IFAST IIF PITCH

Permanent Magnet for High Efficiency Klystrons
PM4HEK

CERN
&
ELYTT

Submitted by:
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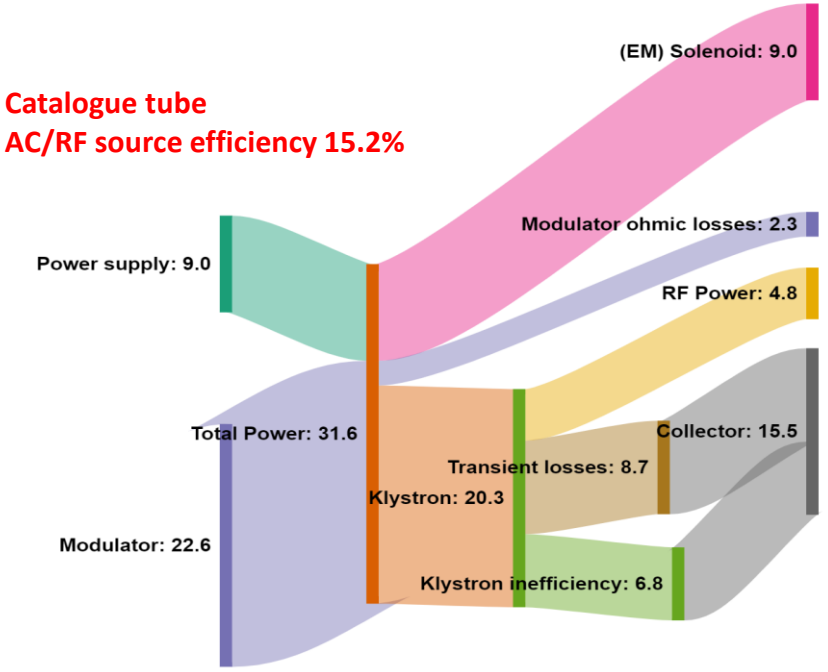
iFAST

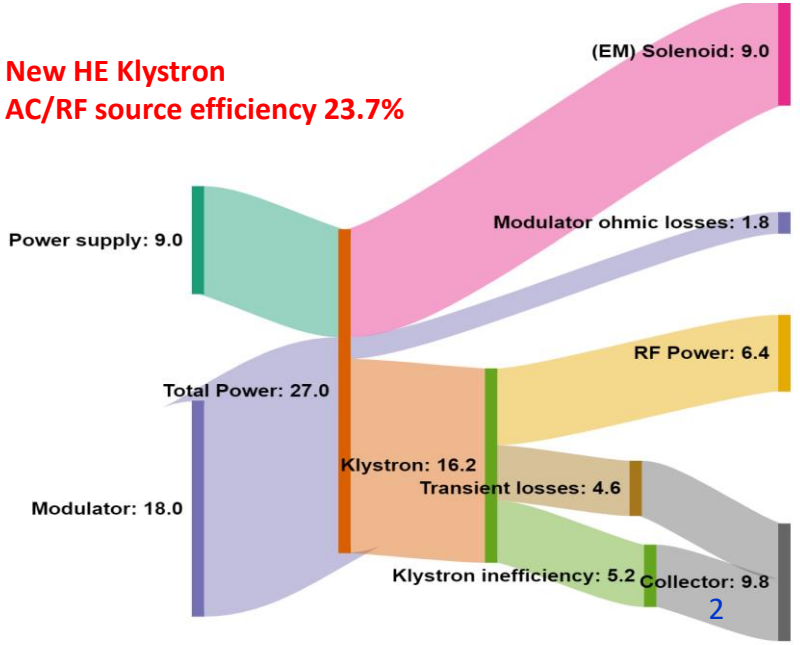
Background and aim

- Klystrons need an electromagnetic solenoid to guide the electrons on a vacuum tube.
- Electrical and cooling energy required by them represents a large fraction of the total energy, especially in low duty cycle pulsed systems.
- The contribution of the magnet is only enhanced when designing and building high efficiency klystrons. 28% to 32%
- We want to design and build a permanent magnet solenoid for an available klystron
- The final product will reduce the operational costs of any accelerator together with the associated carbon footprint.

Catalogue tube
AC/RF source efficiency 15.2%



New HE Klystron
AC/RF source efficiency 23.7%



Technical overview

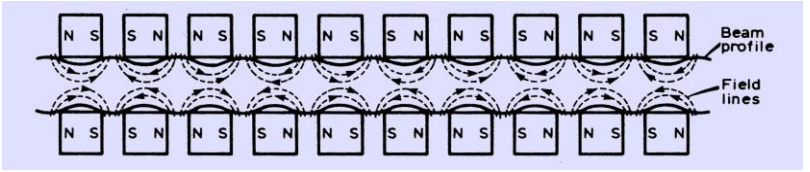
- A team led by Dr. I. Syratchev has been working for the last 8 years on the development of the tools and techniques to improve klystrons for accelerators.
  - https://indico.cern.ch/event/1138197/contributions/4821294/

- CERN collaboration with U. Lancaster, and University of Chengdu (7 members)
- Design and simulation software KLYC benchmarked against available codes with striking similar results and much faster computational speed.

