Dragos Dancila and Alireza Mohadeskasaei (Uppsala University - FREIA)

I.FAST 2nd Annual meeting, 19.04.2023

WP13 / Task 3 structure and objectives

- *Task 13.3: New RF amplifiers based on GaN semiconductors M1 – M24*

  Realization and evaluation of a new RF amplifier based on GaN semiconductors at kilowatt level. Identification of the advantages of GaN semiconductor technology for accelerator RF amplifiers.

  The task aims to investigate the use of Gallium Nitride (GaN) semiconductor technology for solid-state power amplifiers in the kilowatt level and radio frequencies (RF) range. GaN is expected to be widely used for next-generation power semiconductor devices due to its superior performance compared to silicon-based power transistors. The current nominal power level of single GaN transistors is 100 W. The University of Uppsala (UU) will develop a kilowatt-level GaN module at 750 MHz using the facilities at the UU Technological Platform, which are part of AMICI.
  In addition, UU will share their knowledge and advancements in the field with the other AMICI partners, I.FAST project members, and the wider community.

Summary of activities

- *A new solid-state power amplifier in Gallium Nitride (GaN) semiconductor technology was developed and is reported to deliver 205 W with 82% power added efficiency at 750 MHz. This is the first demonstration of operation with high efficiency and nominal power of the first GaN power amplifier at this power level and frequency in the project, the results were realized by UU and represent MS63.*
- Today we will show the first combined results of six of these amplifiers demonstrating more than 1kW output power with similar efficiency.
- *GaN is anticipated to be extensively used for the next-generation power semiconductor devices, as it significantly outperforms silicon-based power transistors, thanks to a higher breakdown strength, faster switching speed, higher thermal conductivity and lower on-resistance. Presently, the nominal power level of single GaN transistors is only in the hundreds watts level.*
- *This work contributes to improve the state-of-the-art for kilowatt level amplifiers at 750 MHz and has direct industrial applications as the RF power source of the RFQ developed at CERN.*

Deliverables and Milestones

- *MS63 Demonstration of operation with high efficiency and nominal power of the first GaN amplifier.*

  Planned for M12, MS63 delayed to M18 (Oct. 2022).

  It is now delivered and approved.

- *D13.3: GaN RF amplifier module at kW level.*

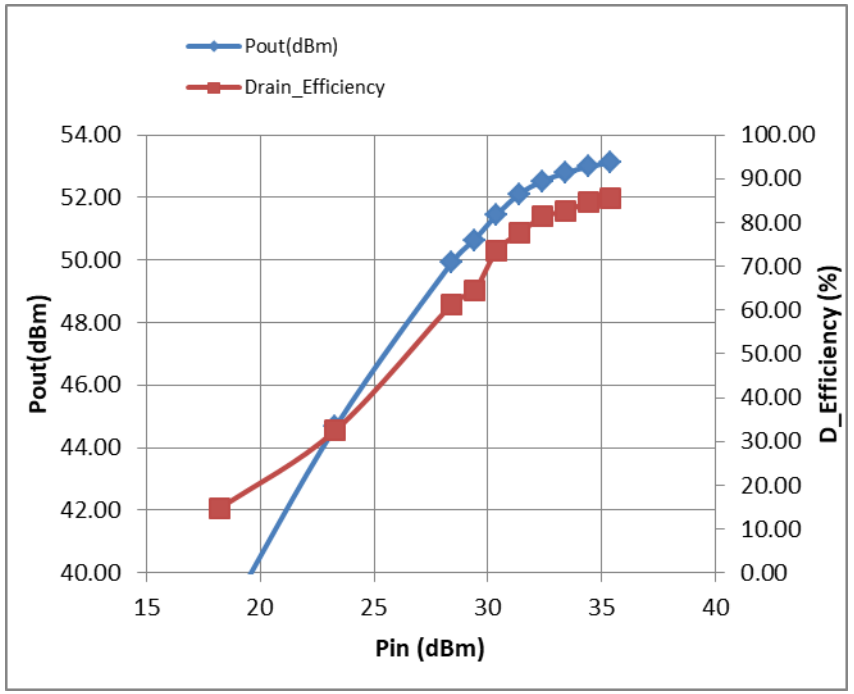
  Realization of an RF amplifier module based on GaN semiconductor technology and demonstration of combined power at kW level.

  Planed for M24, D13.3 delayed to M33 (Jan. 2024).

