Preliminary Conceptual Design of the 400 kW Solid-State Power Amplifier Station for ESS

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Summary

The initial conceptual design of the 400 kW Solid-State Power Amplifier station for ESS is presented. A total of 26 stations are required, each providing pulsed power output of 400 kW, to energize the superconducting double spoke cavities section. To produce this extremely high power output, a significant number of SSPAs starting from a nominal module with an output of approximately 1.6 kW. Therefore, it will be necessary to combine a significant number of SSPAs modules to generate the extremely high-power output of 400 kW. Several power combiners will be developed: one will be capable of handling 64 SSPAs at a 100 kW level. Four of these combiners will be combined in a second stage, to achieve a total output of 400 kW.

1. Introduction

ESS is set to become the most powerful long pulse neutron source in the world. It relies on a superconducting proton linac, which has a final beam power of 5 MW at 2 GeV. This linac is made up of various types of superconducting cavities operating in pulsed mode. Specifically, there are 26 superconducting double spoke cavities at 352 MHz, and 36 six-cell superconducting medium-beta and 84 five-cell high beta elliptical cavities at 704 MHz. The cavities have different nominal power ratings and collectively they can produce a beam power of up to 5 MW. To support current operations and future expansions, a power station capable of producing 400 kW at 5% duty cycle has been developed. In addition, there are plans to extend the duty cycle to 10% to meet the future needs of ESSvSB. While the current design employs tetrodes and klystrons, solid-state technology is expected to be used in the future at both 352 MHz and 704 MHz. A lattice diagram of the ESS linac is provided in Figure 1.

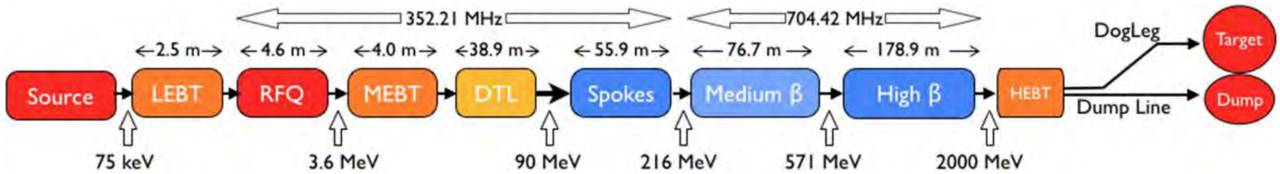


Figure 1. ESS' linac lattice overview.

2. Station specifications and footprint

This new Solid-State Power Amplifier (SSPA) station should have the same footprint as the currently commissioned tetrode station at ESS, as shown in Figure 2. The SSPA station has been developed with the following specifications in mind, a high wall plug efficiency of over 70%, a small total footprint area of $4m^2$, a nominal power of 400 kW, and a duty cycle of 10%. Moreover, the SSPA station is designed to be plug-compatible with the existing Spoke RF power station.

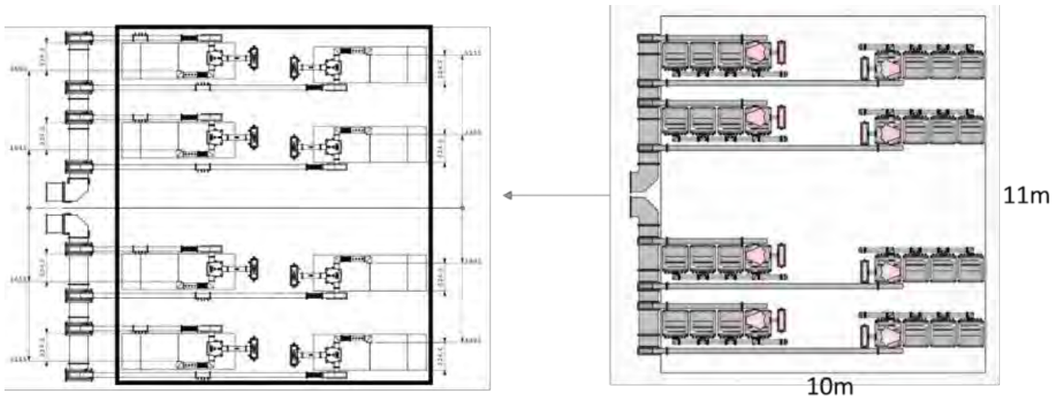


Figure. 2. The SSPA station's footprint (right) is designed to be compatible with the existing 400 kW vacuum-tube-based RF power stations (left), and it is also space-efficient, fitting within the total available footprint of 10m x 11m at ESS.