- Collaboration with klystron manufacturers on producing operational prototypes.
  - One tube built by CANON ETD (Japan) has achieved an efficiency of 54% from an original 43% design. https://cerncourier.com/a/cern-and-canon-demonstrate-efficient-klystron/
  - A new tube is under construction in Thales as part of the IFAST 11.2 work package.

We would like to design and build a permanent magnet solenoid for the high efficiency 12 GHz, 8 MW pulsed klystron to reduce further the energy consumption and CO2 footprint

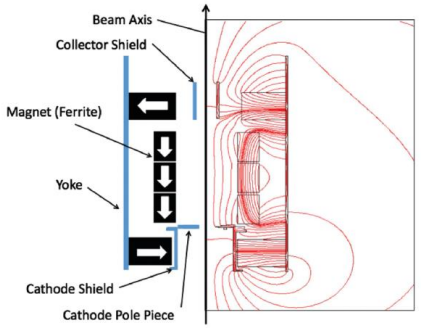
Technical overview /2

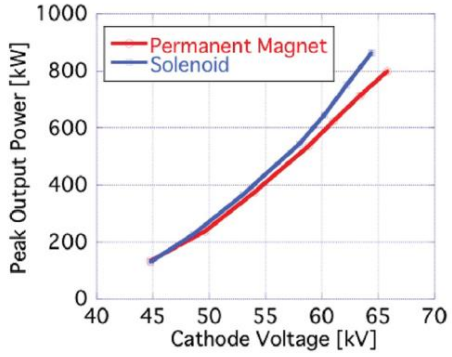


- Most tubes in the market use electromagnets as focusing field for a klystron
- Periodic permanent magnet (PPM) configuration consists of alternating polarity rings set around the RF cavities
  - (DOI:10.1109/JRPROC.1954.274515).
  - https://accelconf.web.cern.ch/l02/PAPERS/TU465.PDF

- This topology produces an oscillating envelope for the electron beam and generate losses along the tube.
- High efficiency klystrons require a much tighter control of the beam

- Already demonstrated PM pure solenoid by KEK/CANON (DOI:10.1109/JRPROC.1954.274515) (TRL6) with some loss of performance





We propose to use a pure solenoid topology optimized together n operation conditions (TRL7)