  Due essentially to the unavailability of some critical electronic components.

  The first measurements at 1kW are shown today.

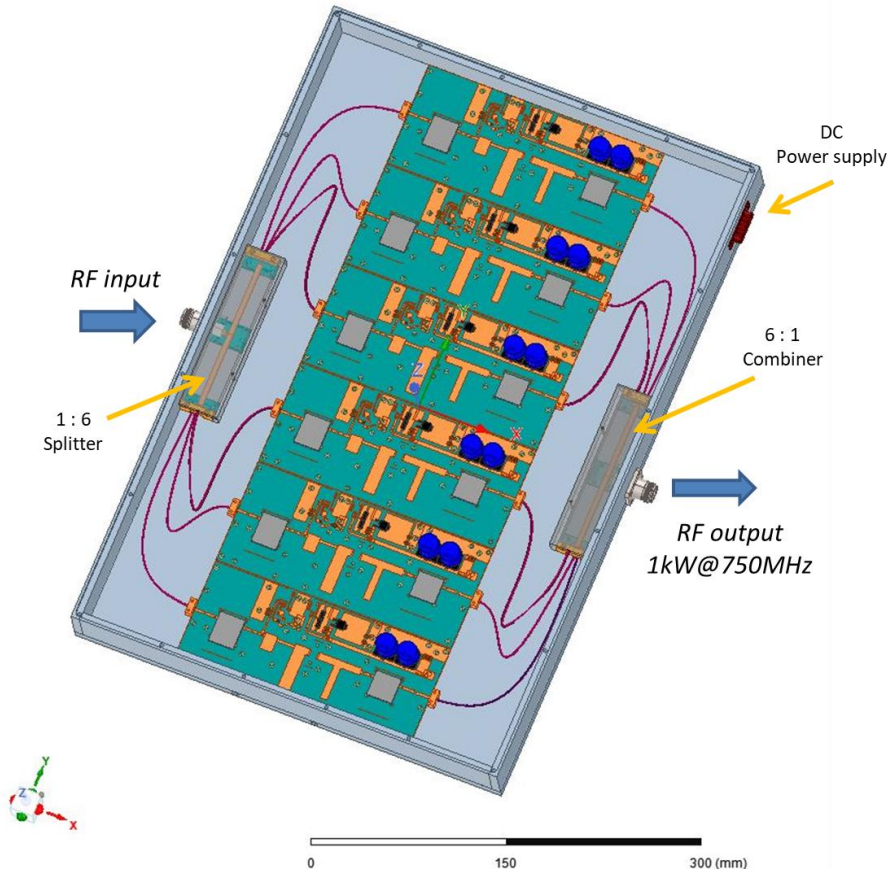
MS63: Demonstration of operation with high efficiency and nominal power of the first GaN amplifier.