3. Description of the 400 kW station

The station will consist of 256 high-power solid-state power amplifiers, with each amplifier capable of delivering 1.6 kW. The modules are based on a preliminary design built using commercially available LDMOS transistors in a single-ended architecture with 71% efficiency in pulsed operation [1]. A 10 kW amplifier was demonstrated combining with a 8:1 Gysel combiner, combining eight SSPA modules [2-3]. The 10 kW solid-state pulsed power amplifier was subjected to low level RF feedback, and the results were satisfactory in demonstrating pulse droop compensation [4]. As part of the conceptual design, not all 256 amplifiers of the station will be utilized at the nominal power level. Instead, a certain number of amplifiers will be installed as spares to increase redundancy. The need to increase the overall efficiency of the 400 kW station translates into reducing combination losses. Thus, we are developing a cavity combiner combining 64 SSPAs till 100 kW in one step, with very low insertion loss, i.e. in the order of 0.1 dB. This cavity combiner design allows for additional modules to be connected if any amplifiers are deficient, which enhances the mean-time-between-failure (MTBF) and is expected to enable long term operation. The modules are combined using a two-step architecture, with a 4:1 combiner at the 400 kW level and four 64:1 100 kW combiners, as illustrated in Figure 3. The possibility to change amplitude and phase in front of each SSPA module would make it possible to compensate for imbalances possible in different operational scenarios. Both static phase shifts due to cable lengths variations and dynamically operational variations, such as those induced by temperature variations could be compensated using e.g machine learning control techniques towards optimizing the operation at high-power.

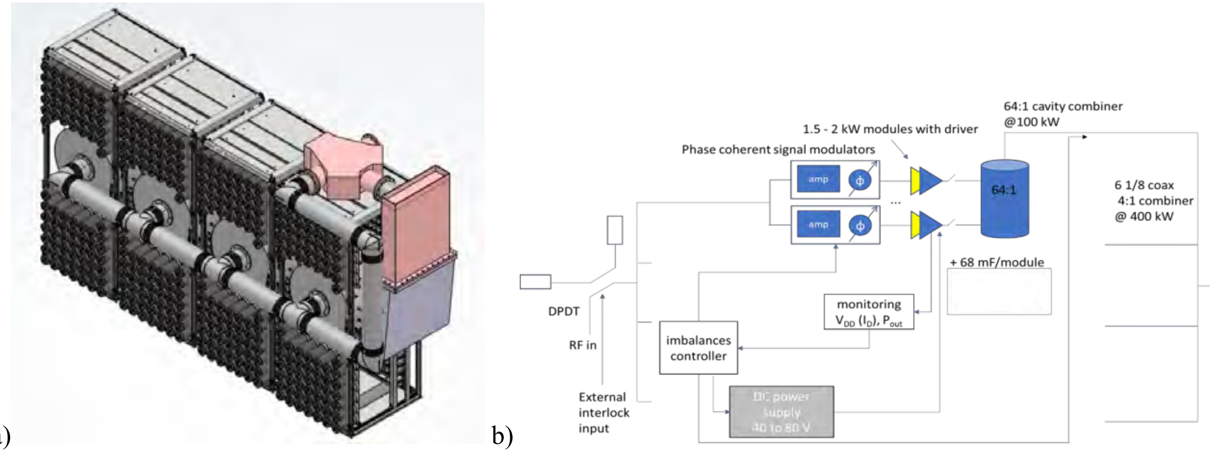
a)  b)

Figure. 3. a) 3D view of the Solid State Power Amplifier station at 400 kW and b) schematics of the station.

6. Acknowledgements

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References

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