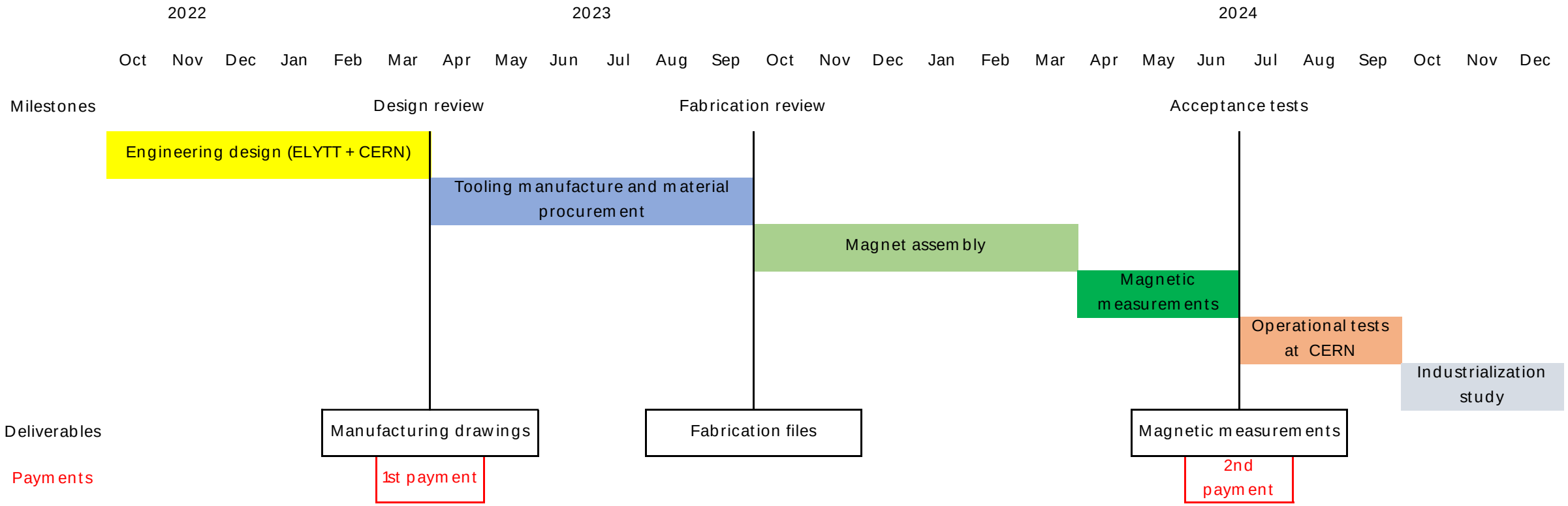
ELYTT experience

- ELYTT team: Led by J. Lucas. Ample experience in permanent magnets and (EM) solenoids for klystrons.
- The team in Elytt has designed and built magnets, power supplies, and energy storage systems for highly exigent science universities and laboratories (ITER, CERN, DESY, GSI, SESAME, etc.).
- Their team consists of engineers with large experience in the area of high technologies together with a high-quality manufacturing unit in the north of Spain.

Work plan

Work package	Partner in charge	Description
WP1: Magnet specification	CERN	Definition of magnetic field profile, mechanical envelope. Setting up of the verification process
WP2: Design of the PM solenoid	ELYTT	Design of the magnetic channel, verifications in klystron simulations. Manufacturing drawings
WP3: Magnet fabrication	ELYTT	Procurement of tooling and materials. Manufacturing,. Assembly
WP4: Magnet tests	CERN	Magnetic tests in stand alone magnet. Insertion in the klystron and RF tets
WP5: Industrialization	ELYTT	Cost optimization, Industrialization model, ISO standardization

Work schedule



Risks analysis

Risk	Likelyhood	Mitigation
Supply chain problems	Likely	PM material already identified. Start procurement from CERN stores as soon as project approved
Cost overrun	Unlikely	Eventual overrun covered by CERN HE budget
Integration of solenoid proves dificult	Unlikely	Decision during the design phase 1. Sacrifice klystron-only efficiency against total system efficiency 2. Redesign and re-fabricate klystron with new ancillaries. As a CERN spare and with CERN funding

Applications and Impact

- Klystrons are used for communications, defense, industry, medical, radar, and scientific applications. Their use in accelerators represents only a small fraction of the current market.

- The solenoid currently used by CANON fits two different klystrons used for science, industry and radar.

- After validation of the prototype in operational conditions, the technology can be transferred to a large fraction of products already available (short channel and high frequency).

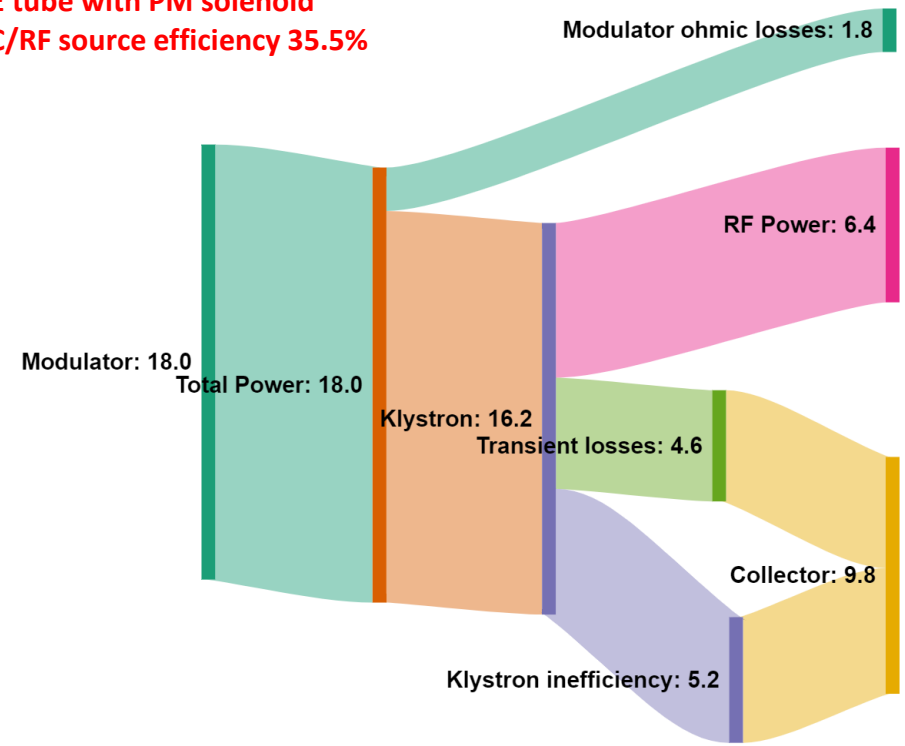
- Similar products also commercialized by CPI and THALES