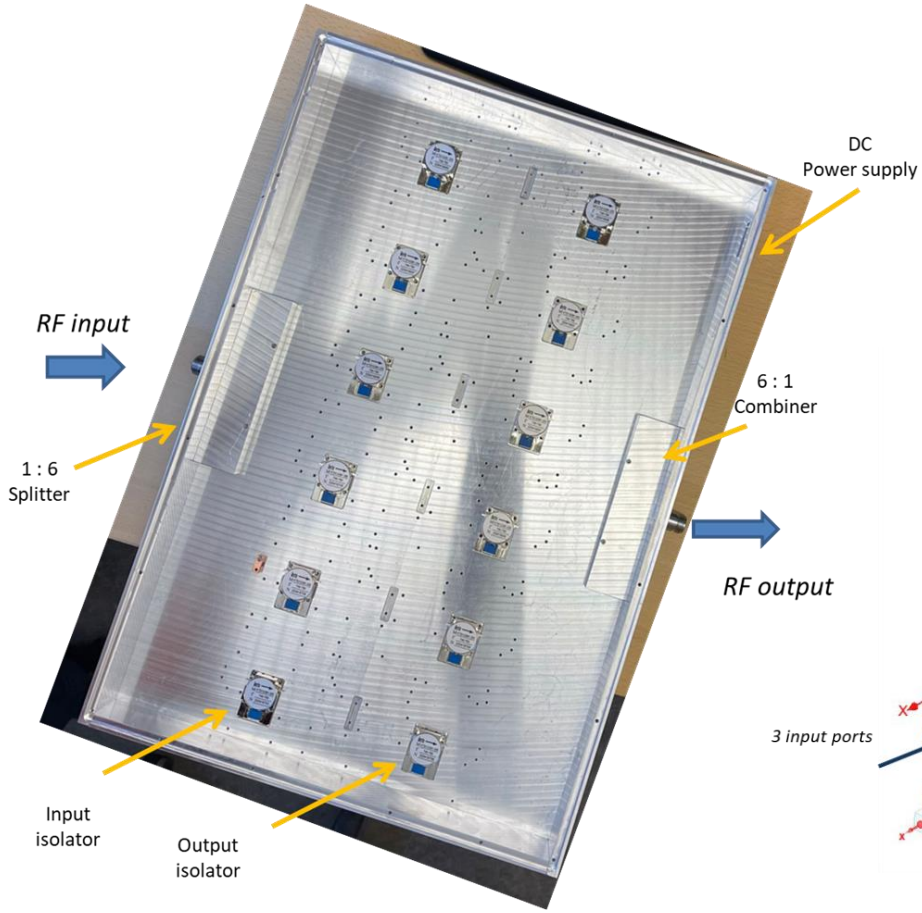


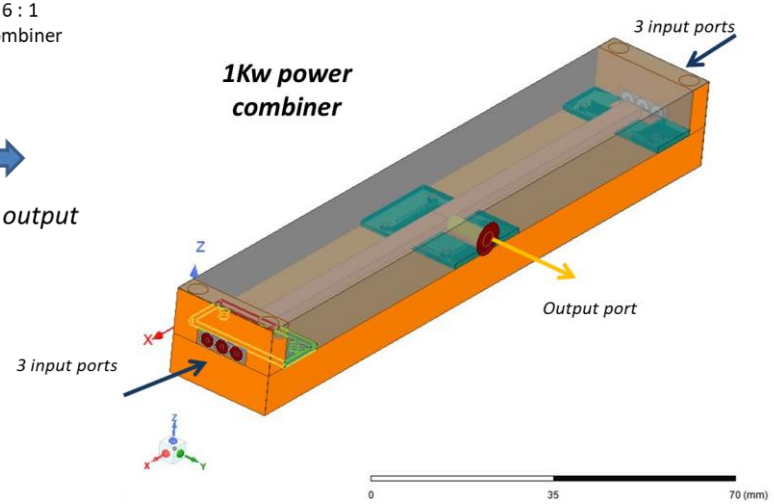
- A measured output power of 205 W was possible, with a signal gain of 17 dB and an efficiency of 82% in compression.
- This result is improving the State of the Art.

Pout = 53 dBm (60 dBm with combiner) / PAE = 82% @ 750 MHz

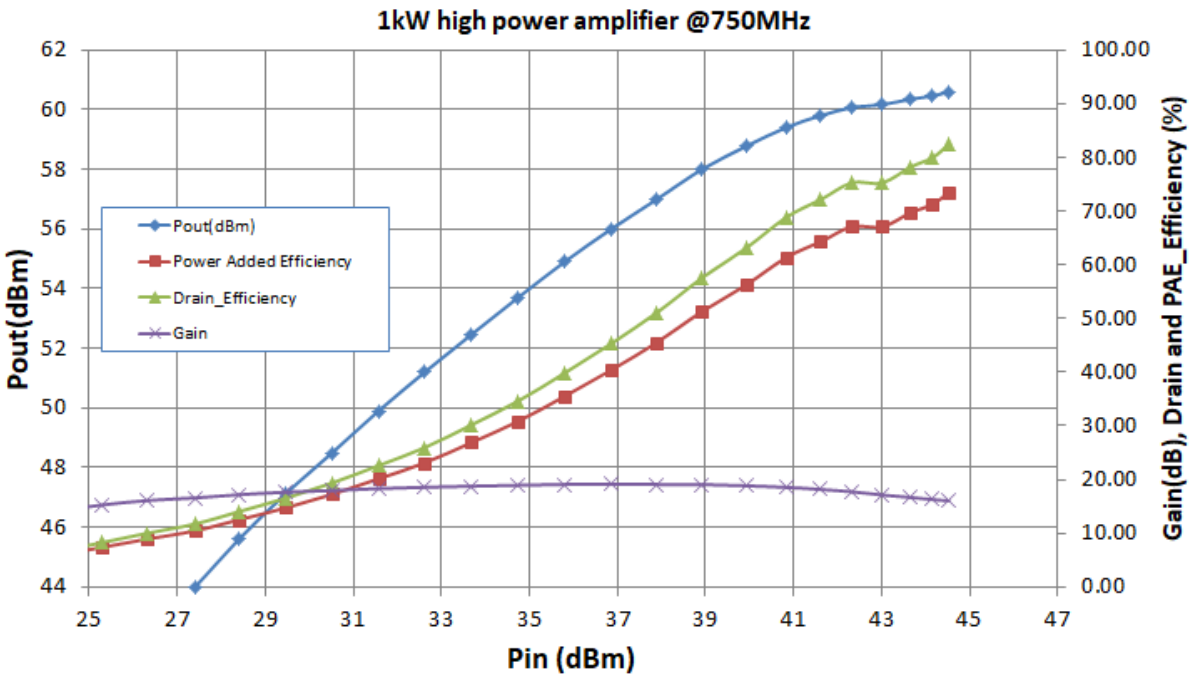
D13.3: GaN RF amplifier module at kW level (status M18) planned delivery M33.







