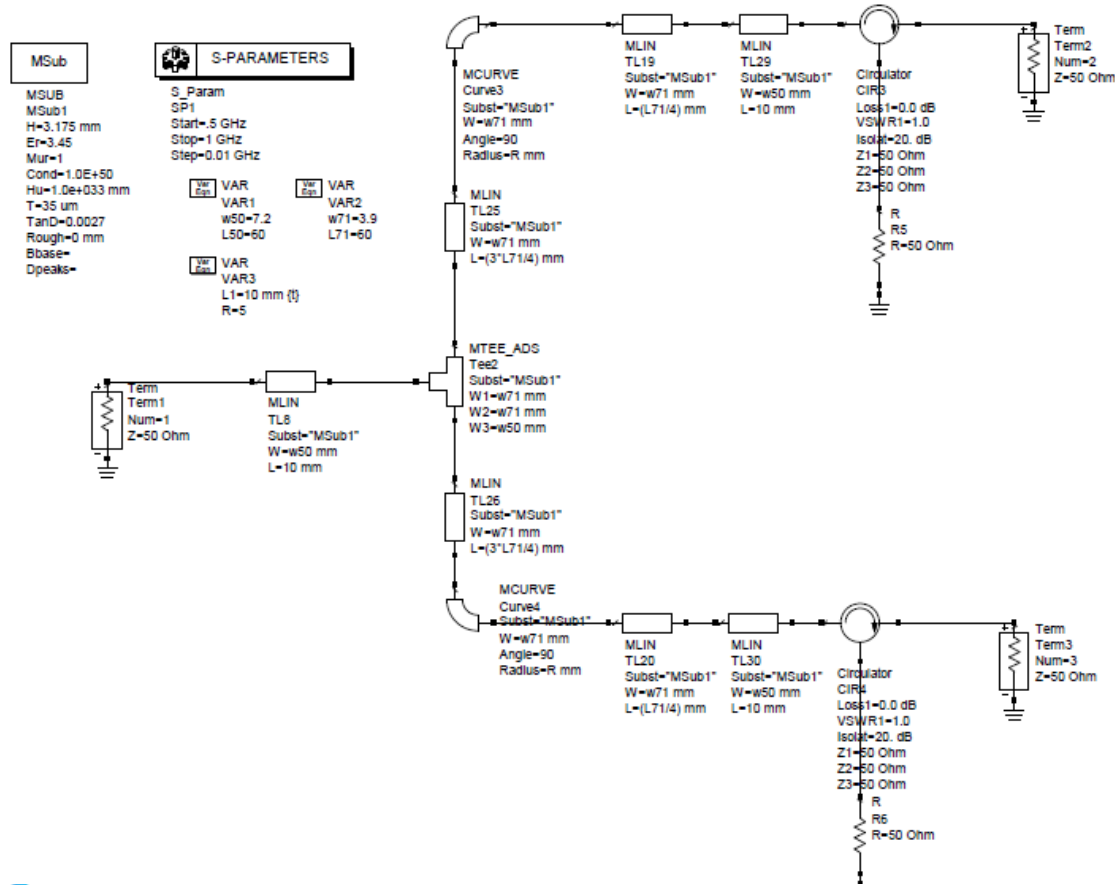


Amplifier fabrication and first measurements

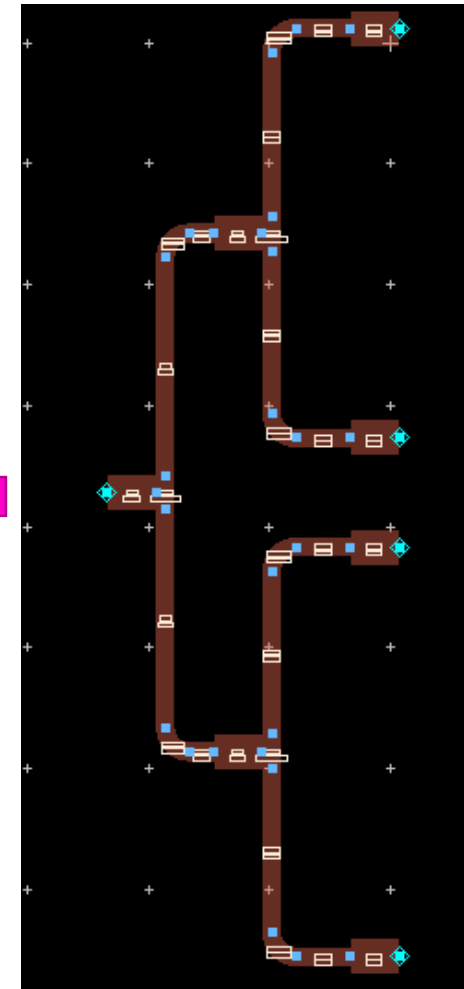


- A measured output power of 205 W was possible, with a signal gain of 17 dB and an efficiency of 84% in compression.
- This is improving the State of the Art.

Planner Wilkinson power combiner 2:1, 4:1 and 6:1



output port



Port1

Port2

Port3

Port4

Overall contribution to task 13.3

- This Task 13.3 is an excellent opportunity to develop further our competence, at the FREIA Laboratory as an AMICI partner and share via IFAST. At FREIA, we are now producing a 352 MHz, 400 kW, 14 Hz pulsed SSPA station to be finished by end 2022. This could be an option for the ESS RF power sources.
- Furthermore, we have the ambitious goal to train the new generation of scientists and engineers, via the newly started Traineeship Programme. This would support the transfer of knowledge between laboratories and industry and enhance the collaboration possibilities with industrial partners and other technology stakeholders.
- On example reaching out, is the ongoing discussion on establishing a collaboration with the MINERVA/MYRRHA project from Belgium. In this project a similar amplifier module operating at 704 MHz would need to be developed. We plan also to develop further our testing facilities for modules and full stations, which is fully aligned with the needs for the MYRRHA project and FREIA's laboratory's development strategy.



iFAST

Thanks and questions



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