Image	Type	Klystron	Coil Current (A)	Coil Voltage (V)	Cooling	Coil Weight (kg)	Coil L × Φ (m)	Oil Tank (kg)	Oil Tank W × D × H (m)	Down load
For CW / Long pulsed klystron										
–	VT-68960B	E37504	15/15/15	300/300/300	L	450	1.6×0.6	–	–	–
–	E3766A,ADC	E3766A	20/20	20/470	L	1,100	1.4×0.9	550	1.5×1.5×1.0	–
–	VT-68933B	E3766A	20/20	20/470	L	1,100	1.4×0.9	–	–	–
–	VT-68958	E37503	50/50/50	10/150/25	L	3,100	2.1×0.9	–	–	–
–	VT-68945	E37701	8.2	450	L	900	1.1×0.9	–	–	–
–	VT-68950	E37501	24	100	L	280	0.6×0.5	–	–	–
–	VT-68948	E37750	25	100	L	520	0.6×0.6	–	–	–
–	E37750,ADC	E37750	25	100	L	520	0.6×0.6	430	1.0×1.3×1.3	–
–	VT-68927B	E3739B	33	30	L	120	0.4×0.3	–	–	–
For pulsed klystron										
–	VT-68946	E37612	18	250	L	835	1.2×0.5	–	–	–
–	VT-68934,E/ (VT-68934,G)	E3772 E3779,B E3783 E3765,A E3735A E37325 E37326	42/32	160/5	L	400	0.6×0.5	–	–	–
–	VT-68934,F	E37307	42/32	160/5	L	400	0.6×0.5	–	–	–
–	VT-68931A	E3730A E3754 E37300 E37302 E37308 E37310	20	250	L	520	0.7×0.5	–	–	–
–	VT-68922	E3730A E3754 E37300 E37302 E37308 E37310	25/38/13 24/17/10	15/30/25 40/23/10	L	520	0.7×0.5	–	–	–
–	VT-68915	E3712 E3729 E37320	24	250	L	1,000	1.1×0.6	–	–	–
–	VT-68953	E37314,A E37333	24	250	L	1,400	1.1×0.6	–	–	–
–	VT-68924A	E3734 E37201	22	100	FA	135	0.3×0.5	–	–	–
–	VT-68926B	E37202	30	250	L	850	0.7×0.6	–	–	–
–	VT-68954	E37210 E37212	30	260/280	L	1,000/1,460	0.7×0.7	–	–	–
–	VT-68956	E37113 E37115	34/30	200/20	L	420	0.3×0.7	–	–	–
–	VT-68970	E37116	27	233	L	800	0.4×0.8	–	–	–

https://etd.canon/en/product/category/microwave/klystron.html

Business plan and commercialization

HE tube with PM solenoid
AC/RF source efficiency 35.5%



- Final product might be sold to CANON by the consortium. Potential licensing to ELYTT as exclusive manufacturer

- We (CERN and ELYTT) are already in contact with all three main klystron manufacturers. Ultimate clients of the product
- Engineering services for similar products to be delivered by ELYTT with support from CERN

- Klystron manufacturer does not have a strong interest or knowledge to develop the technology

- Ultimate client for klystron however has great interest on:
  - reducing the electricity bill,
  - reducing capital investment (no power supplies, no cooling of solenoid),
  - have a smaller footprint (embarked solutions like cargo scanners, X-rays…)

- Commercialization, scalability, industrialization and manufacturability will be studied as part of the project

Resources and budget

Work package	Resources (total 115 KEuros)
WP1: Magnet specification	CERN: Fellow and supervision covered by CERN funding ~0.3 FTE
WP2: Design of the PM solenoid	ELYTT: design team 20 K CERN: Fellow and supervision covered by CERN funding ~0.3 FTE
WP3: Magnet fabrication	ELYTT: production team 60K CERN: Travel 10K
WP4: Magnet tests	ELYTT: design and production team 10 KE CERN: travel 5 K
WP5: Industrialization study	ELYTT: commercial team 10K

Questions

- Could you express in quantitative and verifiable terms the improvements with respect to the state-of-the-art that your project is pursuing. *9 kW power saving in a single system. 23.7% to 35.5% efficiency*
- What are the characteristics of the magnet and are there possible technical challenges in integrating it in the klystron? *Permanent magnets. Integration may prove difficult around input/output windows*
- What it the level of co-funding, in any, in the project? *0.6FTE from HE-klystron project plus eventual klystron modifications (<100K)*
- What are the key parameters to be measured when performing the magnetic stand alone test and the klystron RF tests and what are the values expected to be achieved? *Magnetic field value and profile ~ 0.4T*
- It seems strange that the interest of possible customers for the benefits of the technology does not induce and interest on the klystron producers. Are there aspects that make this technology unattractive for klystron producers? *Generally small market, specialised R&D needed, and lack of magnet expertise*

Contact information

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