D13.3: GaN RF amplifier module at kW level (status M18) planned delivery M33 – measured !



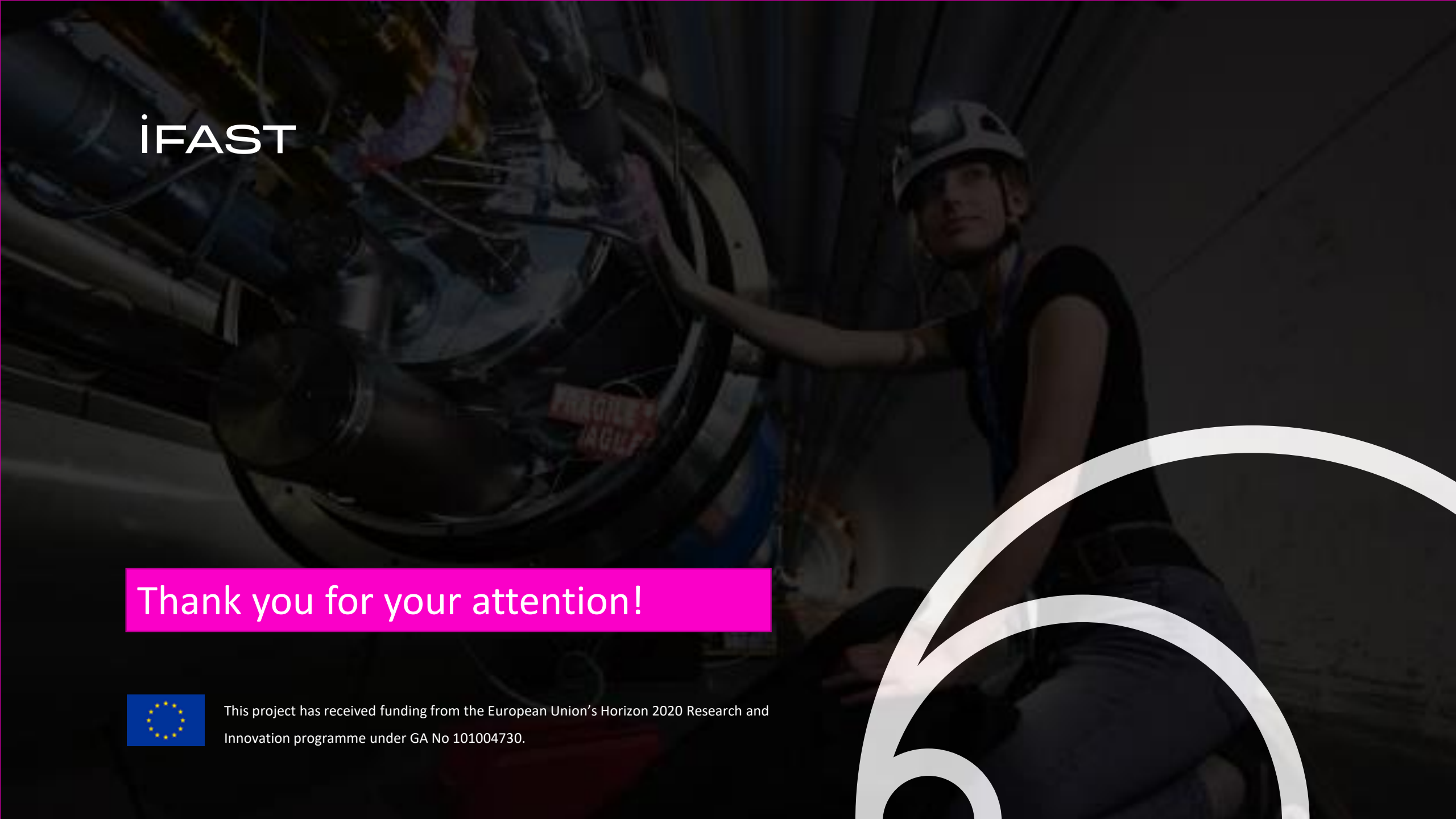
$P_{in(dBm)}$ Driver	$P_{in(dBm)HPA} = P_{outDriver}$	Pout(dBm)	I_Drain (A)	Power added_Efficiency(%)	Pout (W)	Drain_Efficiency	Gain
-25	23.3	36.36	1.87	4.63	4.33	5.19	13.06
-24	24.3	38.5	2.4	5.90	7.08	6.62	14.20
-23	25.3	40.6	3.1	7.41	11.48	8.31	15.30
-22	26.3	42.4	3.9	8.91	17.38	10.00	16.10
-21	27.4	44	4.8	10.47	25.12	11.74	16.60
-20	28.4	45.6	5.8	12.52	36.31	14.05	17.20
-19	29.47	47.13	7	14.75	51.64	16.56	17.66
-18	30.52	48.5	8.2	17.27	70.79	19.37	17.98
-17	31.57	49.9	9.7	20.15	97.72	22.61	18.33
-16	32.62	51.2	11.4	23.13	131.83	25.95	18.58
-15	33.68	52.46	13.1	26.90	176.2	30.18	18.78
-14	34.74	53.7	15.2	30.85	234.42	34.61	18.96
-13	35.8	54.9	17.4	35.52	309.03	39.85	19.10
-12	36.86	56	19.7	40.42	398.11	45.35	19.14
-11	37.9	57	22	45.56	501.19	51.12	19.10
-10	38.92	58	24.6	51.30	630.96	57.56	19.08
-9	39.92	58.77	26.8	56.22	753.36	63.08	18.85
-8	40.83	59.4	28.4	61.34	870.96	68.82	18.57
-7	41.62	59.8	29.7	64.31	954.99	72.16	18.18
-6	42.32	60.07	30.3	67.08	1016.25	75.26	17.75
-5	43.02	60.17	31	67.09	1039.92	75.28	17.15
-4	43.66	60.35	31.1	69.71	1083.93	78.21	16.69
-3	44.16	60.46	31.2	71.26	1111.73	79.96	16.30
-2	44.53	60.60	31.25	73.48	1148.15	82.45	16.07

1 kW solid-state RF power amplifier @750 MHz

RF amplifier characteristics

Relevance of objectives and impact

- The initial goals of Task 13.3 is fulfilled. A significant achievement was made with the demonstration of a GaN amplifier producing 205 W with 82% efficiency at 750 MHz. Today we have shown combined six of these amplifiers demonstrating 1148 W output power with 82.45%.
- This amplifier will serve as a driver for a Crossed Field Amplifier (CFA) to be developed at UU/FREIA as part of a new project selected for funding by the I.FAST Innovation Fund (IIF), see Friday 21 April talk at 9.25.
- GaN semiconductor technology is anticipated to play a significant role in the development of future power semiconductor devices, due to its superior characteristics compared to silicon-based transistors. This research advances the field of kilowatt-level amplifiers at 750 MHz and has direct applications in industries, including as the RF power source for the RFQ developed at CERN.
- Our aim is to disseminate the knowledge and advancements made in the field among the other AMICI partners, project members and the wider community. We contribute actively to the Traineeship Programme initiated by I.FAST and provide a platform to groom the future generation of scientists and engineers, thereby facilitating the transfer of knowledge between laboratories and industry and fostering collaboration with industrial partners and other key players in the technology domain. Furthermore, we plan to publish our findings in prestigious journals and present them at high-profile conferences such as IMS, EUMW and IPAC to reach a wider audience.



iFAST

Thank you for your attention!

This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under GA No 101004730.